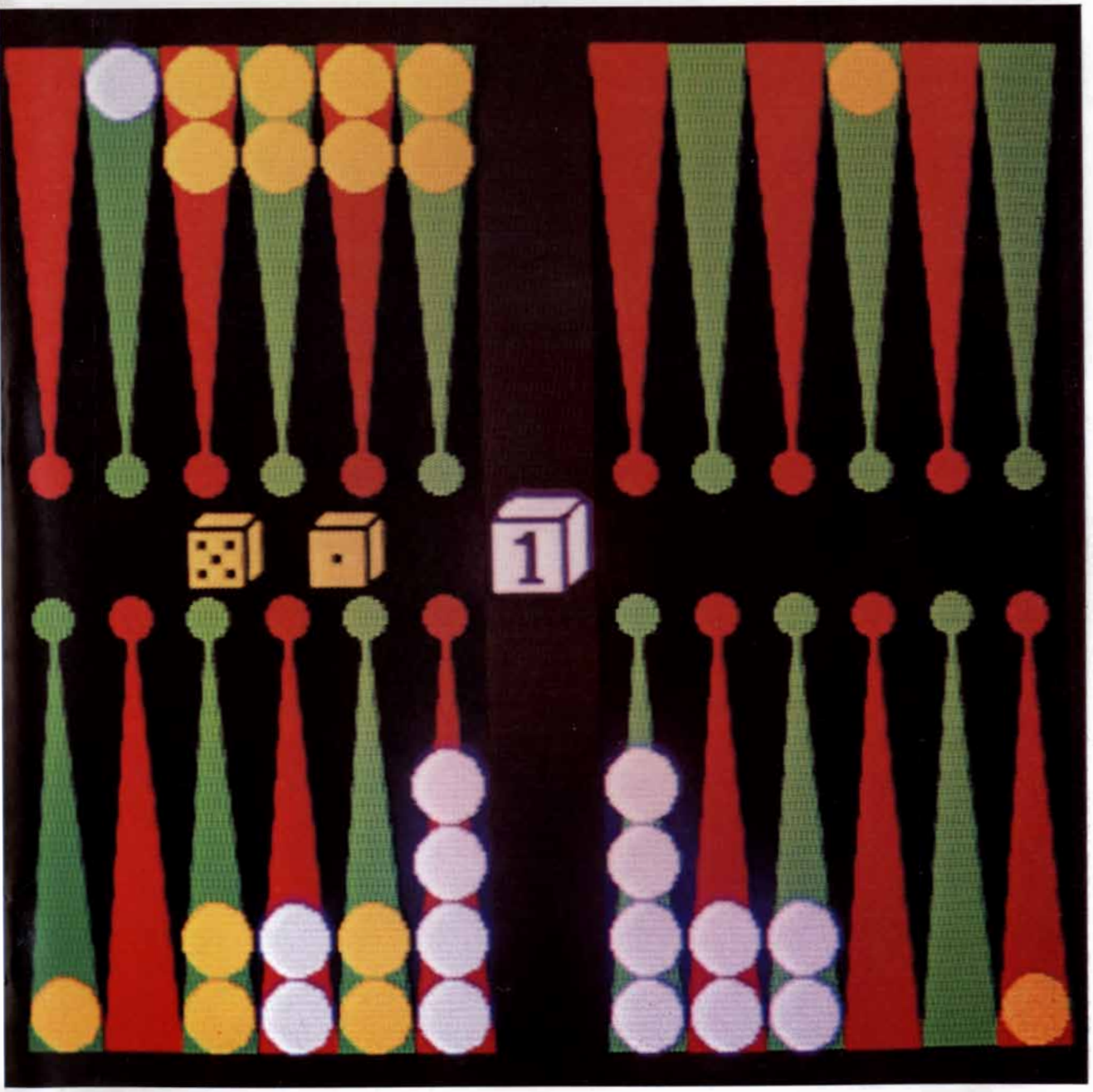
SCIENTIFIC AMERICAN



COMPUTER BACKGAMMON

$2.00

June 1980

WHAT DO YOU THINK IT IS?

Need some help? Then consider the following:

The car you're looking at has a CIS fuel-injected engine that can take you from 0 to 50 in 8.5 seconds.

And power-assisted disc drum brakes that can take you from 50 to 0 in less than three.

It has 4-wheel independent suspension to keep you from going like this on bad roads.

And front-wheel drive to give you responsive handling even in bad weather.

In back, there's a trunk so large it can hold six suitcases.

All standing up.

And inside, there's room enough for a family of four.

Got it yet?

Well, maybe it would help to know that for all its impressive performance on the road, this car still turns in a pretty spectacular performance at the gas pump.

It gets an EPA estimated 25 mpg, 40 estimated highway. (Use "estimated mpg" for comparisons. Your mileage may vary with weather, speed and trip length.

Actual highway mileage will probably be less.)

You still don't know?

Then we should probably mention one last thing.

This car doesn't look like what it is, and most people have a hard time guessing.

So why don't we just tell you.

We call it the Jetta.

Of course, Autoweek had a different name for it.

They called it, "another winner from Volkswagen."

THINK AGAIN.

Established 1845 **SCIENTIFIC AMERICAN** June 1980 Volume 242 Number 6

ARTICLES

DEPARTMENTS

SCIENTIFIC AMERICAN (USPS 509-530), PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. SUBSCRIPTION RATE: $21 PER YEAR, U.S., ITS POSSESSIONS AND CANADA; $27 PER YEAR, ALL OTHER COUNTRIES POSTMASTER: SEND ADDRESS CHANGES TO SCIENTIFIC AMERICAN, 415 MADISON AVENUE, NEW YORK, N.Y. 10017.

The Citicorp Travele

If you can't use them w maybe where you're

Just a few of the places we're welcome...

Carrara, Italy
New York, New York
Amman, Jordan
Manama, Bahrain
Casablanca, Morocco
Dunstable, England
Montevideo, Uruguay
Portland, Oregon
Kowloon, Hong Kong
Abidjan, Ivory Coast
Feuerthalen, Switzerland
Scranton, Pennsylvania
Cannes, France
Seoul, Korea
Valencia, Spain
Kashmir, India
Punchbowl, Australia
Tijuana, Mexico
Sabah, East Malaysia
Lusaka, Zambia
Canberra, Australia
Bridgetown, Barbados
Brasilia, Brazil
Columbus, Ohio
Monte Carlo, Monaco
Hollywood, Florida
Maputo, Mozambique
Boca Raton, Florida
Madras, India
Bucharest, Rumania
Houston, Texas
Quezon City, Philippines
Brussels, Belgium
Sanaa, Yemen
Wilmington, Delaware
Basel, Switzerland
Stockholm, Sweden
Rochefort sur Mer, France
Karlsruhe, Germany
Bristol, Tennessee
Medellin, Colombia
Esperance, Australia
Paris, France
Los Angeles, California
Doha, Qatar
Milano, Italy
Dover, England
Capetown, South Africa
Malaga, Spain
Lancaster, Pennsylvania
Laon, France
Namur, Belgium
San Cristobal, Venezuela
Philadelphia, Pennsylvania
Adelaide, Australia
Eureka, Missouri
Rawalpindi City, Pakistan
Racine, Wisconsin
Mombasa, Kenya
Asheville, North Carolina
Rorschach, Switzerland
Banbury, England
Coos Bay, Oregon
Belgrade, Yugoslavia
Liechtenstein
Dearborn, Michigan
Katmandu, Nepal
Fukuoka, Japan
Aruba, Netherlands Antilles
Miami, Florida
Innsbruck, Austria
San Salvador, El Salvador
Torshavn, Faeroe Islands
Poona, India
Nice, France
Papua, New Guinea
Jeddah, Saudi Arabia
Cincinnati, Ohio
Botany, Australia
Tortola, British Virgin Islands
Cagliari, Italy
Hannover, Germany
San Sebastian, Spain
Rio de Janeiro, Brazil
Kinshasa, Zaire
Salt Lake City, Utah
Geneva, Switzerland
Bordeaux, France
Richmond, Virginia
Mullheim, Switzerland
Salzburg, Austria
Kansas City, Missouri
Managua, Nicaragua
Nicosia, Cyprus
Stamford, Connecticut
Scone, Australia
Austin, Texas
Papecte, Tahiti
Saarbrueken, Germany
Lyon, France
Cairo, Egypt
Hokkaido, Japan
Barneveld, Netherlands
Guanajuato, Mexico
Ruwi, Oman
Detroit, Michigan
Kuala Lumpur, Malaysia
Lisbon, Portugal
Ba, Fiji Islands
Boise, Idaho
Soissons, France
Arlington, Virginia
Darlinghurst, Australia
Monrovia, Liberia
Zurich, Switzerland
Ciudad Real, Spain
Buenos Aires, Argentina
Orlando, Florida
Macao, Macao
Khulna, Bangladesh
London, England
Modesto, California
Port-au-Prince, Haiti
Nigata, Japan
Le Paz, Bolivia
Malvern, Australia
Bamako, Mali
Nairobi, Kenya
Buffalo, New York
Hong Kong, Hong Kong
Durham, England
Waterbury, Connecticut
Puerto Ordaz, Venezuela
Bangkok, Thailand
Klagenfurt, Austria
Carcassonne, France
Boeblingen, Germany
Fort-de-France, Martinique
Guatemala City, Guatemala
Macon, Georgia
Ivanhoe, Australia
Porto, Portugal
Tampa, Florida
Champigne sur Marne, France
Sneek, Netherlands
Quito, Ecuador
Dallas, Texas
Perth, Australia
Port Said, Egypt
Eagle Point, Oregon
Fig Tree, Australia
Mainz, Germany
Jewett, Ohio
Strasborg, France
Mykonos, Greece
Providence, Rhode Island
Taipei, Taiwan
Dusseldorf, Germany
Lexington, Kentucky
Paramaribo, Surinam
Porto Alegre, Brazil
Bristol, England
Sumter, South Carolina
Port Louis, Mauritius
Amsterdam, Netherlands
Chittagong, Bangladesh
Roubaix, France
Ouagadougou, Upper Volta
Denver, Colorado
Segovia, Spain
Port-of-Spain, Trinidad
Riyadh, Saudi Arabia
Grindewald, Switzerland
San Antonio, Texas
Auckland, New Zealand
Balboa, Canal Zone
Caloocan City, Philippines
Madrid, Spain
Verdun, France
Accra, Ghana
Derbyshire, England
Paco, Philippines
Montreal, Canada
Paducah, Kentucky
Turramurra, Australia
Berlin, Germany
Lumberton, North Carolin
Harrisburg, Pennsylvania
Jaipur, India
Puebla, Mexico
Belfort, France
Channel Islands, England
Toronto, Canada
Ozark, Alabama
Ohakune, New Zealand
Honolulu, Hawaii
Bolton Landing, New York
Urdorf, Switzerland
Castellon de la Plana, Spa
Bhawanipur, India
Tuxpan Nayarit, Mexico
Santa Cruz de la Sierra, Bolivia
Kagoshima, Japan
Bala Cynwyd, Pennsylvar
Bludenz, Austria
Winnipeg, Canada
Jalapo, Mexico
Fayetteville, North Carolir
Haarlem, Netherlands
Cadiz, Spain
Calgary, Canada
Mantes la Jolie, France
Friborg, Switzerland
Butterworth, Malaysia
Wagga Wagga, Australia
Birmingham, England
Punto Fijo, Venezuela
Toowoomba, Australia
Nevers, France
Saint Malo, France
Cortazar, Mexico
Buelach, Switzerland
Edmonton, Canada
Agwam, Massachusetts
Malmo, Sweden

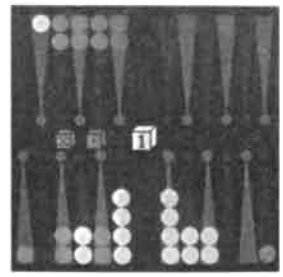
Anchorage, Alaska
Prague, Czechoslovakia
Hamilton, New Zealand
Lima, Ohio
Barranquilla, Colombia
Colts Neck, New Jersey
Montreux, Switzerland
Te Awamuto, New Zealand
Rutland, Vermont
Ankara, Turkey
Koohsiung, Taiwan
Cork, Ireland
Memphis, Tennessee
Nancy, France
Bombay, India
Rarotonga, Cook Islands
Veracruz, Mexico
Algiers, Algeria
Brisbane, Australia
Hartford, Connecticut
Barquisimeto, Venezuela
Goteborg, Sweden
Chantilly, France
Sevilla, Spain
Aubonne, Switzerland
Kiel, Germany
Augusta, Maine
Perugia, Italy
Oxford, England
Minneapolis, Minnesota
Niamey, Niger
Sydney, Australia
Ponta del Gada, Azores
Keene, New Hampshire
Santo Domingo, Dominican Republic
Antwerpen, Belgium
Limassol, Cyprus
Lima, Peru
Copenhagen, Denmark
Pucallpa, Peru
Chicago, Illinois
Addis Ababa, Ethiopia
Tel Aviv, Israel
Davenport, Iowa
Kingston, Jamaica
Jackson, Mississippi
Agra, India
Mermaid Beach, Australia
Durham, North Carolina
Labasa, Fiji Islands
Split, Yugoslavia
Palma de Mallorca, Spain
Khartoum, Sudan
New Orleans, Louisiana
Lachen, Switzerland
Sapporo, Japan
El Dorado, Kansas
Graz, Austria
Cortland, New York
Saint Denis, France
Acapulco, Mexico
Faaborg, Denmark
Mont a Mousson, France
Upper Hutt, New Zealand
St. Louis, Missouri
Tegucigalpa, Honduras
Albury, Australia
Gran Canaria, Canary Islands
Sioux City, Iowa
Firenze, Italy

Jerusalem, Israel
Rio Bravo, Mexico
Ghent, Belgium
Oslo, Norway
New Delhi, India
Brie Comte Robert, France
San Francisco, California
Thessalonike, Greece
Columbus, Ohio
Maroubra Junction, Australia
Durango, Mexico
Flagstaff, Arizona
Lugano, Switzerland
Lacey, Washington
Rakiraki, Fiji Islands
Terni, Italy
Albuquerque, New Mexico
Helsinki, Finland
Milwaukee, Wisconsin
Vienna, Austria
Curacao, Netherlands Antilles
Salerno, Spain
Jakarta, Indonesia
Melbourne, Australia
Albany, New York
Grenoble, France
Athens, Greece
Honiara, Solomon Islands
Maracaibo, Venezuela
Tarragona, Spain
Atlanta, Georgia
Rangoon, Burma
Hamburg, Germany
Las Vegas, Nevada
Valetta, Malta
Cardiff, England
Quelzaltenango, Guatemala
Kuwait
Nottingham, England
Hargesia, Somalia
Grand Rapids, Michigan
Liege, Belgium
Marseilles, France
Las Palmas, Canary Islands
Recife, Brazil
Osaka, Japan
Calcutta, India
Boston, Massachusetts
Gisors, France
Funchal, Madeira
Ogden, Utah
Brazzaville, Congo
Seattle, Washington
Singapore
Greeley, Colorado
Caracas, Venezuela
Belo Horizonte, Brazil
Warsaw, Poland
Oklahoma City, Oklahoma
Agana, Guam
Alessandria, Italy
Manila, Philippines
Birmingham, Alabama
Moonee Ponds, Australia
Gravesend, England
Chihuahua, Mexico
Tokyo, Japan
Garoua, Cameroons
Selangor, Malaysia
Croydon, England
Dayton, Ohio

Piraeus, Greece
Tunis, Tunisia
Rotterdam, Netherlands
Rugby, England
Rabat, Morocco
Bonn, Germany
Blois, France
Lille, France
Cordoba, Spain
Santos, Brazil
Karachi, Pakistan
Rapid City, South Dakota
Queenscliff, Australia
Cleveland, Ohio
Pisa, Italy
Valley City, North Dakota
Libreville, Gabon
Toms River, New Jersey
Aachen, Germany
Mexico City, Mexico
Guimaraes, Portugal
Corfu, Greece
Bozeman, Montana
Noumea, New Caledonia
Laramie, Wyoming
Aix-en-Provence, France
Sucre, Bolivia
Merrylands, Australia
Nagoya, Japan
Djibouti, Djibouti
Charmes, France
Baltimore, Maryland
Wanchai, Hong Kong
Granada, Spain
Philipsburg, St. Maarten
Penang, Malaysia
Eton, England
Louisville, Kentucky
Roma, Italy
Dubai, United Arab Emirates
St. Moritz, Switzerland
Leicester, England
Nashville, Tennessee
Pointe-a-Pitre, Guadeloupe
The Hague, Netherlands
Monterrey, Mexico
Bergen, Norway
Maharashtra, India
Dijon, France
Peorzheinz, Germany
Washington, D C
Guayaquil, Ecuador
Dakar, Senegal
Urbandale, Iowa
Vila, New Hebrides
Liverpool, England
Ravenna, Italy
Phoenix, Arizona
Montana, Switzerland
Istanbul, Turkey
Stuttgart, Germany
Norfolk, Virginia
Santiago, Chile
Dar es Salaam, Tanzania
Yokohama, Japan
Simla, India
Ciudad Bolivar, Venezuela
Guadalajara, Mexico
Indianapolis, Indiana
Johannesburg, South Africa
Kotara Fair, Australia

Montego Bay, Jamaica
Yamagata, Japan
Pretoria, South Africa
Rouen, France
Pittsburgh, Pennsylvania
Kurri Kurri, Australia
Frankfurt, Germany
Baton Rouge, Louisiana
Almeria, Spain
Bogota, Colombia
Bern, Switzerland
Glasgow, Scotland
Islamabad, Pakistan
Andorra La Vella, Andorra
Charlotte, North Carolina
Kyoto, Japan
Torino, Italy
Ansuncion, Paraguay
Malacca, Malaysia
Madison, Indiana
Dublin, Ireland
Leeds, England
Cosne sur Loire, France
São Paulo, Brazil
Sacramento, California
Utrecht, Netherlands
Tripoli, Libya
Joliet, Illinois
San Pedro Sula, Honduras
Donnybrook, Australia
Barcelona, Spain
Abu Dhabi, United Arab Emirates
Zagreb, Yugoslavia
Aubervilliers, France
Bridgeport, Connecticut
Genoa, Italy
Seacaucus, New Jersey
San Tropez, France
Cochabamba, Bolivia
Sarawak, Malaysia
Regina, Canada
Rizal, Philippines
Cuenco, Ecuador
Parma, Italy
Huntsville, Alabama
Putten, Netherlands
Kanpur, India
Gutierrez, Mexico
Braintree, Massachusetts
Peshawar, Pakistan
Halifax, Canada
Raleigh, North Carolina
Olive Branch, Mississippi
Callao, Peru
Cologne, Germany
Sneedsville, Tennessee
Panjim Goa, India
Surfers Paradise, Australia
Penang, Malaysia
Bologna, Italy
Epsom Surrey, England
Oxford, Alabama
Poitiers, France
Brugge, Belgium
Prosperity, South Carolina
Papakura, New Zealand
Bangor, Maine
Safat, Kuwait
Fishkill, New York
Trujillo, Venezuela

Nagoyashi, Japan
Ahmedabad, India
Brest, France
Parsippany, New Jersey
Seremban, Malaysia
Pasto, Colombia
Kawasaki, Japan
Cebu City, Philippines
Brugg, Switzerland
Ottawa, Canada
Gaillac, France
Pickens, South Carolina
Gorham, Maine
Framenfeld, Switzerland
Arequipa, Peru
Warrawong, Australia
Ancona, Italy
Dives sur Mer, France
San Fernando, Trinidad
Wyong, Australia
Egg, Switzerland
Bolsward, Netherlands
Juan Griego, Venezuela
Araçaju, Brazil
Bergamo, Italy
Deposit, New York
Johore Bahru, Malaysia
Stockton, California
Patrai, Greece
Roanne, France
Bowling Green, Ohio
Concepcion, Chile
Pfaffikon, Switzerland
Cartagena, Colombia
Amritsar, India
Embarrass, Minnesota
Oatley, Australia
Kavala, Greece
Toledo, Ohio
Padova, Italy
Dubuque, Iowa
Maracay, Venezuela
Valparaiso, Chile
Aarau, Switzerland
Ramsgate, Australia
Sevres, France
Los Reyes, Mexico
Quiapo, Philippines
Scottsdale, Arizona
Izmir, Turkey
Wausau, Wisconsin
La Coruna, Spain
Sunshine, Australia
Brescia, Italy
Sharjah, United Arab Emirates
Dunkerque, France
Orly, France
Yakima, Washington
Quetta, Pakistan
Paphos, Cyprus
Timaru, New Zealand
Viziaya, Spain
Ipoh Perak, Malaysia
Burbank, California
Bangalore, India
Ragusa, Italy
Montpellier, France
Callao, Peru
Bucaramanga, Colombia
Bouake, Ivory Coast



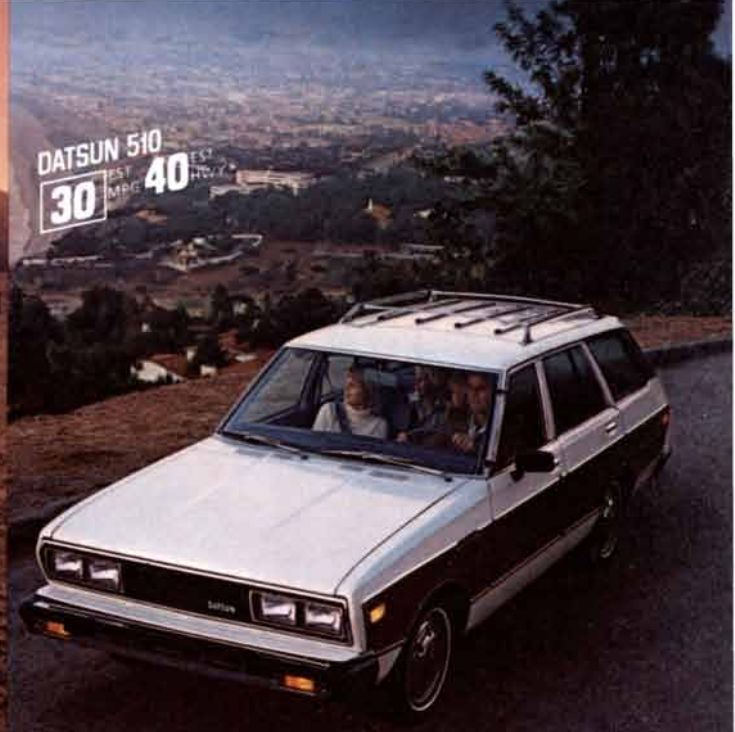
THE COVER

The photograph on the cover shows a computer-graphics display of a critical position in the fifth and final game of a backgammon match between the world backgammon champion, Luigi Villa, and a computer program, BKG 9.8. The program, which defeated Villa by the score of 7–1, became the first computer program to beat a world champion at any board or card game. Villa had the white pieces and moved clockwise; BKG 9.8 had the orange pieces and moved counterclockwise. In this position BKG 9.8, which had rolled a five and a one on the dice, made a sensational play that surprised its programmers and won the applause of the experts who watched the game (see "Computer Backgammon," by Hans Berliner, page 64). The computer-graphics display was provided by the Three Rivers Computer Corporation of Pittsburgh.

THE ILLUSTRATIONS

Cover photograph by Ralph Morse

Page	Source
20–32	Ilil Arbel
48	Carol Donner
49	Division of Ultrasound, New York Hospital–Cornell Medical Center (*top*); Cytogenetics Laboratory, New York Hospital–Cornell Medical Center (*bottom*)
50–53	Albert Miller
55	Dane A. Penland
56	Harry Y. McSween, Jr., University of Tennessee
57	Walken Graphics
58	National Aeronautics and Space Administration
59	Walken Graphics
60	Walken Graphics (*top and bottom left*), Harry Y. McSween, Jr. (*bottom right*)
61–62	Walken Graphics
63	Jet Propulsion Laboratory
65	Ralph Morse
66–72	Jerome Kuhl
87	Hans R. Baumgartner, F. Hoffmann–La Roche & Co.
88	James G. White, University of Minnesota Medical School (*left*); Patricia J. Wynne (*right*)
89	Patricia J. Wynne
90	James G. White, University of Minnesota Medical School
92–99	Patricia J. Wynne
100	Hans R. Baumgartner, F. Hoffmann–La Roche & Co.
102–103	Hans R. Baumgartner, F. Hoffmann–La Roche & Co. (*top*); Patricia J. Wynne (*bottom*)
105–136	Allen Beechel
143	Lawrence Guy Straus, University of New Mexico
144–145	Andrew Tomko
147–152	Alan D. Iselin
155–159	George V. Kelvin
160–161	Sovfoto
163	Randy Thornhill, University of New Mexico
164–172	Tom Prentiss
175	Alan L. Falk (*top*), Jearl Walker (*bottom*)
176–183	Michael Goodman



DATSUN: WIDEST CHOICE OF HIGH-MILEAGE WAGONS.

Datsun has more high-mileage wagons in the top ten than anybody. According to EPA gas-mileage estimates, six out of the top ten wagons† sold in America belong to Datsun.

But stingy as Datsuns are with gas, they're lavish with quality. Even when the 210 Sports Luxury wagon is unloaded, it's loaded... with reclining bucket seats in front, split fold-down seats in back, elbow room all around.

Our family wagon, the freshly styled Datsun 510, boasts the exclusive new NAPS-Z engine that actually delivers better performance from less gas than last year!

Datsun's luxury wagon, the fuel-injected 810, offers all the posh and performance you'd expect in a European touring sedan for thousands less than you'd expect. Visit your Datsun Wagon-station and test-drive a wagon that's built to give you more miles per gallon and more miles per wagon.

* EPA estimates for comparisons. Standard transmission. Actual mileage may differ depending on speed, trip length and weather. Actual highway mileage will probably be lower than EPA estimates. California mileages lower.
† Not applicable to 810 models.

DATSUN
WE ARE DRIVEN

NISSAN

LETTERS

Sirs:

Your article "The Allocation of the Radio Spectrum," by Charles Lee Jackson [SCIENTIFIC AMERICAN, February], treats a complex subject in a somewhat simplistic way. Considering the allocation of a multiple-use resource from a single economic viewpoint ignores the use of the radio spectrum for radio astronomy. In the illustration in the article the band from 1,400 to 1,427 megahertz has been marked for "intersatellite" use. This is a long-standing radio-astronomy band containing the famous spectral line of atomic hydrogen.

Radio-astronomy receivers are usually much more sensitive than communications receivers, and therefore the principle of "symmetrical interference" does not apply (even to neighboring bands). Moreover, there are no alternatives to observing astronomical spectral lines at the frequencies where they naturally occur (as there is, for example, in the case of television broadcasting the alternative of using a cable network).

In the near future there will be serious conflicts of interest between satellite communications and radio astronomy. Radio-astronomy receivers are obviously very sensitive to interference from a skyward direction. Since the laws of economics referred to in the article cannot be applied to radio astronomy, it is important that criteria such as those expressed by Jackson are not the only ones on which future allocations of the electromagnetic spectrum will be based.

PETER E. DEWDNEY

Dominion Radio Astrophysical Observatory
Penticton, B.C.

Sirs:

I cannot resist commenting on A. D. Brockman's letter ["Letters," SCIENTIFIC AMERICAN, April], in which he points out that the algorithm for computing the square root of a number, described by Jerome A. Feldman ["Programming Languages," SCIENTIFIC AMERICAN, December, 1979] and attributed to Newton, actually occurs in Hero's work (first century A.D.). Far more interesting, to my mind, are indications that the Mesopotamians had developed this algorithm at least 15 centuries before Hero. The evidence for this is a small clay tablet in the Yale Babylonian Collection (No. 7289) that shows a square with its diagonals and numbers indicating that the diagonal is obtained from the side on multiplication by the sexagesimal (base 60) expansion: $1 + 24/60 + 51/(60^2) + 10/(60^3)$. If we use the "Newton" method for calculating $\sqrt{2}$ with initial guess 1, the fourth approximation is precisely the above sexagesimal! This is almost certainly the technique used by the Babylonians in about the 16th century B.C. Note in addition that the tablet indicates a knowledge of the Pythagorean theorem 1,000 years before Pythagoras.

JEAN-PIERRE MEYER

Johns Hopkins University
Baltimore, Md.

Sirs:

Marjorie Guthrie, the founder and president emeritus of the Committee to Combat Huntington's Disease, has called my attention to the need to clarify the mode of its transmission ["Diseases Caused by Impaired Communication among Cells," by Edward Rubenstein; SCIENTIFIC AMERICAN, March]. This genetic disease, an autosomal dominant disorder, affects both males and females, and there is one chance in two that an offspring of an affected parent will develop the disease.

Those interested in getting more information about Huntington's disease should write to the Committee to Combat Huntington's Disease, 250 West 57th Street, New York, N.Y. 10019.

EDWARD RUBENSTEIN, M.D.

Stanford University School of Medicine
Stanford, Calif.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to C. John Kirby, Advertising Director, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 40 cents.

Subscription correspondence should be addressed to Subscription Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. For change of address, notify us at least four weeks in advance. Send both old and new addresses and enclose an address imprint from a recent issue. (Date of last issue on your subscription is shown at upper right-hand corner of each month's mailing label.)

Name

New Address

Old Address

HP SOLVES MORE PROBLEMS...

...With a broader range of programmables and more extensive software solutions than anyone else.

Hewlett-Packard's extensive line of programmable calculators coupled with its vast range of software solutions lets you solve more problems more quickly and easily.

MORE SOLUTIONS

With programmable calculators hardware is only half the story. Hewlett-Packard's superior software support lets you spend your time solving problems rather than writing programs to solve your problems.

HP offers a growing collection of software solutions, from aviation navigation to x-ray diffraction. For use on-the-job or at your leisure. And HP software is available in several convenient forms: hundreds of easy to use, step by step key-in programs for all HP programmables; and preprogrammed magnetic cards, plug-in modules, and soon, bar-coded programs for fully-programmables. Plus thousands of software solutions in HP's Users' Library. So when you buy a Hewlett-Packard programmable, you're buying a more useful, efficient, and complete problem solver.

A PROGRAMMABLE FOR YOU

Hewlett-Packard has a full line of scientific and engineering programmables to choose from: six different programmables with a full range of capabilities. One of them is sure to meet your particular needs.

HP Scientific Programmables

HP-33E	Scientific Programmable	$ 90.00*
HP-33C	Scientific Programmable with Continuous Memory	$120.00*
HP-34C	Advanced Scientific Programmable with Continuous Memory	$150.00*
HP-67	Fully-Programmable	$375.00*
HP-97	Fully-Programmable Printing	$750.00*
HP-41C	Alphanumeric Fully-Programmable with Continuous Memory	$295.00*

The most extensive range of programmable calculators backed by the most extensive line of software solutions. It's an unbeatable combination and another example of Hewlett-Packard's commitment to the principle of "excellence by design."

For the address of your nearest HP dealer, CALL TOLL-FREE 800-547-3400 except from Hawaii or Alaska. In Oregon, call 758-1010. For details, send the attached coupon or write: Hewlett-Packard, 1000 N.E. Circle Blvd., Corvallis, OR 97330, Dept. 236R.

HEWLETT PACKARD

HEWLETT-PACKARD
Dept.236R
1000 N.E. Circle Blvd.
Corvallis, OR 97330
Please send details on HP programmable calculators and software solutions.

NAME _____
TITLE _____
COMPANY _____
ADDRESS _____
CITY _____
STATE _____ ZIP _____

*Suggested retail price excluding applicable state and local taxes — Continental U.S.A., Alaska and Hawaii.

Displays photographed separately to simulate typical appearance. 610/03

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1930: "A three-power naval pact has been agreed upon by the United States, Great Britain and Japan. The United States is to have 15 capital ships, 323,500 tons of cruisers, 150,000 tons of destroyers and 52,000 tons of submarines. Great Britain is to have 15 capital ships, 339,600 tons of cruisers, 150,000 tons of destroyers and 52,000 tons of submarines. Japan is to have nine capital ships, 208,900 tons of cruisers, 105,000 tons of destroyers and 52,000 tons of submarines. The United States will scrap 70,000 tons of capital ships, 76,000 tons of destroyers and 8,000 tons of submarines. Great Britain will scrap 134,000 tons of capital ships and 35,000 tons of destroyers. Japan will scrap 29,000 tons of capital ships, 17,000 tons of destroyers and 14,000 tons of submarines."

"The strength of the earth's magnetic field is about half a gauss. Very strong electro-magnets can generate fields of upward of 100,000 gauss, although 30,000 or 40,000 is about their usual limit. Dr. Peter Kapitza, working at the Cavendish Laboratory of the University of Cambridge, has generated fields of 300,000 gauss by sending a current of 30,000 amperes through a coil for less than 1/100th of a second. For many years the study of magnetism has been a jumble. Straightening out the jumble will almost certainly reveal an atomic design of the profoundest significance."

"Until November, 1928, nothing was known of the existence of early Pleistocene man in China beyond some teeth, on the basis of which Professor Davidson Black, with great daring, created the new genus and species of the human family, *Sinanthropus pekinensis,* to which he assigned the same antiquity as the famous ape-man of Java, *Pithecanthropus,* found by Dr. Eugène Dubois in 1891. On the last day of the excavations in 1928, however, Professor Black's boldness was completely justified by the discovery of fragments of two jaws, those of an adult and a child, in association with the fragments of two brain cases of corresponding age. History repeated itself last winter. Again on the closing day of the season's excavations, December 2, 1929, a young Chinese paleontologist, Mr. W. E. Pei of the staff of the Geological Survey of China, while excavating the sheltered recess of the main deposit at Chou Kou Tien, discovered the greater part of an uncrushed skull of *Sinanthropus pekinensis.* The different sites where *Sinanthropus* has been discovered in the Chou Kou Tien deposit are all clearly contemporaneous with one another, being Lower Quaternary in age. The evidence collected in a preliminary report on the geology and paleontology of the site by Pierre Teilhard de Chardin and Dr. C. C. Yong definitely establishes this fact."

"After showing a deficit for 1927 in excess of $42,000,000 due to the shutdown in the latter half of the year for retooling incident to the production of the new model, and a deficit of more than $72,000,000 for 1928 due to large expenditures to bring up production, the Ford Motor Company showed a profit of $81,797,861 for 1929, the second year of production of the Model A. The profit was equal to $473.79 a share on the 172,645 shares of stock, all of which are held by Henry Ford, Mrs. Henry Ford and their son, Edsel Ford."

JUNE, 1880: "Professor N. A. E. Nordenskjöld's recent grand achievement of navigating the Arctic seas north of Asia, and passing eastward through the Behring Strait down into the Pacific Ocean, has been crowned with a triumphal welcome at his arrival home in Stockholm. The *Vega,* a small steamer built at Bremen, of 300 tons' register, with an engine of 60 horse power, has circumnavigated the entire joint continent of Europe and Asia, having left Gothenburg on July 4, 1878, and arrived at Stockholm April 24, 1880. The voyage consisted of two stages, the first being the passage from the port of departure to that part of the Siberian coast in the neighborhood of the mouth of the river Lena. There, on September 28, the *Vega* became fixed in the ice at a short distance from the mainland, and further progress of the expedition was checked during the winter months. With the return of the brief Arctic summer in July of last year the vessel was released, and Nordenskjöld, boldly pushing his way eastward through unknown waters, succeeded with comparative facility in skirting the coast and, rounding the northern capes of Kamtschatka, was enabled to direct his course southward into the North Pacific Ocean, arriving on September 2, 1879, at Yokohama in Japan."

"It is now nearly 40 years since Professor Charles G. Page's discoveries in electricity suggested to him the possibility of an electric railway, but in those days the costly galvanic battery was the only source of electricity available for such purposes, and his experimental electric locomotive was a practical failure. The development of dynamo-electric machines during recent years has so lessened the cost of electricity as a mode of power as to remove the most serious obstacle to the success of Professor Page's experiments. The problem had been so long in abeyance that when Dr. Siemens set up his electrical merry-go-round in Berlin last year, most men were disposed to look upon him as the propounder of a radically novel idea and the electric railway as the product of the latest speculative thought in this direction. And when Mr. Edison adopted the system for practical use not a few people thought that he had switched off from the line of practical work to play with a novel toy, the outcome purely of his experiments in electric lighting. The electric railway, however, is not a plaything. It is a practical reality, though just now entering upon the stage of useful and economical development."

"It is reported that Memphis is at last clean and so far worthy of exemption from further epidemics of yellow fever. Thirty miles of sewer pipes have been laid, and more than 700 men are now at work for the district government. An equal number of miles of drain tile have been laid. Aside from sewerage and drainage, mention must be made of the cleaning and filling of vaults, the demolition of hundreds of old buildings, the cleaning up of cellars and the general renovation of stores and dwellings."

"Our readers will recall the interesting illustrations of the motions of a trotting horse, drawn from Mr. E. J. Muybridge's instantaneous photographs, that appeared in this paper for October 19, 1878. The suggestion then made, that the motions of horses and other animals might be exhibited by an arrangement of such photographs in connection with a zootrope, has been carried out, and a private exhibition of the device has been given by Mr. Muybridge in the gallery of the San Francisco Art Association. Mr. Muybridge calls his instrument the zoogyroscope. It is described as a circular glass having a series of photographs of the animal to be represented in motion, the photographs being successively illuminated by an oxyhydrogen lantern as the glass is turned, throwing a single continuous yet ever changing picture upon the screen. While the separate photographs had shown the successive positions of a trotting or running horse making a single stride, the zoogyroscope threw upon the screen apparently the living, moving animal. Nothing was wanted but the clatter of the hooves upon the turf and an occasional breath of steam from the nostrils to make the spectator believe that he had before him genuine flesh-and-blood steeds."

The Crown Jewel of England.™

100% Grain Neutral Spirits.

Painting by Wilson McLean

The future is coming. And with it will come great benefits for mankind. And a whole new set of problems. Because we are a forest products company, and plant seeds that take up to 50 years to become mature trees, Champion International has to think a lot about the future. We'd like to share some of the things we've learned with you—to help you make intelligent choices in the years to come. Here is something you might want to think about.

In the future, a new science called gene splicing could produce miracles—like the regeneration of limbs, a cure for cancer, even the flowering of a "better" human being.

But who is going to decide what makes a "better" human being?

Some years ago, a child was checked into a hospital; the tip of one finger had been sliced away. The wound was dressed, but the patient neglected. Days later, the dressing was removed. The finger tip was growing back.

At the time, regeneration was a baffling and spooky phenomenon.

Today, we are beginning to learn more about it through the science of genetic engineering. Genetic engineering has the potential to alter the make-up of mankind as no other science ever has or possibly ever will. Gene splicing, one aspect of this new science, is the transferral of genetic material from one living thing to another. With this technique, a gene can be isolated and, when planted in a bacterium, start a whole new process of organic reproduction.

The realizable benefits of genetic engineering are both stunning and myriad.

Splice a gene that produces human insulin into a replicating microorganism, and diabetics have ready access to a purer, yet less expensive insulin. Researchers have already synthesized the hormone responsible for human growth, an immediate boon to children with stunted growth. It's increasingly likely that gene splicing will be able to mass-produce interferon, the anti-viral wonder drug that may put the brakes on flu, hepatitis, and certain kinds of cancer.

Eventually, bacteria may become assembly lines for the creation of whole new life forms, including "better" human beings.

In the long reach after his own betterment, man has covered incalculable ground: from primitive man domesticating wild wheat to his use, to modern man on the threshold of making a better organic self out of his existing self.

The promise for our future is almost beyond comprehension.

Which means questions have to be asked (and answered) right now.

Most critical: who is qualified to decide what makes a "better" human being? Who among us has the capacity, much less the right, to choose?

Also: what safeguards will there be against bacteria containing poisoned genes escaping from the laboratory and contaminating the very life we're trying to improve? Can patents be awarded to private industry for what is essentially life itself? If so, can science retain its necessary purity and freedom in a commercial situation?

These are questions that desperately concern us all because we are the subject matter.

If you're concerned with the immediate future, and would like a bibliography for further reading, send for our free brochure. Write:
Champion International Corporation
Dept. 200A, P.O. Box 10142
Stamford, Connecticut 06921

Write us today. The future is tomorrow.

Champion—
a forest products company with its roots planted firmly in the future.

We are in the forest products business. We plant trees, grow trees, harvest trees. And from trees we make wood building products. Plus fine paper for printing and business. And paper packaging for shipping and selling.

Because we make our living from the forest, our success depends, in one way or another, on the future. And we're planning—and planting—for it.

Champion
Champion International Corporation
Planting seeds for the future

INTRODUCING THE AX-5 FROM FUJI. IT KNOWS WHAT TO DO EVEN WHEN YOU DON'T.

At Fuji, we realize that while you might appreciate the workings of the tiniest computer chip or the most intricate electronic system, you don't necessarily know the difference between an aperture and a focal length.

As a result, you might be settling for photographs that leave a little something to be desired.

Which is why we've developed the new Fujica AX-5, the most advanced SLR in the world. A camera that knows what to do even when you don't.

A COMPUTER THAT CAN SAVE YOU FROM YOURSELF.

Central to the AX-5 is a 7,000-element cybernetic computer system that checks and adjusts for correct exposure up to the instant the shutter fires, automatically compensating for accidental over- and under-exposure.

We've even put LED's right in the viewfinder so you have complete exposure information without losing sight of your subject.

SIX EXPOSURE MODES. DO-IT-YOURSELF. OR DON'T.

The AX-5's exposure modes range from fully manual to fully automatic.

If you want challenge, there's manual control, allowing total flexibility. Automatic aperture priority for depth of field. Automatic shutter priority for fast action. An automatic stopped-down mode for use with highly specialized accessories. And auto-flash exposure for error-free flash photography.

Finally, there's a fully automatic mode that does all the work for you, leaving you free to concentrate on the moment, rather than the mechanics.

EXPANDING YOUR OPTIONS.

In addition to our new computer system, we have an optional auto winder, twin-head electronic flash, even a data back with a unique light pen that allows you to write directly on the exposure.

And the AX-5 accepts the new bayonet mount Fujinon lenses. Their patented Electron Beam Coating eliminates flare for absolutely clear pictures.

THE BETTER THE FILM, THE BETTER THE PHOTOGRAPH.

Good film can only complement any camera.

So after you've invested both time and money in the AX-5 or one of our other new SLR's, invest in a film that's designed to help you get the most out of your picture taking: Fuji film.

At Fuji, we worked as hard perfecting our film as we did perfecting our new cameras.

FUJI. BECAUSE A MEMORY HAPPENS ONLY ONCE.

For a free brochure telling all about our new camera line, write us at Fuji Photo Film, USA, Inc., Box Y5, 350 Fifth Avenue, New York, New York 10001.

THE AUTHORS

FRITZ FUCHS ("Genetic Amniocentesis") is the Harold and Percy Uris Professor of Reproductive Biology at the Cornell University Medical College. Born in Denmark, he was a medical student in Copenhagen at the time of the German occupation of the country in World War II. As president of the Danish Council of Students he was warned that he was on one of the German "lists" and fled to Sweden, where he finished his medical education at the Karolinska Institute in Stockholm. After the war he returned to Denmark and received approval of the degree he had taken in Sweden. He then trained in obstetrics and gynecology and also in surgery at Danish hospitals. From 1958 to 1965 he was gynecologist-in-chief of the Kommunehospital in Copenhagen. In 1964 Fuchs accepted a call from Cornell to be the Given Foundation Professor and chairman of the department of obstetrics and gynecology at the Cornell Medical College and obstetrician and gynecologist-in-chief at New York Hospital. He served in those posts until taking up his present appointment in 1978.

HARRY Y. McSWEEN, JR., and EDWARD M. STOLPER ("Basaltic Meteorites") began their collaboration as graduate students at Harvard University. McSween, who is now assistant professor of geology at the University of Tennessee, did his undergraduate work in chemistry at The Citadel and received his master's degree (in geology) at the University of Georgia. After several years as an Air Force pilot flying jet transport planes on worldwide routes he resumed his graduate studies, obtaining his Ph.D. from Harvard in 1977. Stolper was graduated from Harvard College in 1974 with a degree in geology. After two years as a Marshall Scholar at the University of Edinburgh, where he received his M.Phil. in geology, he returned to Harvard and earned his Ph.D. in 1979. He is assistant professor of geology at the California Institute of Technology.

HANS BERLINER ("Computer Backgammon") is a senior research computer scientist at Carnegie-Mellon University and the holder of the permanent title Grandmaster of Correspondence Chess. After being graduated from George Washington University in 1954 with a bachelor's degree in psychology he worked in the field of human factors for seven years until he decided to become more involved with computers. From 1961 to 1969 he worked in the Federal Systems Division of the International Business Machines Corporation, helping to develop large data-processing applications for the Federal Government. In 1969 he decided that he was more interested in research topics associated with computers, principally artificial intelligence, and went to Carnegie-Mellon, where he obtained his Ph.D. (in computer science) in 1975. By 1969 he had played on the U.S. Olympic chess team, had won the U.S. correspondence-chess championship the three times he tried for it and had won the international correspondence-chess championship (in 1968). Berliner stopped playing chess in 1969.

MARJORIE B. ZUCKER ("The Functioning of Blood Platelets") is professor of pathology at the New York University School of Medicine. She was graduated from Vassar College in 1939 and obtained her Ph.D. (in physiology) from Columbia University in 1944, while she was also a medical student at Columbia. "I taught physiology initially," she writes, "and then set up clotting tests at Memorial Hospital–Sloan-Kettering Institute. In 1962 I went to work in the branch of the research laboratory of the American Red Cross at the New York University Medical Center. When the Red Cross opened its research building in Bethesda, Md., I stayed at N.Y.U." Zucker is coauthor with Aaron Marcus of a book on blood platelets. She is the author of *The Squash Family Cookbook,* which is sold for the benefit of the School of Musical Education in New York. "The squash is grown on our summer and weekend place in northwestern Connecticut in the company of my husband (a practicing psychiatrist who works part-time as liaison to the department of medicine at the Mount Sinai School of Medicine) and intermittently four grown children and three grandchildren. Besides gardening I enjoy bird watching, which I have combined with national and international professional trips."

GERARD 'T HOOFT ("Gauge Theories of the Forces between Elementary Particles") is professor of physics at the University of Utrecht, from which he received his bachelor's degree in 1969 and his Ph.D. in 1972 and to which he returned as a member of the faculty after two years at the European Organization for Nuclear Research (CERN). "My interest in physics dates back to the age of six," he writes. "I thought I was going to choose between painting, music and physics. I chose physics, inspired by other physicists in my family, but I still like to make a painting or play the piano every now and then."

LAWRENCE GUY STRAUS, GEOFFREY A. CLARK, JESUS ALTUNA and JESUS A. ORTEA ("Ice-Age Subsistence in Northern Spain")

collaborate in anthropological and archaeological studies in Spain with funding from the National Science Foundation. Straus, who is assistant professor of anthropology at the University of New Mexico, holds his bachelor's, master's and Ph.D. degrees from the University of Chicago. Clark is associate professor of anthropology at Arizona State University; his bachelor's and master's degrees are from the University of Arizona, and he did his doctoral research at the University of Chicago. Altuna is director of a paleontological laboratory for the Sociedad de Ciencias Naturales Aranzadi in San Sebastián (and the current president of that interdisciplinary society); he obtained his doctorate (in biological sciences) from the University of Madrid. Ortea is assistant professor of zoology at the University of Oviedo, from which he received his doctorate (in biological sciences), and director of the recently founded Asturian Center for Marine Studies.

THOMAS GOLD and STEVEN SOTER ("The Deep-Earth-Gas Hypothesis") are on leave from Cornell University; Gold, the John L. Wetherill Professor of Astronomy and also the director of the Center for Radiophysics and Space Research, is at the Niels Bohr Institute in Copenhagen and Soter, a research associate at the center, is at television station KCET in Los Angeles, where he is working on "Cosmos," a forthcoming public-television documentary on astronomy being prepared by his Cornell colleague Carl Sagan. Gold was born in Vienna and took his degrees at the University of Cambridge: his B.A. and M.A. (both in mechanical sciences) in 1942 and 1946 respectively and his Sc.D. in 1969. He worked in England, first at the British Admiralty and then at Cambridge, until 1957, when he became professor of astronomy at Harvard University, moving to Cornell in 1959 to become chairman of the department of astronomy. Soter was graduated from the University of California at Los Angeles in 1965; he took his Ph.D. (in astronomy) at Cornell in 1971.

RANDY THORNHILL ("Sexual Selection in the Black-tipped Hangingfly") is assistant professor of biology at the University of New Mexico. "I received my bachelor's and master's degrees at Auburn University," he writes, "and my Ph.D. (in zoology) from the University of Michigan in 1974. I was on the faculty of the University of Florida before moving to New Mexico in 1975. In my spare time I enjoy activities with my family, particularly camping combined with collecting and observing insects. I want to thank the National Science Foundation for financial support and also my wife, Nancy, and son, Patrick, for helping with my studies of hangingflies."

SCIENCE/SCOPE

An infrared sensor that would detect and track ballistic missiles -- and perhaps even distinguish "live" missiles from decoys -- has proven extremely successful in initial tests. The device, a part of the Designating Optical Tracker (DOT) program, is designed to be carried by a rocket to an altitude of 100 nautical miles. There, at the outer edge of the atmosphere, it scans a wide area of space and then relays the data it gathers to the ground. The infrared sensor is much more sensitive than conventional infrared devices because it's supercooled. The device was developed by Hughes for the U.S. Army Ballistic Missile Defense Advanced Technology Center under subcontract to Boeing Aerospace Company.

New three-dimensional polymer fiber networks show promise for a variety of industrial and commercial applications. The unique materials, comprised of high-strength fibers, are produced by vibrating an object in a supercooled polymer solution. The fibers can be grown directly on electronic devices prior to encapsulation with plastic, thereby providing internal fiber reinforcement. Hughes, with U.S. Air Force sponsorship, will apply its proprietary in situ fiber technology to a number of high-voltage electronic devices to validate a production process. Other potential uses include filters, high-strength composites, and medical implants.

Manual tracking systems that are 10 times more precise than any previously used by the U.S. Army have been developed by Hughes through extensive research and simulation. Studies have carefully matched tracking system characteristics like inertia, sight magnification, and damping to the neuromuscular and perceptual characteristics of the human operator. The new systems have been applied to wire-guided, anti-tank missile launchers and laser devices used to spotlight targets for laser-homing weapons.

Hughes Research Laboratories needs scientists for a whole spectrum of long-term sophisticated experiments. Advanced research programs include three-dimensional microelectronics, digital picture processing, space optics, solid-state devices, fiber optics, integrated optics, integrated circuit design, and electro-optical materials. Send resume to Professional Staffing, Dept. SE, Hughes Research Laboratories, 3011 Malibu Canyon Road, Malibu, CA 90265. Equal opportunity M/F/HC.

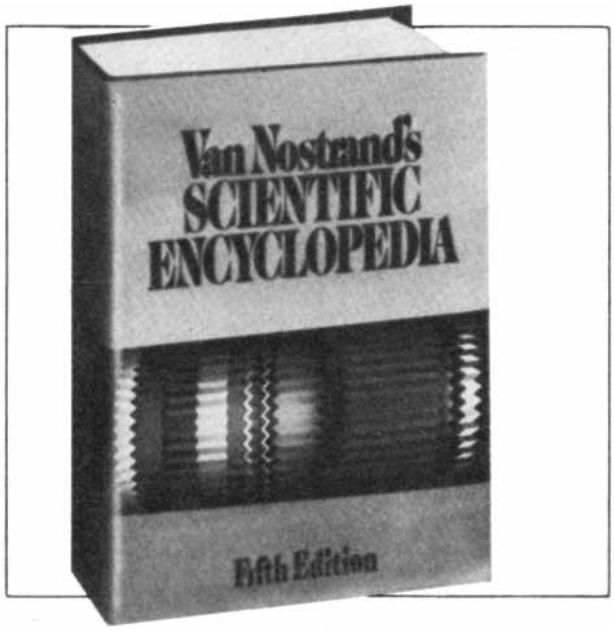
TV coverage of the 1980 Winter Olympics was beamed to millions of viewers around the world via satellites built by Hughes and operated by the International Telecommunications Satellite Organization (Intelsat). Approximately 500 hours of coverage were relayed by Intelsat IV and Intelsat IV-A spacecraft to earth stations in Australia, France, Japan, Mexico, the United Kingdom, Venezuela, West Germany, and Yugoslavia. Many of the telecasts then were distributed to neighboring countries via microwave link or cable for local broadcast.

Creating a new world with electronics

HUGHES

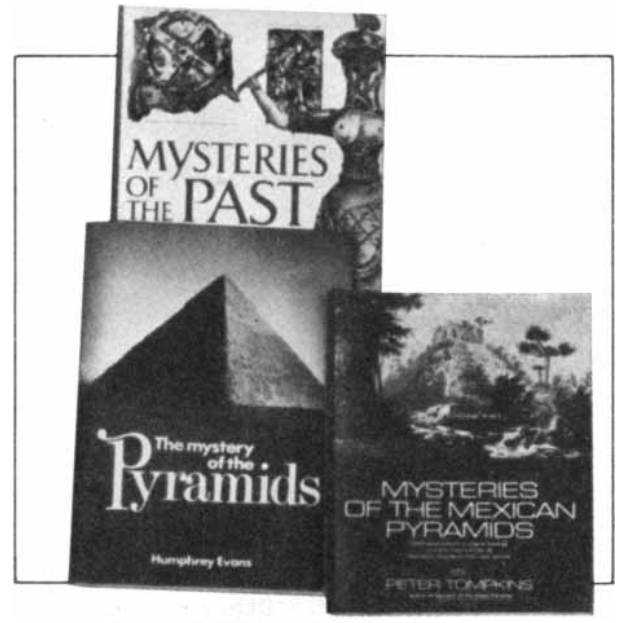
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA 90230

5 good reasons for joining the Natural Science Book Club



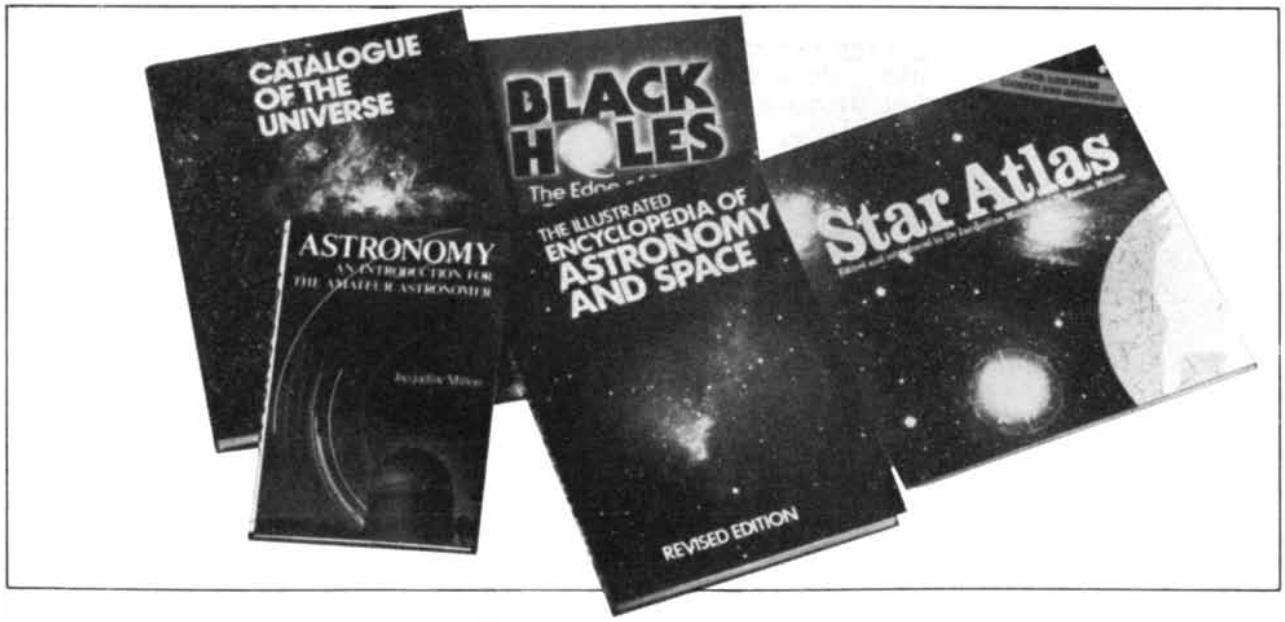
1. Van Nostrand's Scientific Encyclopedia

Edited by Douglas M. Considine. Nearly 200 experts have contributed to this thoroughly revised and greatly expanded fifth edition of the most authoritative single-volume source of scientific knowledge ever assembled. Enormous 9¼″ × 12″ volume contains 2.2 million words, 2382 pages, 2500 photographs, drawings and charts, and 500 tables. 7200 articles cover everything from mathematics and information sciences to physics and chemistry. ". . . an amazing book . . for both the general and scientific reader."—*The New York Times.* Publisher's Price $69.50.



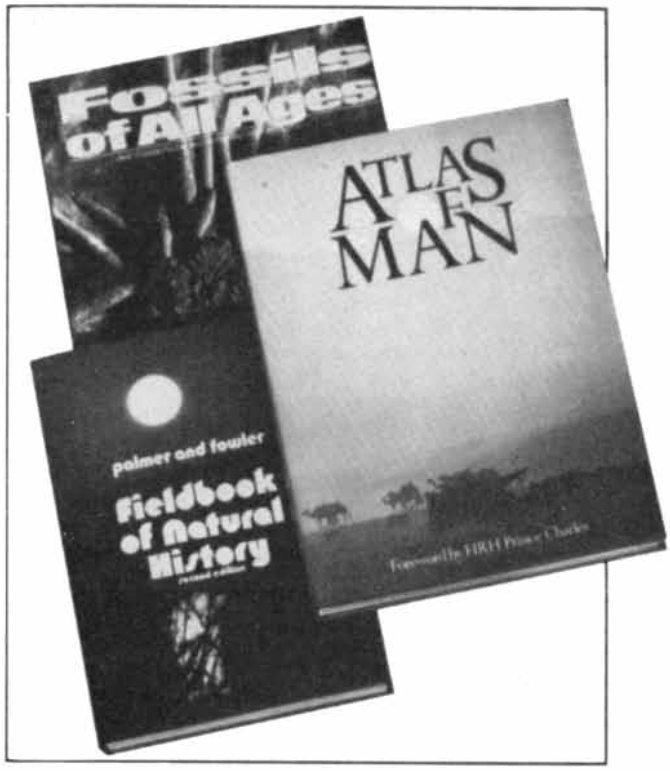
2. Library of Ancient Mysteries

Stunningly beautiful set consisting of three 8½″ × 11″ volumes overflowing with magnificent color photographs consists of ***Mysteries of the Past***—a captivating investigation of such great riddles as who raised the megaliths? what caused the sudden rise of modern man? what caused the collapse of the Maya? and many more; ***The Mystery of the Pyramids***—a thoroughly fascinating overview of Egyptian civilization and the historical, religious, cultural, and political reasons for its awesome pyramids; and Peter Tompkin's ***Mysteries of the Mexican Pyramids***—an absorbing look at the Mesoamerican pyramids and the civilization that built them. Publishers' Price $74.90.



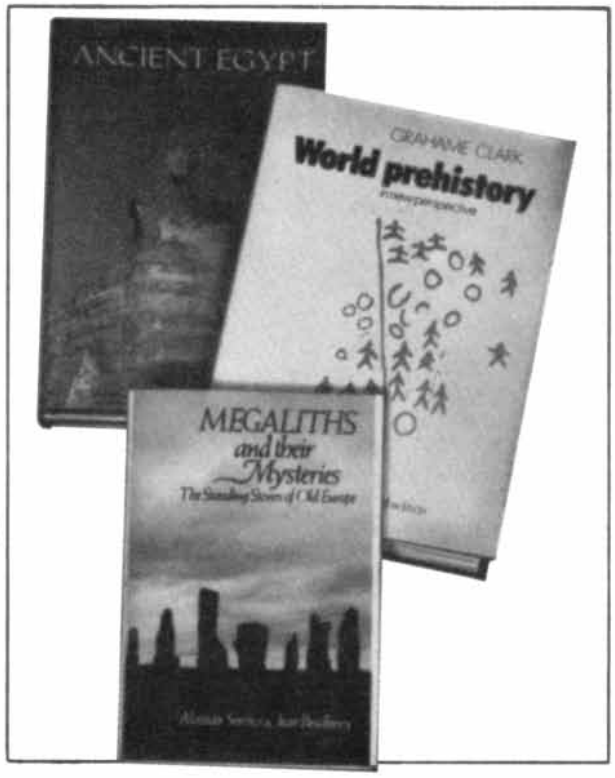
3. Astronomy Library

Here's a carefully selected set of five books that will provide you with a basic, well-rounded astronomy library. First, a "must" for any astronomy reader, the ***Illustrated Encyclopedia of Astronomy and Space.*** Then, Jacqueline Mitton's invaluable introduction to the fundamentals, ***Astronomy: An Introduction for the Amateur Astronomer.*** Next, a marvelously readable overview of the latest advances in the "new astronomy." Walter Sullivan's ***Black Holes.*** Then, the ***Catalog of the Universe,*** which features more than 300 photographs. Finally, a useful guide that will show you how to locate and identify more than 4,000 stars that are visible to the naked eye, ***Star Atlas.*** Publishers' Price $61.75.



4. Nature Library

This sumptuously illustrated three-volume set consists of Palmer and Fowler's *Fieldbook of Natural History*—a huge volume acclaimed as the most authoritative and comprehensive field guide to plants, animals, and minerals ever published; *Atlas of Man*—9″ × 12″ volume filled with over 450 full-color photographs and maps which cover the culture, climate, religion, and geography of more than 400 tribes and peoples; and *Fossils of All Ages*—9″ × 13″ word-and-picture masterpiece revealing the history of fossils, how they are formed, and the rules that dictate their shape and symmetry. Publishers' Price $79.95.



5. Archaeology Library

World Prehistory in New Perspective—three-volume set consisting of Grahame Clark's enormous, global survey of *all* ancient civilizations from the first paleolithic gatherings through the Stone and Iron Ages to the Minoans, Aztecs, and Vikings; T.G.H. James's *An Introduction to Ancient Egypt*—a lavishly illustrated look at the history, religion, and culture of ancient Egypt; and Service and Bradbery's *Megaliths and Their Mysteries*—a detailed exploration of the astronomical, religious, and symbolic significance of the neolithic structures of Europe. Publishers' Price $62.90.

Select either **Van Nostrand's Scientific Encyclopedia** or any one of the four outstanding sets shown here for **only $2.97**

Values to $79.95!

You simply agree to join for a trial period and take only 3 more books—at handsome discounts—over the next 12 months.

As a member, you'll be kept informed of the most interesting, most important science books being published. You'll get to choose from a dazzling array of books—from fascinating accounts of the discovery of lost civilizations to speculations on the origin of our universe, from sumptuous word-and-picture books on the world of nature to stimulating books on where man came from and where he is going.

And you get these books at handsome savings. In addition to receiving up to $79.95 worth of books for less than three dollars when you join, you keep on saving substantially—up to 30% and occasionally more. Your total savings as a trial member, for example, can *easily* be over 50% if you include your introductory offer. And these are real savings, because our books are always of equal quality to the publishers' editions, *never* "economy" editions.

Moreover, you will *immediately* become eligible for our Bonus Book Plan, with savings of at least 70% off the publishers' prices. And you can choose your Bonus Book from *any* of the titles we offer.

Why not start enjoying the many benefits of Club membership? Join the **Natural Science Book Club** today.

If the reply card has been removed, please write to **Natural Science Book Club, Dept. 4-AB7, Riverside, N.J. 08370** to obtain membership information and an application.

MATHEMATICAL GAMES

The capture of the monster: a mathematical group with a ridiculous number of elements

by Martin Gardner

What's purple and commutes?
An Abelian grape.
—Anonymous mathematical riddle, ca. 1965

For the past six years all over the world experts in the branch of abstract algebra called group theory have been struggling to capture a group known as the monster. The name of the group is related to its size: the number of elements in the monster is 808,017,424,794,512,875,886,459,904,961,710,757,005,754,368,000,000,000, or $2^{46} \times 3^{20} \times 5^9 \times 7^6 \times 11^2 \times 13^3 \times 17 \times 19 \times 23 \times 29 \times 31 \times 41 \times 47 \times 59 \times 71$. Robert L. Griess, Jr., a mathematician at the University of Michigan who is currently on sabbatical leave at the Institute for Advanced Study in Princeton, N.J., prefers to identify the monster with its proper mathematical symbol, F_1. In January, Griess (his name rhymes with rice) proved that the monster exists by actually constructing it. The news is enormously exciting to group theorists because it brings them closer to completing a task that has occupied them for more than a century: the classification of all groups.

The colorful story of this undertaking begins with a bang. In 1832 Évariste Galois, a French mathematical genius and student radical, was killed by a pistol shot in an idiotic duel over a woman. He was not yet 21. Some early, fragmentary work had already been done on groups, but it was Galois who laid the foundations of modern group theory and even named it, all in a long, sad letter that he wrote to a friend the night before he died.

What is a group? Roughly speaking, it is a set of operations performed on something, with the property that if any operation in the set is followed by any operation in the set, the outcome can also be reached by a single operation in the set. The operations are called the elements of the group, and their number is called the order of the group.

Before going on to a more precise definition let us consider an example. You are standing at attention and must carry out any of four commands: "Do nothing," "Left face," "About face" and "Right face." Now suppose you execute a left face followed by an about face. A sequence of this kind will be called a multiplication of the two operations. Note that the "product" of this particular multiplication can be reached by the single operation right face. This set of four operations is a group because it meets the following axioms.

1. Closure: The product of any pair of operations is equivalent to a single operation in the set.

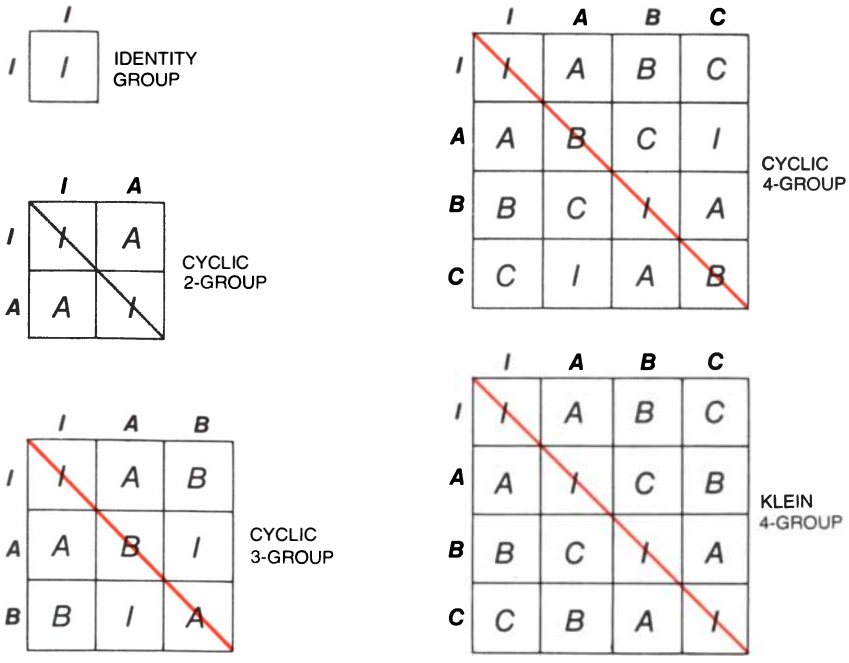
2. Associativity: If the product of any two operations is followed by any operation, the result is the same as following the first operation with the product of the second and the third.

3. Identity: There is just one operation that has no effect, in this case doing nothing.

4. Inverse: For every operation there is an inverse operation such that executing an operation and then its inverse is equivalent to executing the identity operation. In this example left face and right face are inverses of each other, whereas do nothing (the identity) and about face are each their own inverse.

Any set of operations that satisfies these four axioms is a group, and the group of four commands I have just described is called the cyclic 4-group because it can also be modeled by the cyclic permutations of four objects in a row. (In a cyclic permutation of a set of ordered elements the first element moves into the second position, the second element moves into the third position and so on, with the last element moving into the first position.) Label the four objects 1, 2, 3 and 4 and assume that they are lined up in numerical order: 1234. The identity operation, which I shall call *I*, leaves the order of the objects unaltered. Operation *A* permutes them to 4123, *B* to 3412 and *C* to 2341 This group can be completely characterized by the "multiplication" table at the top right in the illustration at the left. Each cell in the table gives the operation that is equivalent to performing the operation indicated at the left end of its row followed by the operation indicated at the top of its column. If a similar construction is carried out for the first model, letting *I, A, B* and *C* stand for the four commands ("Do nothing," "Left face" and so on) in their listed order, the same table results, proving that the cyclic 4-group and the group of four commands are isomorphic, or equivalent.

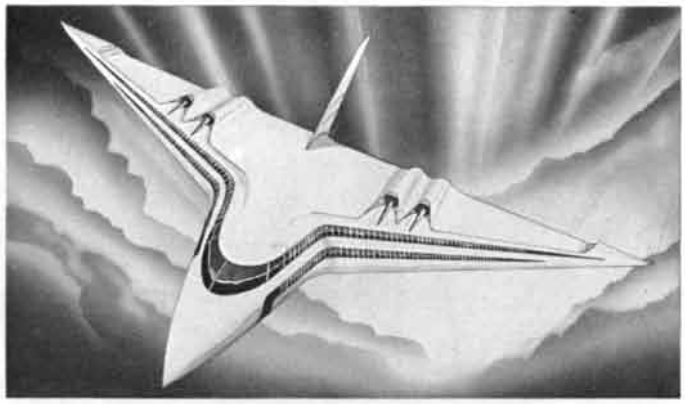
Note that the table for the cyclic 4-group is symmetrical about one of its



The only groups of order 1 through order 4

Technology:

Mongols on horseback, planes without jets, and a plant that grows gas.



For almost all of man's history, human transportation was made possible by the energy of human or animal muscle, or by the inanimate and uncontrolled motion of water or air.

Like many other animals, man carried or dragged himself and the objects he needed moved. By taming the horse around 4000 B.C., he arranged to move himself much more efficiently—so well, in fact, that by the 13th century, Mongol armies swept across much of the known world using nothing but shaggy ponies.

Still, for over 5,000 years, little progress was made in the way man transported himself.

A century of progress.

Suddenly, in the 19th century, inanimate energy under the complete control of human beings came into being. Fulton's steamship, Stephenson's steam locomotive and Otto's internal combustion engine are but three examples. In the 20th century, the jet principle carried transportation beyond the atmosphere. Yet, despite our progress, today's declining oil supplies have placed us in the same position in which previous centuries would have been if their horses started dying out.

World, where now?

It may appear that the future of transportation looks bleak. Energy shortages, escalating fuel prices and the pollution from the internal combustion engine all seem to suggest new limitations on our ability to transport ourselves.

We have three basic choices: to abandon our ease of travel, endure the cost, shortages and pollution, or advance to new levels of technology that solve the problem.

Electrification of the car is one solution already near at hand. These noiseless and exhaust-free vehicles will be powered by nickel-zinc batteries which can store three times as much electrical energy, pound for pound, as the traditional lead-acid battery.

There are, of course, other alternatives besides electrification. We already have nuclear submarines, and nuclear surface vessels have been built. There has even been considerable talk again of nuclear-powered airplanes. Unfortunately, the public's apprehension of nuclear fission makes this seem unlikely in the near-term. But what about fusion or solar vehicles? Not airplanes bearing solar cells, but rather, airplanes depending on fuels generated by fusion or sunlight.

The plant world's role.

By using the energy of sunlight, plants can combine carbon dioxide and water to form foodstuffs and oxygen. Plants could be harvested for fuel-worthy alcohols and hydrocarbons. Given sufficient energy (and either fusion or the sun can supply that), human beings can synthetically combine carbon dioxide and water to form liquid fuel and oxygen in any desired quantity.

A big lift for transportation.

Today, Vertical Take-Off and Landing (VTOL) planes and helicopters are relieving some of the transportation pressure on earth's surface. But it might also be possible to lift automobiles above the surface of the earth by making them travel on compressed air jets. This type of car could travel over water as easily as over land.

Another solution might be magnetic levitation. For instance, a central magnetized guide-rail would repel a train that is similarly magnetized. If the magnetic field intensities are great enough, the train will lift a tiny distance above the rail. The train could move forward under the impulse of an electromagnetic field. Since there would be virtually no friction without solid contact, vibration-free speeds of three hundred miles an hour could be maintained.

A world without the horse?

Just a hundred years ago, most people could not conceive of a world in which the horse was not a major form of transportation. But a few people had the vision to develop new and better ideas.

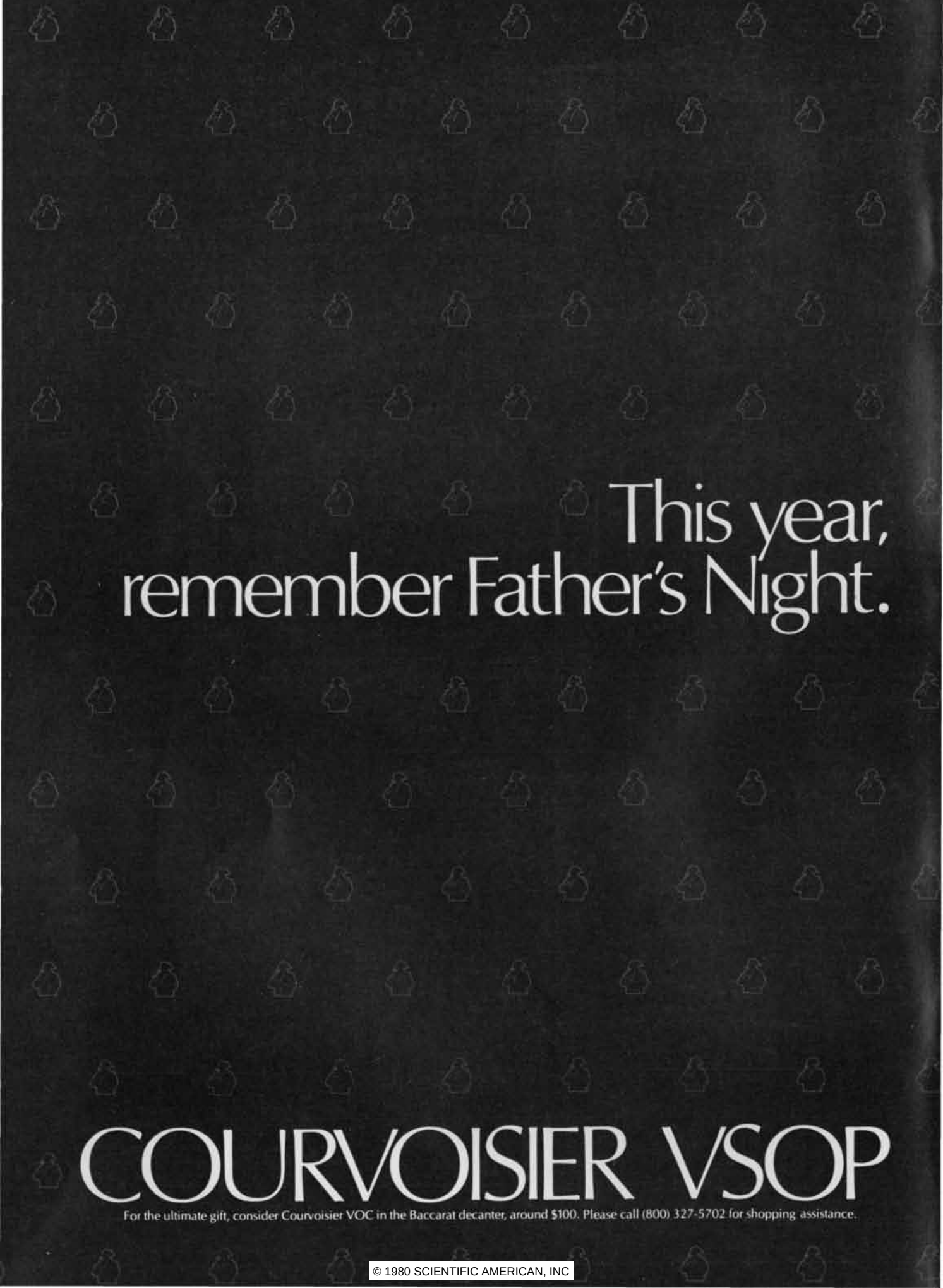
We believe the answer to today's transportation problems will be the creative use of both existing and yet-to-be discovered technologies.

Science and Technology can solve many problems? If they don't, what else will?

Gould is an electrical/electronics company committed to growth through technology. This message is a condensation of a 12-page White Paper, "Technology and the Future of Transportation." For the complete text, write Gould Inc., Dept. S11, 10 Gould Center, Rolling Meadows, IL 60008.

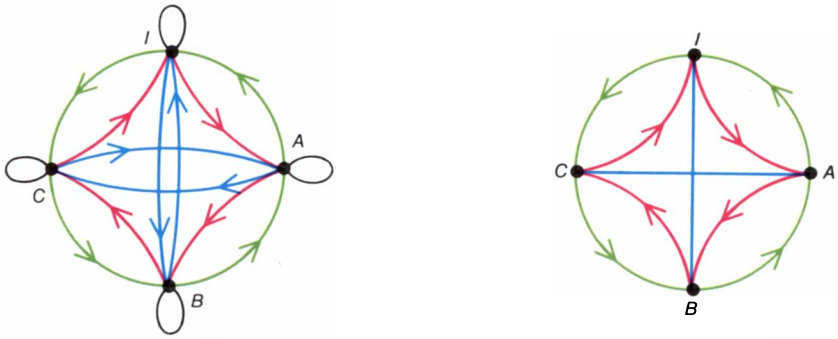
GOULD

An Electrical/Electronics Company



The Brandy of Napoleon

	I	A	B	C
I	I	A	B	C
A	A	B	C	I
B	B	C	I	A
C	C	I	A	B



A Cayley color graph for the cyclic 4-group **(lower left)** *and a simplified version* **(lower right)**

diagonal axes, which is shown in color. This characteristic of the table indicates that the group also obeys the commutative axiom, meaning that the product of any two operations is the same regardless of which one is performed first. Groups that display this property are called Abelian groups after the Norwegian mathematician Niels Henrik Abel. Any cyclic permutation of n objects generates an Abelian group, which is equivalent to the group of the orientation-preserving rotations of a regular polygon of n sides. (A rotation preserves a figure's orientation if the figure ends up in exactly the same position in which it began.) Thus the cyclic 4-group can be modeled by the orientation-preserving rotations of a square.

There is just one group of order 1: the trivial group consisting of the identity operation. It is not hard to see that this operation meets all four of the criteria defining a group. For example, if you do nothing to something twice in succession, it is the same as doing nothing, and so the closure axiom is satisfied. The only order-2 group is almost as trivial. This group, the table for which is shown in the illustration on page 20, can be modeled with two operations to be performed on a penny: doing nothing to the penny (I) and turning the penny over (A). The only group of order 3 is the cyclic 3-group, which is equivalent to the set of cyclic permutations of three objects and to the set of orientation-preserving rotations of an equilateral triangle. There are just two groups of order 4: the cyclic 4-group and another group known as the Klein 4-group.

The Klein 4-group can be easily modeled with the following operations on two pennies placed side by side: doing nothing (I), turning over the left penny (A), turning over the right penny (B) and turning over both pennies (C). The table for the group, shown in the illustration on page 20, reveals that this group too is Abelian.

The simplest example of a non-Abelian group is the set of six symmetry operations on the equilateral triangle: the identity, rotating the triangle 120 degrees clockwise, rotating it 120 degrees counterclockwise, and flipping it over about any of its three altitudes. To prove that the elements of this group do not commute label the corners of a cardboard triangle, rotate the triangle 120 degrees in either direction and turn it over about any altitude; then perform the same two operations in the reverse order and compare the results. If each vertex of the triangle is identified with a different object, the resulting 6-group is equivalent to the group of all permutations on three objects.

To test your understanding of a group you might pause to consider the following three models.

1. With a deck consisting of four face-down playing cards the following operations are defined: the identity operation (I), transposing the top two cards in the deck (A), transposing the bottom two cards (B) and removing the middle two cards and putting the lower one on the bottom of the deck and the other one on the top (C).

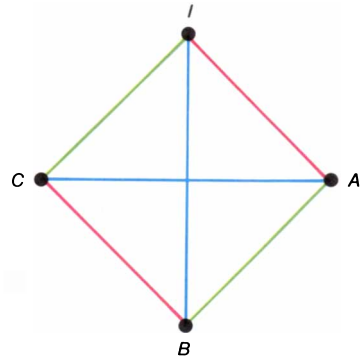
2. A dollar bill is placed either face up or face down and either right-side up or upside down. The operations are the identity (I), rotating the bill 180 degrees (A), turning it over about its vertical axis (B) and turning it over about its horizontal axis (C).

3. A sock is on either the left foot or the right foot in one of two states, right-side out or inside out. The operations are the identity (I), taking off the sock, reversing it and putting it back on the same foot (A), moving the sock to the other foot without reversing it (B) and taking off the sock, reversing it and moving it to the other foot (C).

For each of these groups make a multiplication table and determine whether the group is equivalent to the cyclic 4-group or the Klein 4-group. The answers will be given next month.

The multiplication table of a group can be represented graphically by a diagram called a Cayley color graph after the mathematician Arthur Cayley. For example, the graph at the lower left in the top illustration on this page is a Cayley color graph for the cyclic 4-group, the table for which is at the top of the illustration. The four points of the graph correspond to the four operations of the group. Every pair of points have been joined by a pair of lines going in opposite directions, with the direction of each line indicated by an arrowhead, and a

	I	A	B	C
I	I	A	B	C
A	A	I	C	B
B	B	C	I	A
C	C	B	A	I



A simplified Cayley color graph for the Klein 4-group

A NEW AMERICAN SUCCESS STORY.

Seville for the 80's. Since its introduction, more Americans have chosen to own the new front-wheel-drive Seville than any luxury import model. Including all 12 models of the best selling luxury import... combined.

Only Seville. Only Seville offers such distinctive styling with so many advanced driving features. Seville has front-wheel drive for traction, plus four-wheel independent suspension, four-wheel disc brakes and an electronic level control. And Seville is the only car in the world with a Diesel V8 engine as standard.

An unprecedented choice in power plants. Seville alone gives you the choice between a standard 5.7 liter fuel-injected Diesel V8 and Cadillac's new gasoline-powered V8 with Digital Electronic Fuel Injection (Digital EFI).

Available with Touring Suspension. For those who prefer a greater feel of the road, Seville is now available with a special Touring Suspension.

Seven new two-tone combinations. Seville is now available in seven dramatic new two-tone combinations of the French curve design, along with chrome side moldings and new accent stripes that follow the same sweeping curve.

Seville for the 80's. Sevilles are equipped with GM-built engines produced by various divisions. See your Cadillac dealer for details.

Unique in all the world. What other cars aspire to be, Seville is today. Whether you buy or lease, Cadillac invites you to see and drive Seville for the 80's... at your Cadillac dealer's now.

color has been assigned to each operation in accordance with the key shown at the top of the table. To understand how the graph reproduces the information in the table consider the line from *B* to *A*. The color of the line is determined by starting at *B* on the left side of the table, moving to the right to the cell containing *A* and then using the color assigned to the letter, *C*, at the top of the column the cell is in. The same procedure yields the colors of all the other lines.

When two points in a Cayley color graph are joined by two lines of differing color, the operations represented by the two colors are the inverse of each other. If both lines are the same color, the operation associated with that color is its own inverse. In this case the graph can be simplified by replacing the two directed lines of like color with a single undirected line of that color. In addition the identity operation is represented by a loop that joins each point to itself, and so because one of these loops is at each corner of the graph they can all be omitted. The simplified version of the graph is at the lower right in the top illustration on page 24.

A simplified Cayley graph for the Klein 4-group is shown at the bottom of page 24 and one for the non-Abelian permutation 6-group is shown below. For graphs of higher order it is more convenient to stop using colors and instead label each line with the symbol corresponding to the operation it represents.

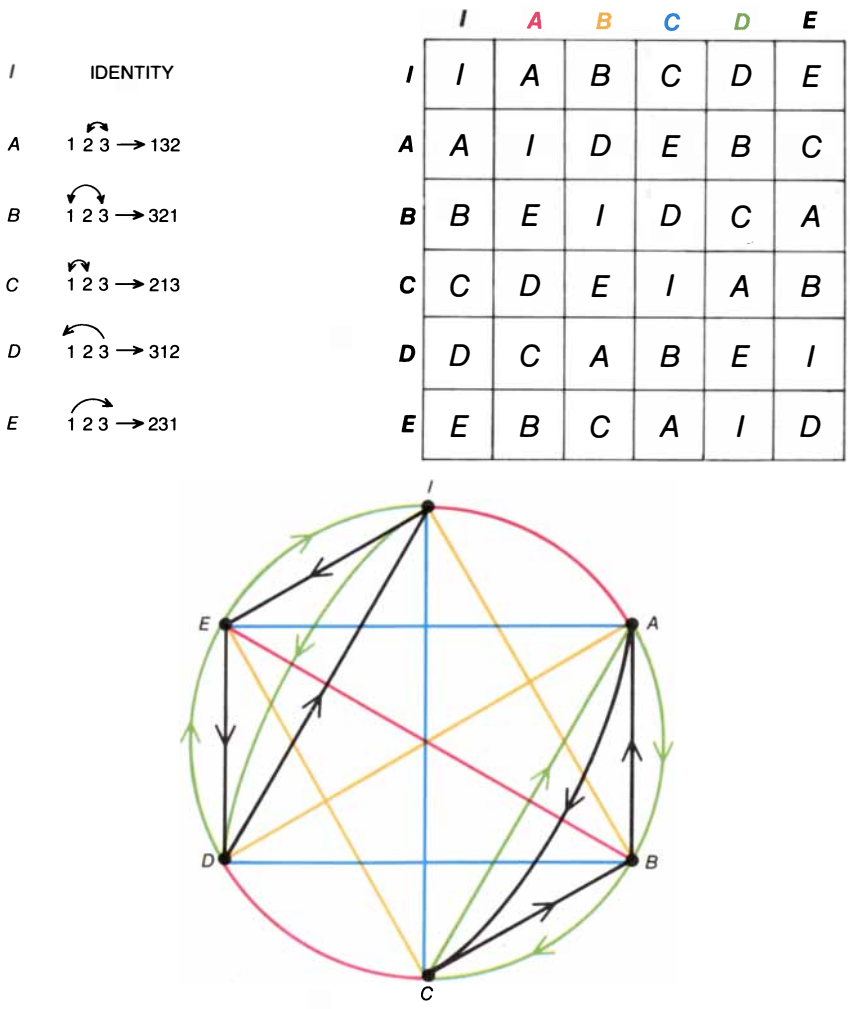
It should be obvious that given the color graph for any group, the table for the group can be constructed. The converse is also true. The graphs are valuable aids, however, because they often reveal properties that are not easily seen in a multiplication table. For example, it is not difficult to see that if on the 6-graph the lines corresponding to operations *A*, *B* and *C* are omitted, leaving only the lines corresponding to *D* and *E*, two disconnected graphs are obtained. Each is a color graph for a cyclic 3-group, but only the set of operations *I*, *D*, *E* actually forms such a group because this set alone contains the identity operation. Any subset of the elements of a group that itself forms a group is called a subgroup, and so inspection of the color graph has revealed that the cyclic 3-group is a subgroup of the permutation 6-group.

So far only groups with a finite number of operations, or elements, have been discussed. There are also infinite groups, and they fall into two classes: discrete groups, which have a countable infinity of elements, and continuous groups, which have an uncountable infinity of elements. An infinite set is said to be countable if its members can be matched up one for one with the positive integers 0, 1, 2.... Hence the integers themselves are an example of a countably infinite set, whereas the points on the real-number line are an example of an uncountably infinite set. In fact, the integers form a discrete Abelian group under the operation of addition, with 0 as the identity element and $-a$ as the inverse of any element a. The real numbers, on the other hand, form a continuous group with respect to addition, and if 0 is excluded, they form a continuous group with respect to multiplication as well. (In the latter case 1 is the identity element, and $1/a$ is the inverse of a.) Continuous groups are called Lie (pronounced Lee) groups after the Norwegian mathematician Marius Sophus Lie. A trivial geometrical example of a Lie group is the group of symmetry rotations of a circle (or a sphere or a hypersphere). The degree of rotation can be as small as one likes.

The group is one of the most powerful and unifying of all concepts in mathematics. Moreover, in addition to turning up in every branch of mathematics, groups have endless applications in science. Wherever there is symmetry there is a group. The Lorentz transformations of relativity theory form a Lie group based on the continuous rotation of an object in space-time. Finite groups underlie the structure of all crystals and are indispensable in chemistry, quantum mechanics and particle physics. The famous eightfold way, which classifies the family of subatomic particles known as hadrons, is a Lie group. Every geometry can be defined as the study of the properties of a figure that are left invariant by a group of transformations.

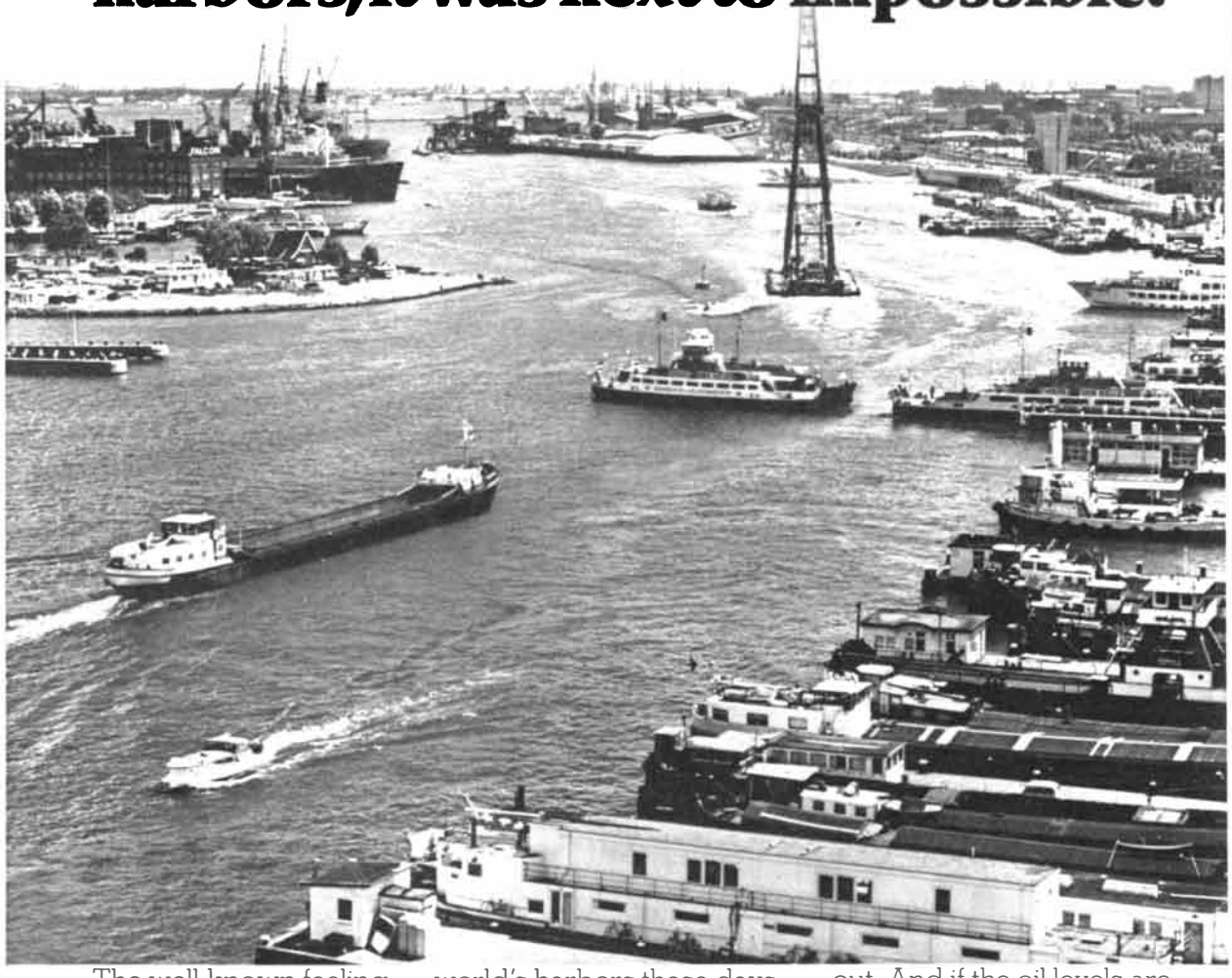
Even recreational mathematics sometimes involves groups. Since every finite group can be modeled by a set of permutations on n objects, it is hardly surprising to find groups related to card shuffling, ball juggling, campanology (bell ringing), sliding-block puzzles and all kinds of combinatorial puzzles. In an earlier column (reprinted in my *New Mathematical Diversions from Scientific American*) I explained how groups apply to braiding theory and so underlie numerous magic tricks involving ropes and twisted handkerchiefs.

In view of the great elegance and utility of groups it is understandable that mathematicians would like to be able to classify them. The Lie groups have been classified, but there are other infinite



A simplified Cayley color graph for the permutation 6-group

Cleanliness may be next to godliness. But in some Dutch harbors, it was next to impossible.



The well-known feeling of the Dutch for cleanliness didn't stop at the water's edge.

And what they saw in some of their harbors was disconcerting, to say the least.

Every time that a ship pumped water out of its bilge, there was a good chance waste oil would be pumped out with it.

The result was a worrisome oil slick—a slick spreading over many of the world's harbors these days.

(Indeed, back in 1973 an international maritime ruling called on ships everywhere to monitor their oil waste, to avoid worries like these.)

What to do? Some of the people of ITT came up with an ingenious answer—an optical fiber device that carefully "watches" a ship's bilge water.

A laser beam scans the bilge waste being pumped out. And if the oil levels are too high, an alarm goes off.

So, the pumping can be stopped.

Our ITT device was the first anywhere to be government certified, meeting the required performance standards for this urgent monitoring task.

Obviously, no one expects to unpollute the world's harbors overnight.

But the least we can do is give it a good, clean try.

The best ideas are the ideas that help people. ITT

groups that still elude classification. What about finite groups? One might suppose they would be easier to classify than Lie groups, but that has not proved to be the case. It is this difficult task that is now on the brink of being completed.

All finite groups are constructed from building blocks called simple groups in much the same way that chemical compounds are constructed from elements, proteins from amino acids and composite numbers from primes. A simple group is one that has no "normal" subgroups other than itself and the trivial identity subgroup. Remember that a subgroup is defined as any subset of the elements of a group that is itself a group. What is meant by "normal" is best explained as follows. Consider a group G with a subgroup S. The set of products obtained by multiplying each element of

A Simple Ballad

(To be sung to the tune of "Sweet Betsy from Pike")

What are the orders of all simple groups?
I speak of the honest ones, not of the loops.
It seems that old Burnside their orders has guessed
Except for the cyclic ones, even the rest.

Groups made up with permutes will produce some more:
For A_n is simple, if n exceeds 4.
Then, there was Sir Matthew who came into view
Exhibiting groups of an order quite new.

Still others have come on to study this thing.
Of Artin and Chevalley now we shall sing.
With matrices finite they made quite a list.
The question is: Could there be others they've missed?

Suzuki and Ree then maintained it's the case
That these methods had not reached the end of the chase.
They wrote down some matrices, just four by four,
That made up a simple group. Why not make more?

And then came the opus of Thompson and Feit
Which shed on the problem remarkable light.
A group, when the order won't factor by two,
Is cyclic or solvable. That's what is true.

Suzuki and Ree had caused eyebrows to raise,
But the theoreticians they just couldn't faze.
Their groups were not new: if you added a twist,
You could get them from old ones with a flick of the wrist.

Still, some hardy souls felt a thorn in their side.
For the five groups of Mathieu all reason defied;
Not A_n, not twisted, and not Chevalley,
They called them sporadic and filed them away.

Are Mathieu groups creatures of heaven or hell?
Zvonimir Janko determined to tell.
He found out what nobody wanted to know:
The masters had missed 1 7 5 5 6 0.

The floodgates were opened! New groups were the rage!
(And twelve or more sprouted, to greet the new age.)
By Janko and Conway and Fischer and Held,
McLaughlin, Suzuki, and Higman, and Sims.

No doubt you noted the last lines don't rhyme.
Well, that is, quite simply, a sign of the time.
There's chaos, not order, among simple groups;
And maybe we'd better go back to the loops.

Olivetti Breakthrough

The world's smallest electronic printer will never run out of paper, ink or batteries thanks to Olivetti, JS&A and some incredible new technology.

The new pocket-sized Olivetti calculator slides open to unveil one of the most advanced printing heads ever developed.

It's a major breakthrough. That calculator shown above is the most advanced printing calculator in the world.

SLIP TOP PRINTER

The new Olivetti Logos 9 is only 1" x 2½" x 4⅝"—smaller than many cigarette packages. It has a full 12-digit liquid crystal display with add mode and full-floating or fixed position decimal.

To turn the unit into a printer, you simply slide up the top of the unit to expose the world's smallest and one of the most precise printing heads. The printing head prints letters and numbers, identifies each entry and even clearly separates groups of three whole numbers for easy readability.

PLENTY MORE

If its size and printing head are breakthroughs, so is its paper system. The paper is loaded in special cartridges with enough paper per cartridge for 1300 entries. All you do is simply pop a cartridge into the bottom of the unit each time you change rolls. It's the most convenient way ever designed to change a roll of paper for a printing calculator.

But if you're like most Americans, you'd be concerned about paper supply. Where do you get those special cartridges, and how do you know if you can get them years from now?

That's where JS&A comes in. A 32-roll supply—all you'll ever need for three full years—is only $16. That's enough paper for 41,000 entries or approximately 52 line entries each working day for three full years.

But even more important, within one year stationery stores will stock the cartridges, and we predict that the Olivetti cartridge will become a standard in the industry.

NO INK CARTRIDGES

The paper is a new type that looks exactly like conventional paper. But the paper, when struck, leaves a clear sharp image without the use of ink. So there's no messy cartridge required and no space needed to store one. You'll never need ink again.

The rechargeable batteries last for 8,000 lines when you use just the printer and 80 hours using just the liquid crystal display. The batteries can be recharged 500 times, so theoretically the batteries should last for 300 rolls of paper, or more than nine times the life of your paper supply. The batteries can also be easily replaced.

POWERFUL COMPUTER

The features looked great. The world's smallest size, the paper roll convenience, the no-ink system, the battery life and the large 12-digit liquid crystal display were enough to convince us, but would the new Olivetti be considered a toy? Then we learned about its computational power and features which we feel are better than many of the most professional full-featured printing calculators.

Speed It's the world's fastest small printer with a speed of 2.1 lines per second. The unit also has a buffer so if you enter data faster than the unit, it will still print out each entry.

Memories The Logos 9 has two separate memories. One is an accumulating memory, and the other is a fully independent memory. And the display and printer indicate which memory is on the paper tape.

Printing Head The totally new printing head is a semi-alpha numeric system which labels all entries with letters to indicate the entry. For example LP is list price and CNT means item count.

Clock The unit is so complete, Olivetti even threw in a digital clock function. Your unit will display accurate time when the 12-digit display is not in use.

Gross Margin It automatically computes everything from gross margins to discounts and retail pricing. You just enter your percentage mark-ups in its memory, and it will automatically compute the results while retaining the formula and percentage in memory.

Plus More It has automatic round off, letting you select which figure to round off to. You can add a column of figures and then average your calculations automatically. The full-information liquid crystal display will tell you everything from when you're in the printer mode to whether you have something in memory and in which memory.

The technological breakthroughs in the Logos 9 were possible because Olivetti was able to eliminate the many interface components between the integrated circuit and the printing head. This was all made possible because Olivetti designed the entire system, not just a few of the components as is the case with most calculators.

So there it was. Great features, great convenience and great value for only $89.95 complete with batteries, charger and 90-day limited warranty. For $16 more, you can get 32 cartridges—all the paper you'll ever need for three years or for $10 more you can get 16 cartridges. So impresed are we with the Olivetti Logos 9 that we are making the following offer:

FREE TRIAL OFFER

We urge you to test the Olivetti Logos 9 now. Order one for our 30-day no obligation trial. See the clear and easy-to-read paper tape and display. Use it as a pocket calculator, and carry it in your briefcase wherever you go. Experience the convenience of always having a printing calculator there whenever you need a permanent record of your transactions.

After 30-days of actual use, decide if you want to keep it. If you do you'll own the smallest, most advanced and convenient pocket printing calculator in the world. If for any reason you're not completely satisfied, simply return your unit within 30-days for a prompt and courteous refund, including your $2.50 postage and handling. You can't lose.

Olivetti selected JS&A to exclusively introduce this exciting new product. With its solid-state design and high quality printing mechanism, the Olivetti should not require service. But if service is ever required, Olivetti maintains a convenient service-by-mail center as close as your mailbox.

To order your unit for our trial, simply send your money order or personal check for **$89.95** plus $2.50 for postage and handling (personal check orders, allow 20 days to clear our bank) to the address below, or credit card buyers may call our toll-free number below. Add $16 for 32 paper cartridges or $10 for 16 cartridges. (Illinois residents please add 6% sales tax.)

Who would have imagined a printing calculator this small and this convenient with this much computational power just a few months ago? The Olivetti Logos 9 deserves your test. Order one at no obligation, today.

JS&A PRODUCTS THAT THINK®

Dept. SA One JS&A Plaza
Northbrook, Ill. 60062 (312) 564-7000
Call TOLL-FREE 800 323-6400
In Illinois Call ..... (312) 564-7000

the subgroup by each element of the group is called the right coset of the group, *GS*. Conversely, the set of products obtained by multiplying each element of the group by each element of the subgroup is called the left coset, *SG*. If the two cosets are equivalent, the subgroup is called normal. For example, the cyclic 3-group is a normal subgroup of the permutation 6-group. Hence the 6-group is not simple. Simple groups are the building blocks of all groups, and so to classify the finite groups it is necessary to classify all the finite simple groups.

Almost all finite simple groups belong to families with an infinity of members. Families of this type provide a quite satisfactory system of classification, since there are procedures for constructing any individual member, or group. For example, the cyclic permutation groups of prime order (which are modeled by rotations of regular polygons with a prime number of sides) are finite simple groups. In fact, they are the only finite simple groups that are Abelian as well as the only ones that are cyclic. A famous result in mathematics called Lagrange's theorem states that the order, or number of elements, of any subgroup must be a divisor of the order of the group in which it is contained. Since a prime number has no divisor (other than 1 and itself), this theorem implies that any group of prime order has no subgroups (other than the identity and itself). If a group has no other subgroups, however, then it certainly has no normal subgroups, and so it follows that any group of prime order is simple.

Another important family of finite simple groups is the set of alternating groups, which are modeled by the even permutations on n objects for all integers n greater than 4. An even permutation is one that can be obtained in an even number of steps, where each step consists in switching two objects. For example, the cyclic 3-group is also an alternating group because 231 can be produced from 123 in two steps (transpose first 1 and 2 and then 1 and 3) and the same is true for any other pair of the three cyclic permutations of three objects. Exactly half of all permutations are even, and because n objects can be permuted in $n!$ ways every alternating group has an order of $n!/2$. The odd permutations do not form groups because any odd permutation followed by another odd permutation is equivalent to an even permutation, so that the closure axiom is not satisfied.

There are 16 other infinite families of finite simple groups, all of them non-Abelian and noncyclic. The orders of the simple groups (excluding the cyclics) form an infinite sequence that starts with 60, the order of the alternating group on five objects. (This group is equivalent to the group of rotations of a regular dodecahedron or icosahedron.) The sequence begins 60, 168, 360, 504, 660, 1092, 2448, 2520, 3420, 4080, 5616, 6048, 6072, 7800, 7920.... If 1 and all the prime numbers are inserted into this infinite sequence, the resulting sequence gives the orders of all finite simple groups.

Unfortunately the list includes a small number of groups (starting with the group of order 7920) that cannot be fitted into any infinite family. These are the non-Abelian anomalies, the jokers that defy all classification. Mathematicians know them as the sporadic simple groups, but they are quite complicated. If there is an infinite number of these sporadics, and if there is no pattern ordering them, then the task of classifying all finite simple groups, and therefore all finite groups, is hopeless. There are, however, compelling reasons for thinking there are no sporadics other than the 26 already identified. (A classic history of sporadic groups appears in the box on page 28. First published in *The American Mathematical Monthly* in November, 1973, the tale is said to have been "found scrawled on a library table in Eckhart Library at the University of Chicago; author unknown or in hiding." The "loops" referred to therein are the simple cyclic groups, and A_n is the symbol for the alternating group for n objects.)

The search for the sporadic simple groups began in the 1860's when the French mathematician Émile Léonard Mathieu discovered the first five. The smallest of them, known as M_{11}, has 7,920 operations and is modeled by certain permutations on 11 objects. A century slipped by before the sixth sporadic, of order 175,560, was found in 1965 by Zvonimir Janko of the University of Heidelberg. Three years later John Horton Conway of the University of Cambridge surprised everyone by finding

NAME OF GROUP	NUMBER OF ELEMENTS	DISCOVERED BY
M_{11}	$2^4 \times 3^2 \times 5 \times 11$	Mathieu
M_{12}	$2^6 \times 3^3 \times 5 \times 11$	Mathieu
M_{22}	$2^7 \times 3^2 \times 5 \times 7 \times 11$	Mathieu
M_{23}	$2^7 \times 3^2 \times 5 \times 7 \times 11 \times 23$	Mathieu
M_{24}	$2^{10} \times 3^3 \times 5 \times 7 \times 11 \times 23$	Mathieu
J_1	$2^3 \times 3 \times 5 \times 7 \times 11 \times 19$	Janko
J_2	$2^7 \times 3^3 \times 5^2 \times 7$	Hall, Wales
J_3	$2^7 \times 3^5 \times 5 \times 17 \times 19$	Higman, McKay
J_4	$2^{21} \times 3^3 \times 5 \times 7 \times 11^3 \times 23 \times 29 \times 31 \times 37 \times 43$	Benson, Conway, Janko, Norton, Parker, Thackray
HS	$2^9 \times 3^2 \times 5^3 \times 7 \times 11$	Higman, Sims
MC	$2^7 \times 3^6 \times 5^3 \times 7 \times 11$	McLaughlin
Sz	$2^{13} \times 3^7 \times 5^2 \times 7 \times 11 \times 13$	Suzuki
C_1	$2^{21} \times 3^9 \times 5^4 \times 7^2 \times 11 \times 13 \times 23$	Conway
C_2	$2^{18} \times 3^6 \times 5^3 \times 7 \times 11 \times 23$	Conway
C_3	$2^{10} \times 3^7 \times 5^3 \times 7 \times 11 \times 23$	Conway
He	$2^{10} \times 3^3 \times 5^2 \times 7^3 \times 17$	Held, Higman, McKay
F_{22}	$2^{17} \times 3^9 \times 5^2 \times 7 \times 11 \times 13$	Fischer
F_{23}	$2^{18} \times 3^{13} \times 5^2 \times 7 \times 11 \times 13 \times 17 \times 23$	Fischer
F_{24}	$2^{21} \times 3^{16} \times 5^2 \times 7^3 \times 11 \times 13 \times 17 \times 23 \times 29$	Fischer
Ly	$2^8 \times 3^7 \times 5^6 \times 7 \times 11 \times 31 \times 37 \times 67$	Lyons, Sims
O	$2^9 \times 3^4 \times 5 \times 7^3 \times 11 \times 19 \times 31$	O'Nan, Sims
R	$2_{14} \times 3^3 \times 5^3 \times 7 \times 13 \times 29$	Conway, Rudvalis, Wales
F_5	$2^{14} \times 3^6 \times 5^6 \times 7 \times 11 \times 19$	Conway, Fischer, Harada, Norton, Smith
F_3	$2^{15} \times 3^{10} \times 5^3 \times 7^2 \times 13 \times 19 \times 31$	Smith, Thompson
F_2	$2^{41} \times 3^{13} \times 5^6 \times 7^2 \times 11 \times 13 \times 17 \times 19 \times 23 \times 31 \times 47$	Fischer, Leon, Sims
F_1	$2^{46} \times 3^{20} \times 5^9 \times 7^6 \times 11^2 \times 13^3 \times 17 \times 19 \times 23 \times 29 \times 31 \times 41 \times 47 \times 59 \times 71$	Fischer, Griess

The list of 26 sporadic finite simple groups

Heart Computer

Your heart can tell you three things that can help you live longer and stay healthier. The rest is up to you.

The Pulsetach will shortly become the number one selling system of its type in the nation.

JS&A has never offered a pulse meter. And for good reason.

If you've ever used one, you'll quickly discover that your heart does not beat like a clock. It's irregular. It might beat at 40 beats per minute for one instant and at 120 the next. Since most pulse meters measure each beat as it occurs, you never feel confident that you're getting a very good reading.

We also considered size. Each pulse meter we examined was large or cumbersome and awkward to carry or store.

WE WAITED

We waited a few years. In the meantime, we discovered three ways your heart (through your pulse) helps you monitor your health.

Pulse Rate Your pulse rate can tell you if you are getting enough oxygen throughout your body. A high pulse rate indicates that your heart must pump faster to supply that oxygen and may indicate poor physical condition.

Target Zone Your pulse can tell you if your heart is beating fast enough during exercise. There's an area called the "Target Zone." Below this level, you're not exercising hard enough to do your heart or respiratory system any good. Above this level, you can be dangerously over-exerting yourself.

Cardiac Recovery Time The time it takes for your pulse rate to return to normal after you've exercised is the real measure of whether or not your exercise program is doing you any good. This time can be as healthy as one minute or as poor as several minutes.

The three things we learned convinced us that the ideal pulse meter must have the following features:

1. It must measure a series of heart beats and simultaneously compute the average to avoid the strange readings from irregular heart beats.

2. It must be small enough to use while exercising.

3. It should have a timing capability to determine the Cardiac Recovery Time.

It wasn't until a small Utah medical electronic instrument company created what we feel not only provides the capabilities listed above, but excels in other areas too.

FITS ON FINGER

The unit is called the Pulsetach, and it fits right over your finger. It weighs less than an ounce and can be worn easily during most exercise programs.

The large liquid crystal display can easily be seen in normal room lighting or in bright sunlight, and because liquid crystal displays consume very little power, the readily-available watch batteries will last for years. The Pulsetach automatically turns itself off in five minutes if you forget.

The heart of the system is a powerful microcomputer CMOS semi-conductor integrated circuit that will take up to 4 pulse beats, compute an average pulse rate, and then flash that rate on the liquid crystal display.

FINGERTIP SCANNER

The sensor consists of a Gallium Arsenide infrared light-emitting diode which scans your fingertip hundreds of times a second to determine your pulse rate. This new system is one of the most accurate and is also used in sophisticated hospital systems.

The unit also contains a quartz-controlled timing circuit which will accurately time either your exercise period or your Cardiac Recovery Time. And you can switch back and forth between the pulse and chronograph mode while you are exercising.

We realize that the Pulsetach sounds like a very sophisticated unit. And it is. But as sophisticated as it is internally, it's an extremely easy unit to operate. There are just two buttons to press which operate the pulse reading and the chronograph timing circuit. A third button engages the audio circuit.

The Pulsetach system fits comfortably on your finger while it monitors your heart and determines your Cardiac Recovery Time.

HEAR YOUR PULSE

The audio circuit simply beeps every time your pulse beeps. This feature lets you monitor your pulse by hearing it as you run or exercise and it can be shut off by pressing the button a second time. The timing circuit is quartz-controlled and extremely accurate.

The Pulsetach not only has combined all of the most advanced technology in an extremely small size, but it costs less than many other systems lacking its advanced features.

The Pulsetach can be used for joggers, athletes, all forms of exercise and even cardiac recovery patients, as it operates quite effectively with pacemakers.

REAL WORKOUT

We suggest you order a Pulsetach for our 30-day no-obligation trial. When you receive your unit, give it a real workout. Notice how simple it is to operate and how easily you can read your pulse rate. Use it to stay in your Target Zone and to determine and then improve your Cardiac Recovery Time.

Monitor your Cardiac Recovery Time. Determine your Target Zone and see if you're really exercising in that area. Then use the Pulsetach to watch those important signs slowly improve thanks to the accuracy and information you get from the unit.

By knowing the important factors that help you monitor your health, you'll feel better, exercise more effectively, and many doctors feel you'll live longer.

TWO UNITS AVAILABLE

To order your Pulsetach pulse meter, send your check for **$119.95** plus $2.50 postage and handling (Illinois residents add 6% sales tax) to the address below. (Allow 20 days for personal checks to clear.) Credit card buyers may call our toll-free number below.

You can also order the more expensive hospital unit that averages 16 beats and has all the features including the small size of the previous unit. It costs **$169.95**.

We'll send your Pulsetach pulse meter complete with 90-day limited warranty and instructions which include information on determining your Target Zone, Cardiac Recovery Time and other helpful information.

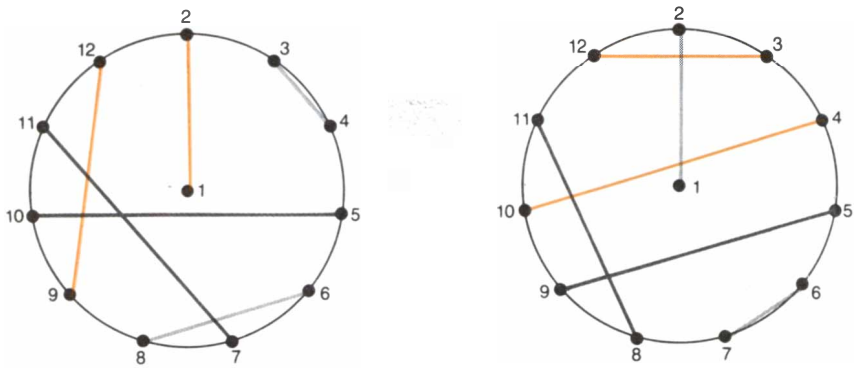
Then after your test, if you're not fully convinced that the Pulsetach is the best unit of its kind, the most convenient, and the greatest value, return it within 30 days for a prompt and courteous refund including the $2.50 charge for postage and handling. You can't lose.

Your Pulsetach is totally solid-state so service should never be required, but if it is, the manufacturer has a national service-by-mail facility backing each unit. JS&A is America's largest single source of space-age products – further assurance that your Pulsetach is backed by a substantial company.

We've waited an awful long time to jump into the pulse monitoring field. But what a great entry. Order your Pulsetach at no obligation today.

JS&A® PRODUCTS THAT THINK®

Dept. SA One JS&A Plaza
Northbrook, Ill. 60062 (312) 564-7000
Call TOLL-FREE 800 323-6400
In Illinois Call ..... (312) 564-7000



Two solutions to last month's bridge-tournament problem

three more sporadics. His work was based on Leech's lattice, a scheme devised by John Leech, a British mathematician, for packing unit hyperspheres densely in a space of 24 dimensions. (In Leech's lattice each hypersphere touches exactly 196,560 others.)

Leech discovered his lattice while working on error-correcting codes. It turns out that there is a close connection between certain sporadic groups and codes employed in reconstructing a message distorted by noise. Two of Mathieu's sporadic groups, M_{23} and M_{24}, are related to the Golay error-correcting code that is often used for military purposes. Roughly speaking, a good error-correcting code is based on a subset of unit hyperspheres placed as far apart from one another as is possible in a dense packing.

An amusing episode involving M_{24} was called to my attention by John McKay, a codiscoverer of two sporadics who is a computer scientist at Concordia University in Montreal. In 1898 George Abram Miller, an American group theorist, published a paper in *Messenger of Mathematics* (Vol. 27, pages 187–190) proving that M_{24} did not exist. As one might expect, this publication does not appear in Miller's collected papers. McKay believes there may be some connection between Miller's ill-fated proof and the fact that although Eric Temple Bell in the index to his *Development of Mathematics* (second edition, 1945) lists page 445 after Miller's name, no mention of Miller can be found on that page. There is, however, a vitriolic attack on group theorists "little advanced beyond mathematical illiteracy," who keep discovering new finite groups by "obstinate grubbing" in narrow categories that they themselves define "apparently with the express purpose of dignifying their calculations with an air of pseudo generality."

At the start of this year two dozen sporadic groups had been proved to exist, and two more, J_4 and F_1, were believed to be authentic. (A complete list of these 26 sporadic groups is shown in the illustration on page 30.) J_4, which was proposed by Janko in 1975, was finally constructed in February by David Benson, Conway, Simon P. Norton, Richard Parker and Jonathan Thackray, a group of mathematicians at Cambridge. F_1 (the monster), which is by far the largest sporadic, was conjectured independently by Griess and by Bernd Fischer of the University of Bielefeld in 1973 and constructed in January by Griess, as I have mentioned. Several much smaller sporadics, the construction of which required long computer calculations, are embedded in F_1 in such a way that their existence follows almost trivially from the existence of F_1. Yet to everyone's astonishment Griess's construction of F_1 was carried out entirely by hand. F_1 is said to be based on a group of symmetry rotations in a space of 196,883 dimensions!

Is the list of 26 sporadics complete? Most group theorists are convinced it is, but the task of proving the conjecture could be formidable. Indeed, the final published proof is likely to require as many as 10,000 printed pages. It should be noted, however, that proofs in group theory tend to be unusually long. A famous proof by John Thompson and Walter Feit, which among other things established William Burnside's conjecture that all non-Abelian finite simple groups are of even order, covered more than 250 pages: an entire issue of *The Pacific Journal of Mathematics* (Vol. 13, pages 775–1029; 1963).

In 1972 Daniel Gorenstein of Rutgers University outlined a 16-step program for completing the classification of the finite simple groups. This guide to a final proof was soon improved and greatly "speeded up" by Michael Aschbacher of the California Institute of Technology. Both men are world experts on groups. (In January, Aschbacher won the much coveted Cole Prize in algebra.) In May, 1977, Gorenstein told *The New York Times* that he had been working on the classification problem five hours a day, seven days a week, 52 weeks a year since 1959. "I want to solve it," he said, "because I want to solve it, not because it will benefit mankind." Like most other group theorists, Gorenstein is convinced that no new sporadic groups will be found, and that a proof that the list of 26 groups is complete is only a year or two away.

There is, of course, no way to predict whether a practical application will or will not be found for any mathematical result whose discovery was not motivated by practical considerations. We do know that groups lie at the very heart of the structure of the universe. Nature seems to prefer small, uncomplicated groups, but this could be an illusion created by the fact that applications of small groups are the easiest to find, particularly in a world limited to three spatial dimensions. Who can say that at some far distant date, if the human race survives, even the monster will not turn out to have some remarkable but at present unimaginable application?

The illustration on this page gives two answers to last month's problem of designing a bridge tournament for 12 players so that they meet at three tables for 11 days and each player is a partner of every other player just once and an opponent of every other player just twice. The first day's distribution is given by a disk on which partners are connected by colored lines and tables are denoted by lines of matching color. Rotating the disk clockwise one step at a time generates the cyclic design for the remaining 10 days. Disk patterns other than the two shown generate additional solutions.

January's column on checkers showed a final position for a blocked game of 24 moves, the shortest game possible if there are no captures. I stated that this pattern was thought to be unique, and Robert F. Holt was the first reader to prove it is not. Alan Beckerson found all the possible final positions, a total of 28. Only two of these patterns (including the one I gave) are symmetrical, and in 16 of them if it were not Black's turn, White would be able to make one more move.

Many variations on last December's "impossible problem" have been received that eliminate the need for an upper bound on the two numbers to guarantee a unique solution. One of the most elegant variants comes from Barry Wolk of the University of Manitoba. As in the original version, mathematicians S and P are discussing two unknown integers, both of them greater than 1. S knows only the sum of the numbers, whereas P knows only their product.

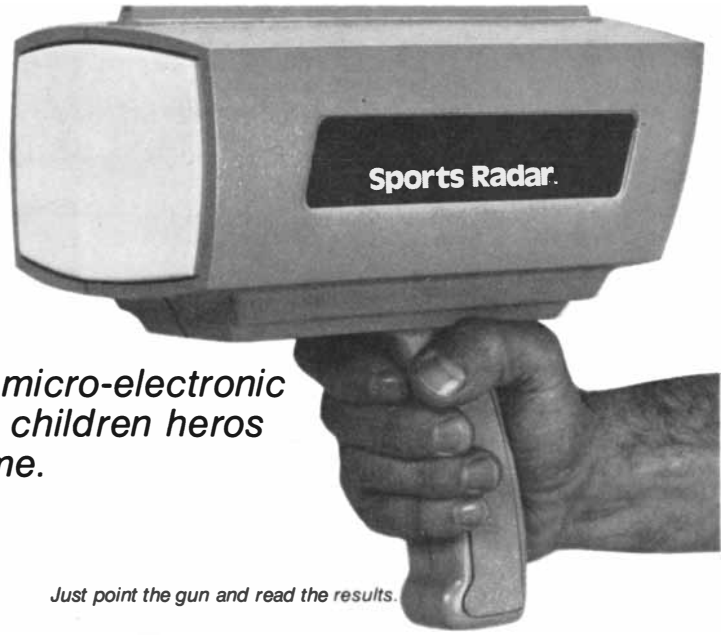
S: "I see no way you can determine my sum."

P (after a suitable delay): "That didn't help me. I still don't know your sum."

S (after another delay): "Now I know your product."

What are the two numbers? If Goldbach's conjecture is assumed to be true, one can show that they must be 5 and 6.

Sports Radar T.M.



Here's how an exciting new micro-electronic breakthrough will make your children heros and improve your tennis game.

Just point the gun and read the results.

When Roger started pitching for his little league team, he was just another player. And his arm was no better than anybody elses.

Two months later a small miracle took place. Roger was the best pitcher on the team and had a fast ball that was the most powerful in his league–and all thanks to his father.

Roger's success came from a radar gun–the same type device used by police to catch speeding motorists.

SCRAMBLED EGGS

The minute Roger's father was able to clock his son's pitching speed, Roger was subconsciously given a daily challenge of pitching harder and faster to beat his previous speed. The more he practiced, the better he got.

Roger's father paid $2,000 for the radar gun. But in his upper class neighborhood, it wasn't too unusual for a father to spend that kind of money to help his son.

SPEEDING CITATION

A large manufacturer of radar-type security devices saw what Roger's father had done and felt that there was a definite need to produce a low cost radar unit designed exclusively for the sports market.

The company, Solfan Systems, developed the Sports Radar gun–a major breakthrough in projectile speed detection as well as electronic radar circuitry.

Using the doppler effect of radar and phased-lock-loop circuits, Solfan has developed the Sports Radar gun that compares to even the most sophisticated of police radar units that cost $2,000.

OVERLAND EXPRESS

The Sports Radar gun is held in your hand and pointed toward the pitcher. You turn it on, press the ready button, and point the gun. The gun will ignore the moving arm of the pitcher but will lock in on the moving ball. The radar unit would then follow the ball for approximately ten milliseconds and the built in computer measures and computes the speed and flashes the reading on the display. The gun registers the speed to the exact mileage within one-half miles per hour.

The gun can be mounted on a tripod so that the person taking the measurements can also catch the ball.

In tennis, the speed of the serve can be measured by aiming the gun at the person serving. You can also use the unit by yourself by setting the unit on a tripod and measuring the speed from behind.

WORKING AND PLAYING

Aside from its extreme accuracy and advanced electronics, the unit is priced to meet the budget of every sports-minded athlete or parent. It's only $189.95 complete.

You can measure the speed of baseballs, soccer balls, tennis balls, golf balls, hockey pucks, downhill skiers, radio controlled model airplanes or anything that moves–even automobiles.

The speed is flashed on the large LED display and is shown in miles per hour.

The unit accepts two commercially available 6-volt lantern batteries which you can purchase locally or from JS&A for only $2 each. The batteries will last for weeks with normal use.

SUCCESS AND GOOD THINGS

The unit comes in a sports blue color and weighs 38.4 ounces, exclusive of batteries. It's rugged, well built and designed to endure the typical use and abuse it would normally receive.

We urge you to test this exciting new product during our 30-day free trial. Order the Sports Radar gun. When you receive it, measure your child's pitching speed. Test it on your own tennis serve. See how knowing your speed will actually improve it as you try to out perform your previous record fast pitch or serve. Then decide if the Sports Radar gun doesn't make a very exciting addition to your sports equipment.

ONE FOR THE MONEY

If you are not convinced that the Sports Radar gun is something that you'll use constantly to help improve your game, return it for a prompt and courteous refund, including your $3.50 postage and handling. You can't lose–and chances are your son will at least have the most popular new product in the neighborhood.

To order one for your test, simply send your check for **$189.95** plus $3.50 for postage and handling to JS&A Group, Inc., at the address shown below. (Illinois residents please add 5% sales tax.) Credit card buyers may call our toll-free number below. If you wish to buy a set of two six-volt batteries, simply add $4.00 to your order.

We'll then send your unit, the batteries (if you order them from us), a 90-day limited warranty and complete easy-to-understand instructions.

Radar electronics for the sports enthusiast is now a reality. Watch your game improve by ordering your Sports Radar gun at no obligation, today.

JS&A® PRODUCTS THAT THINK®

Dept. SA One JS&A Plaza
Northbrook, Ill. 60062 (312) 564-7000
Call TOLL-FREE 800 323-6400
In Illinois Call ..... (312) 564-7000

BOOKS

Battles of wits, the !Kung of the Kalahari, science by balloon and an artist of bridges

by Philip Morrison

THE WIZARD WAR: BRITISH SCIENTIFIC INTELLIGENCE 1939–1945, by R. V. Jones. Coward, McCann & Geoghegan, Inc. ($12.95). The beach at Dunkirk was again deserted, gloomy defeat and bright rescue both over. London was quiet, uneasily making ready. Out at Bletchley Park, the new home of M.I.6, the Secret Intelligence Service, in the huts that spoiled the spacious green lawns men, women and machines were tensely at work. For some two months the ingenious cryptologists there, building on pioneer work in machine computing by mathematicians including no less than Alan Turing, had reached success in decoding the messages routinely ciphered on the German Enigma machines. Luftwaffe centers everywhere freely committed their coded operational messages to radio, careless of interception, confident that the complex electromechanical Enigma codes could not soon be broken. Now a message slip lay on the London desk of the head of the Royal Air Force radio-interception service. The chief signal officer of Flieger Korps IV had filed it (for quite a different address) only a week earlier: "Knickebein, Kleve, ist auf punkt ... eingerichtet," and the coordinates of a point near Sheffield were given accurate to the mile, quite in the clear. "Does this mean anything to you?" was the question.

For the 28-year-old physicist who heard those words, R. V. Jones, the witty author of this unequaled inside story, Knickebein—the dog's leg—was no novelty. Since March some downed bomber crews whose conversation was overheard and a couple of prisoners-of-war under talented interrogation had referred to it. One paper found in a wrecked Heinkel bomber carried a radio operator's scrawl with a bearing to "Radio Beacon Knickebein." The bombers of Flieger Korps IV were Heinkel lll's; a few had been shot down over Britain in recent weeks. The full technical examination of their gear was at hand. The report was not very interesting. The only thing that might possibly fill the bill was the blind-landing receiver, suited for the then standard Lorenz system of beam-guided landings. The expert who had examined the captured radios was consulted. He had noticed nothing unusual, "but now you mention it, it is much more sensitive than they would ever need for blind landing." The radio-propagation experts who had scoffed withdrew under pressure their somewhat paradoxical estimates. Three choices of frequency were established from the tuning pre-set in the Heinkel's receiver. Target spotting would require a second crossing beam from Germany; soon enough a couple more aircraft logs had identified it and its design frequency.

The Prime Minister was convinced, and after a flurry of Whitehall opposition ("The beam theory is all wrong") a receiver-fitted aircraft was dispatched to fly across the line of the beams. Jones had proposed that the beams would cross at Derby, the town of the Rolls Works where Merlin engines for the Spitfires and Hurricanes were made, the crucial power plants of all Fighter Command. The search pilot reported next day. He had been asked to search for transmissions with the Lorenz dot-dash characteristics and had been told the likely frequencies. Flight Lieutenant H. E. Bufton had found two narrow, synchronized beams at the 30-megacycle settings proposed, beams only 400 yards wide crossing near Derby.

Knickebein was quickly jammed. First it was done with a hastily assembled collection of diathermy transmitters making a mush of noise on the Knickebein channels. Within a couple of months special jammers that made matching dashes were put on the air in number. If their dashes had been correctly time-synchronized, they could have acted to "bend" the beam, to displace the equisignal line to the dot side. There had been too little time to arrange this subtlety, but on both sides the legend swiftly grew that the beams were genuinely bent. The night raids continued into the late summer and fall; London burned but smaller cities were often cleanly missed, and many bombs meant for London went astray. R.A.F. fighters could hold off the Luftwaffe by day.

That was only the first battle of the beams; the Luftwaffe had also prepared two more advanced systems, X beam and Y beam. For Knickebein, Jones had been a one-man scientific intelligence service; proved right, promoted, joined by the brilliant theoretical physicist F. Charles Frank, he had recognized clout now. The jamming of Y-Gerät would be deliciously subtle; the pioneer B.B.C. television transmitter at Alexandra Palace was powerful and could work at the frequency band of the single Y beam. Alexandra was commandeered and was arranged to reradiate the Y-beam ranging signals in such a way that the entire Y system would "ring," just as a public-address system squeals when the gain is too high and the microphone picks up sound from the speaker. From its first night Y beam was unusable, all its distance information lost. Coastal towns could still be reached down a single beam, and London sprawled wide enough to be hit somewhere without any aids. Inland, however, cities were now safe, and decoy fires, airborne radar and expert ground-controlled interception gave the fighters good hunting along the German beams.

The Battle of the Beams was "as good as won" by February of 1941. There were 20 beam stations on the French coast by the summer of 1941, but the Luftwaffe had gone east to the Russian front. Again sharp reasoning, Enigma messages and prisoners' hints enabled Jones and his partners to raise timely warnings about a brief final effort against fine old inland towns such as Bath and York in the spring of 1942. This time it was multiple X beams, marked soundlessly with supersonic dashes, which could be separated by receiver filters from the normal high-C modulation. Jones had explicitly warned the jamming services of this possibility a year earlier, but they missed the supersonic signals. The German yield of bombs on target rose for a week or two to 50 percent. Tardy supersonic jamming ended the raids.

The German offensive was quite well served by the beam systems, plainly an artifice of the aggressor, as Home Chain radar was that of the defender. Alone but morally impregnable, the people and the forces of Britain had stoutly and cleverly defended their skies. Now the R.A.F. passed over to its own offensive of fire by night against the homes of the Germans. "Give it to them back!" the people cried; grim, dogged Bomber Command over Europe replaced gallant Fighter Command in home skies. Jones began to worry about German radar. How could the R.A.F. best penetrate the German screens? From early 1941 until the fire storms were kindled by the R.A.F. in Hamburg in the summer of 1943 the R.A.F. played more and more effectively the intruder's role, with bitter losses of life on both sides.

At Jones's suggestion a German radar dish was stripped on its pedestal on the French coast, not far from the path an earlier English expedition under Ed-

Design-it-Yourself...

. . . an environment that really challenges your computer programming skills. You're a Systems Programmer and have great ideas that can pave the way for the future — if only you could use them.

How would you like to come to a place where innovation and creativity are not only encouraged but rewarded! A place where you can try your ideas, and where the only boundaries on growth and ambition are those you set yourself.

That place is National CSS, and there you'll find an environment where independent, creative thinkers make things happen . . . and make a difference!

If you're a unique, high-performance Systems Programmer we'd like to hear from you. Mail in the coupon below and find out for yourself what National CSS has to offer. Where your new ideas today can pave the way for tomorrow. National CSS is an equal opportunity employer.

"Land of Opportunity" poster FREE

Brighten up your future with our colorful 20" x 28" poster. Yours free with coupon.

I'd like to know more about National CSS. Please send me your free brochure and poster.

Name: _____ *Address:* _____

City: _____ *State:* _____ *Zip:* _____

National CSS

Mail to: National CSS, Inc.
Dept. ADC 03061, P.O. Box 209,
West Haven, CT 06516

ward III had taken toward Crécy in A.D. 1346. That little raid at Bruneval, 100 men, was a striking success; it "clinched the future of paratroops in Britain." The Assistant Director of Intelligence (Science), now a bigger frog in the swelling pond, began to rely on new sources. Airborne cameras were first, perhaps. Low-level shots of equipment detail were daringly taken under fire by specialized pilots. The cameras were so awkwardly mounted on the Spitfires that the target lay behind the pilot's shoulder when he had to trigger the exposure. Bomber-borne navigational decimeter radar came into play. German night fighters began to mount radar in turn and indeed often to home on the careless signals of the bombers. The stakes rose as Allied forces increased.

As the air war came to Europe a new kind of intelligence source grew in importance: reports from brave men and women in Belgium, France, the Netherlands, Denmark, Poland and other occupied lands. On pain of Gestapo torture and execution ordinary people sent their information, sometimes detailed insider's drawings, sometimes simple eavesdropping on German gossip, to eager eyes and ears in London. Thus did Jones come to learn of the great rocket laboratories and proving grounds at Peenemünde. Actually that establishment had first been mentioned in a mysterious and farseeing cryptic report received from Oslo back in 1939. The overheard conversations of two captured generals from the Afrika Korps revived a growing concern. "We'll have to take those rockets seriously," Frank remarked in the spring of 1943. The now familiar story has never been so intimately told. The British chemical and engineering experts, strongly aided by the utter disbelief of the powerful Lord Cherwell (Jones's old teacher and confidant) doubted that tales of such big rockets, even though they were now coming in from many quarters, could be real.

The matter was tangled. The big German army rocket, the V-2, was hardly worth its cost to the German war machine, although it was real enough. It was the origin of today's intercontinental ballistic missile. The Luftwaffe, later to start, speedily developed, also at Peenemünde, a brilliantly inexpensive and effective pilotless plane, a crude cruise missile, the V-1. The confusion between these two realities ended only in late 1943. A V-1 flying bomb was found in position on its catapult "just as I had hoped when I specified the optimum time of day for the sortie to be flown." That discovery was no lucky accident, even though the keen-eyed photographic interpreter who first spotted the image of the V-1 had thought so.

Forty years and more have passed since the days of improvisation and insight that Jones recounts at length, literately and excitingly from his memories and some 70 wartime secret reports. He has kept his silence for so long because only during the past few years has Ultra (the decipherment of Enigma) been open to public mention. It is unlikely that many of the secret memorandums that circulate in the big intelligence organizations today show the brilliance of that pastiche "German" report young Jones wrote in battle late in 1940. He adopted the form of mock minutes of a conference of the German Air Staff to bring out one by one the tardy and erring reactions of the British countermeasures groups and to present his own forecasts of the new devices the Germans would seek to develop. Most of his forecasts were right. That report was at once recalled from secret circulation because of the violent reaction of the men palpably hit. The recall was "the most effective way possible of getting every copy read from cover to cover before it was returned."

Jones was patently as formidable an opponent in the Battle of Whitehall as he was in the ether over England. His distinction as an outrageous practical joker preceded his serious intelligence service, but there arose a certain synergy. Who else but R. V. Jones would have undertaken postwar eavesdropping on the interned German nuclear physicists? They had been moved to England after their capture because one colleague had suggested that the Americans might "shoot all [German] nuclear physicists." Not much persuaded, Jones could yet see the "residual advantage" in holding for a while Werner Heisenberg, Otto Hahn and their eminent colleagues. These tape transcripts have never been published; "the official British attitude has been that they never existed." Of course, they have been read, and some have been excerpted in print in the U.S. Jones offers an interesting account of Heisenberg's apparent misunderstanding of the physics of the chain reaction, which would lead to a vast overestimate of the critical mass.

One sees now on two continents the successor organizations both to Bletchley Park and to Peenemünde grown large, their powerful cameras, intercept receivers and weapons all planned for orbit. When the first inexperienced American officer came to see Jones to discuss joint intelligence against the German atomic-bomb effort, the British hosts gleefully shook hands after the American had left "in anticipation that we were so obviously going to be the senior partners in the exchange." It was not so in the outcome; even the captured German nuclear documents of 1945 went first to America. Power has passed to the biggest battalions.

THE !KUNG SAN: MEN, WOMEN, AND WORK IN A FORAGING SOCIETY, by Richard Borshay Lee. Cambridge University Press ($34.95). DEMOGRAPHY OF THE DOBE !KUNG, by Nancy Howell. Academic Press ($24.50). Night is quiet on the high Kalahari plains; the sky is big over the land and bright with the southern stars. Faintly through the masking sounds of distant woodpeckers and creaking trees the people gathered around the campfire can make out the characteristic sound of human presence, the steady pounding of nuts in wood mortars at the next campsite, audible as much as five miles away. ("In this vast and sparsely populated country the unexpected meeting of two groups is usually a cause for rejoicing.") At last the other group too turns in for the night, and "the mortars stop pounding. First three mortars are working, then two, then one, and then silence." Mortar talk is the evocative and unequivocal long-range field mark of our species in !Kung country.

That country is a part of the vast Kalahari plains; a few low hills and lower dunes add relief. The sandy soil bears the shrubs and bushes of the widespread savanna. Along the parallel crests of the fixed dunes are linear groves of the spreading mongongo trees, whose fruit, flesh and kernel alike, are the chief staple food of the !Kung. It is the rich nuts of the mongongo they rhythmically pound in those mortars, often mixed with roots or meat, all roasted in fire coals and sand. The old people prefer the more dilute mortar recipes once teeth and digestion are weak. One mix of nuts pounded with roasted *sha* roots "looks and tastes like tangy creamed cottage cheese."

One informant without hesitation defined his ideal diet: "meat and mongongo for strength, honey for sweetness, and wild orange fruits for refreshment." (He did not mention the truffles of the Kalahari, rivals to the black treasures of the Perigord.) Richard Lee has made a careful quantitative survey of the inputs and outputs of the !Kung economy, in both the fat years and the lean. It is clear that the variability of the rainfall, locally and over rather short time spans as well as annually, defines the main environmental challenge to the skillful !Kung. ("There is no such thing as a typical rainfall year.") The rains come in the hot summer months, and a bone-dry midwinter June can bring weeks of freezing nights and crisp, clear days. The game is taken mainly in the rainy season; the yield is highest from the big antelopes, gemsbok, kudu and wildebeest, although the hunters seek many other species. No living !Kung seems to have taken an elephant (apart from a few who have hunted with the Tswanas using horses and guns). Elephants still come to eat the mongongo's produce in its season; it is said that they gorge and become drunk on the fermenting fruit. Once it was different; as the hunter N!eishi put it: "There were many men of all ages in those days and they could kill

Mumm's the word.

For 150 years now, people who know how to live have been celebrating life with Mumm premium Champagne, imported from France.

"ANYONE WHO'S THINKING OF SPENDING $24,000 FOR A LUXURY CAR SHOULD TALK TO A PSYCHIATRIST."

—Dr. John Boston, psychiatrist and Volvo owner, Austin, Texas

John Boston, a Texas psychiatrist, owns a '73 Volvo.

He bought that Volvo because, as he puts it: "I had admired what Volvo had done in the area of safety. The car seemed well-built. It offered solid European craftsmanship without the inflated price."

We wanted Dr. Boston's opinion of the new Volvo GLE, which has a full assortment of luxury features as standard equipment—and a price tag thousands of dollars below that of the well-known German luxury sedan.

"It's an excellent value. In my opinion, the individual buying this car would have a strong, unsuppressed need to get his or her money's worth. He or she would probably also have a strong enough self-image not to need a blatant status symbol."

When we told him that some people were actually paying five to ten thousand dollars more for a luxury car, Dr. Boston's response was characteristically succinct.

"That's not using your head."

Finally, we asked Dr. Boston if, when he was ready for a new car, he'd consider the Volvo GLE for himself.

"I'd be crazy if I didn't."

VOLVO

A car you can believe in.

elephant." Their method was to set grass fires to trap the beast between the fire and the throng of many hunters gathered together to throw spears.

The shortage of surface water is the most conspicuous desert quality of the Dobe area, the 9,000 square kilometers that is the domain of the people of these studies, who number fewer than 800. For nine of the wettest months of the year they move about in shifting, flexible "camps," perhaps 30 kinsfolk with their "affines who have found that they can live and work together," staying awhile around some seasonal source of water as a foraging base. Nine all-year water holes within this district are geographic centers of the wandering but purposeful life of this foraging people. Each permanent water hole has a stable core of related older people who are the acknowledged "owners" of the hole. They offer continuity with the past. The half-life of the association is close to lifelong, some 30 to 50 years. As each new winter comes, with its greater or lesser degree of drought, the camps gather from longer distances to form larger groups around some of the permanent water holes.

These winter groupings represent the public side of !Kung life; sometimes 200 or more people live together for a while. Here they enjoy the opportunity for long ceremonies that require a number of people of similar age, particularly the young men's initiation. The big trance dances and curing ceremonies also demand many adults to keep the cure going around the clock. The marriage brokers get to work; camp groups are too small to offer a match for every person. The !Kung have a peculiar institution of long-distance trading. It is a gift-giving network, which reaches over hundreds of kilometers with a closure time often of years. It steadily spreads the prized crafts, such as well-carved pipes and ostrich-eggshell beads. ("Nobody keeps hxaro goods very long.") The winter camp is a fine place for hxaro. On the other hand, it is hard to live so publicly. Most fights arise during winter camp, and many winter camps break up in dispute and withdrawal. The mean foraging radius rises from week to week. Food becomes harder to provide, and neighbors who are less than intimate face daily an increasing demand that everyone do a fair share of the work. The big winter camp is self-limited.

Not much is seen of the Leviathan of the state among the !Kung; seniority, continuity through kinship to a waterhole core group and strong personal qualities can sometimes confer a degree of leadership on a man or a woman. The society is nonetheless egalitarian. Arrogance, stinginess and accumulation are its clearest public sins, quiet generosity and modest demeanor its cardinal virtues. There are areas but not boundaries. There are no signs of hereditary chiefs or headmen. One of the owners of a big water hole, /Twi!gum, was asked whether the !Kung have headmen. "Of course we have headmen! In fact, we are all headmen; each one of us is headman over himself!"

The overall results of Lee's study are widely known. Here they are documented in detail, with data on the weight of the people, the hours spent working at various tasks and the rest. All !Kung goods average about 12 kilograms per head. There is not much capital, although what there is of course is literally life-giving. A camp shelter takes two days to build, a winter shelter only hours. The tools of subsistence—from ostrich-eggshell canteens to fire tools and dried-meat racks—and the customary clothing are listed, each with the minutes-per-day cost of manufacture and maintenance. Basic housework is one hour a day of mongongo-nut cracking between two rocks. Children older than eight and all adults do most of their own cracking; parents or siblings help the children younger than eight. Nursing infants and toddlers eat few of the nuts, unless they share some of the pounded product. Men and women cook; firewood is a man's task; fetching water falls to the women. The overall work week averages about 40 hours for women and about 45 for men, summed over subsistence, toolmaking and repair, and household work. The major share of the child care falls to the mothers of the young children and is outside this reckoning. It is of interest that the productivity, measured by calories brought in, is somewhat greater for women than it is for men. The women bring in about 56 percent of the food by energy value; the men gather some plant food but bring in all the meat, a task that yields about 7,000 calories per man-day. Gathering brings in 12,000 calories per person-day. Meat is valued highly by all; feasts and dances and generous gifts of meat accompany every big kill.

These people of the Dobe camps are small, thin and slow to mature. They are hardy and vigorous, however, as adults. There is some evidence that the shorter men are the more successful hunters, and the small infants are certainly no disadvantage to a mother who walks about 2,400 kilometers a year. Besides her personal belongings she must carry for most of this distance each of her children who is younger than four. There seems to be a neat adaptation of these nomads to such a state of affairs: the interval between live births is generally from three to five years. The mechanisms that secure this result are in doubt. Mothers nurse their children on demand, vigorously and frequently, for two or three years. Although during at least the latter half of the interval the mother's sexual life is active, conception does not occur. One view sees the cause in a response to the sucking stimulus itself, which induces a secretion of pituitary hormone. Another view sees a critical threshold of body-fat content as triggering ovulation. One of the interesting sets of data in the Howell volume is a careful approach to a test of the critical-fatness theory, not yet conclusive. It is sure that the overall fertility of !Kung women (exhaustively examined and ingeniously modeled in Nancy Howell's detailed demographic study) is about the lowest ever reported among populations not using contraception. Yet the low !Kung rate does not at all depend on the lateness or failure of marriage.

The principal hunting weapon of the !Kung is the small hunting bow, almost like a toy, with only a nine-kilogram pull. The tiny 15-gram arrow with its grass stem nonetheless has formidable killing power: it is poisoned with matter from a living pupa, harboring a fungal parasite, from any one of three species of chrysomelid beetle. The fresh poison (the material is harmless after a year) will kill a big antelope some 24 hours after a hit by a single poison-tipped arrow, through central-nervous-system effects. The poisoned arrows are a hazard in the camp; in a chronology of homicides Lee shows that of 19 homicides in which the weapon that caused death is known, 13 of the fatal blows came from poisoned arrows. The last such homicide listed was in 1955, but the events are well corroborated, although not witnessed by the anthropologist.

Most of the fights became general melees in a big winter camp. One man began a feud: "≠Gau was a lion. He ate people." In a few instances there is evidence that sanctioned or tacitly sanctioned killings of killers closed the books: "the jural concept of the state in embryonic form." The murder rate is high, comparable to that in Washington, D.C., in 1972. But there is no war, and no weapons other than the hunters' deadly arms. Perhaps these hunters are "the harmless people after all." Let the hunters speak. One afternoon Lee interviewed four men about game. He suddenly posed the question: "And how many men have you killed?" Three gave their scores, a little apologetically. "I shot //Kushe,... but she lived." Last was old Kashe, a kindly grandfather. "'I never shot anyone,' he wistfully replied. 'I always missed.'"

Lee's book is a wide-angle view, gracefully written for the general reader. Howell's is a quantitative, narrow, clear study, with remarkable data and long sequences of photographs of individuals over the life span. The two books (both authors are at the University of Toronto) tell much of our cousins the !Kung, how they were and how swiftly that life is changing. Lee tries to estimate what effect the iron they now use for arrows and spearpoints (and for the one ubiquitous cooking pot) had on their Stone Age economics. He finds it a

useful improvement, perhaps 10 percent effort saved, but nothing major. Nowadays the wandering !Kung are settling down: first it was on the cattle ranches of their landed Bantu neighbors, now it is even more around government posts, near drilled wells, welcome shots of penicillin, handouts of corn, trade in home brew and military patrols. The old order is in swift change. Both of these books, and indeed most of the scholars who have studied the !Kung in the past two decades, are really listening for distant mortar talk: contact not across 10 kilometers of bush but across the hundreds of centuries since all human beings were hunters in a world of hunters.

The firm chronology of human beings in the Dobe area begins 11,000 years ago, when there is archaeological evidence of a foraging population. The next real entry is not until the 1870's. About then it was that iron for blades and points, and flint and metal as a fire kit to replace the fire drill, came first to the !Kung. There is no reason to accept their life as the prototype of the hunters' life of all our forebears, but some sifted fraction of it must lie within the range open to such cultures. These scholars, friends of the !Kung and even dependents, clearly admire and love them. They see a superbly adapted culture, a people of wit, beauty and charm, a deeply sharing way of life. If one stands at a cooler distance from the winning people who look out of the films and the still photographs, one sees human beings like those who spread across southern Africa before the glaciers came the last time. The essence of their story is that they were always few, one of them to 10 square kilometers of land, meeting others invariably with pleasure. We who plant, dwell, war, exploit and describe the world in books are 100 times denser on the land and now wary of strangers.

SCIENTIFIC BALLOONING, edited by W. Riedler. Pergamon Press ($40). The free balloon with its instrument payload has for a long time been the poor man's orbiting satellite. There are national facilities now for launching such balloons on every continent, from Hudson Bay to Alice Springs, from near the North Cape to the broad pampas. The research record is varied and productive; cosmic rays were first found in manned balloons. Any external radiation able to penetrate the equivalent of one book instead of the 30-foot shelf of the entire atmosphere can be studied at balloon altitude. Of course, balloons can search the atmosphere itself, its motions, its electric and magnetic fields, its chemistry and much more.

Most such balloons are zero-pressure balloons, arranged to be in pressure equilibrium with the air around them, more or less open at the bottom. Hydrogen and helium are both used for lift. Such a balloon is nowadays made typically of plastic film, polyethylene or Mylar among others, as thin as one mil but of large size. A small payload these days would be some tens of kilograms; a load of five tons or even more can be flown for a matter of days. Such a large balloon has a diameter at altitude of 100 meters or more, usually in an inverted teardrop form, the stress-free "natural shape." On the ground the gas volume is only 1 percent or so as great. Those acres of flaccid film are no easy matter to launch, and a variety of maneuvers are used, the most effective being the employment of special vehicles that pay out the big structure by whizzing nimbly down the launching field with the payload as the bubble floats up and away.

The natural enemy of the long balloon flight is a pinhole in the plastic film. As the film rises into the cold stratosphere it becomes brittle; crack propagation in the cold material is a second worrying source of failure. In the U.S. the special film used and the means of sealing the segments together (both adhesives and heat sealing) have been the subject of considerable engineering development, pioneered by Winzen Research, Inc., and now extending both to French and to Indian plastics companies. This industry, which is of course tiny compared with the overall manufacture of the more commonplace polyethylenes, "has left its artisanal beginnings well behind." The experienced Indian scientists, unable to import the quality American Stratofilm, tried a simpler scheme. They added a black pigment to the local brittle film in manufacture; the sun's rays aloft kept the film hot, if everything was well done, and ended the brittle cracking. Their black balloons fly of course only by day. In the same spirit a French group reports the ingenious infrared Montgolfière, with an aluminized upper hemisphere and a transparent lower one. Such a balloon—again you must know what you are doing—receives infrared from the earth below, which warms the air because the gas cannot radiate upward into cool space. It has been tested in flights several days long at altitudes up to about 20 kilometers. At the time of the symposium, reported in this volume, which was held at Innsbruck in the summer of 1978, only limited tests of the scheme had been conducted.

The other branch of the art is the superpressure balloon. These balloons are sealed; they hold the lifting gas at a pressure above the ambient one, so that the film must be stronger and leak-free. Two-ply Mylar films are standard. The balloons began rather small, a few meters in diameter, with a payload measured in kilograms. But the French and others, working with special Kevlar-reinforced shapes, should someday soon be able to carry a couple of hundred kilograms up to the topmost levels. The surprising point is that such balloons en-

dure at altitude for very long periods. The open balloons are limited by air-gas mixing, but the well-sealed balloon can float many times around the world, keeping constant-pressure height. Several such orbital experiments have been carried out with large numbers of balloons following the world winds. Aircraft pilots object to fleets of 10-meter spheres touring the stratosphere, even if they are a delicate macroplankton, and so these experiments mainly inhabit the southern oceans, floating high above the wandering albatross.

Collecting the data from the balloon is no easy task. An on-board recording system, retrieved at capture, is a simple but risky style. Telemetry is usually employed; well-to-do balloonists follow the balloon with aircraft or set up downwind stations to extend the range. Having a second balloon at altitude as a communications relay has been tried in Japan, and a British design for such a relay is one of the papers in this volume. The Japanese have made use of a sailing captain's scheme. Their homeland is narrow; you cannot follow the balloon very far as it drifts downwind, even if your site is Sanriku Balloon Center on the Pacific coast. There is need for the boomerang balloon. One launches a balloon into the prevailingly westerly winds during a time when high in the stratosphere the winds are strong from the east. That condition is common from mid-May to early June in Japan; the flights last about 25 hours, some 500 kilometers downwind and 500 back. By letting the balloon control itself, instead of depending on radio command from a tracking station, the balloon can drift far downwind before it rises too high, and a total flight of 40 hours is expected, with a return to within 100 kilometers of the starting point—a long-range boomerang indeed.

There are further data-collection schemes; one of the best was a system called RAMS. It used a satellite that listened to the balloon, whose simple transmitter had only to be a keyed stable oscillator. The Doppler shift measured in orbit indicated the position. The balloon had a tape with an identification code that was transmitted for one second in each minute; the polar satellite *Nimbus 6* collected the data from its entire balloon flock worldwide and then, once in every orbit, fed it all to an Alaskan ground station. The results were excellent. The balloons were located to within five kilometers, with a velocity error of only 1.5 meters per second.

Wealthier balloons will soon employ the coming multiple-satellite navigation systems, but the pioneer of the world-circling balloon armadas navigated very simply indeed. A photocell device ensnared a shadow to detect the altitude of the sun at each balloon. The balloon sent out a simple coded signal and its identification letter on short wave. A

few ground stations could pick up the distant balloons anywhere along their track. Each detection at a known time located the balloon on a circle of constant sun altitude. After a few hours another circle would be found to fit. The intersection of the two circles fixed the position within an ambiguity of just two points. The errors allowed location to within about 100 kilometers. In those days the budget was really low; the distant receiving stations had to send their data back to the investigators in Colorado by mail!

This symposium includes about a dozen rather brief review papers on the operational and technical aspects of scientific balloons, including accounts of the work in India and in Japan, a number of papers on cooperative balloon campaigns and another 10 or so reporting in some detail recent researches in a wide variety of fields. The Finns, the Czechs, the East Germans and the Russians have been triangulating xenon flashes set off under high balloons. Careful photography from several stations works over a distance of 100 kilometers or more at night. In this way the first basic geodetic network over Mongolia is being created in that clear, flat land. Cosmic rays still attract balloon investigators, as do gamma rays from space. The art of able improvisation is still practiced in this domain, but it is clearly giving way to higher performance and to a costlier and corporate style. This agreeable specialized report has four international sponsors but sells at almost 20 cents per typewriter-composed page, another mark of the high cost of research aloft.

ROBERT MAILLART'S BRIDGES: THE ART OF ENGINEERING, by David P. Billington. Princeton University Press ($17.50). The Swiss village of Schuders is home to some 50 people; a single-lane road curves its way there up the mountains toward the Austrian border. That not very busy road is flung across a gorge a little distance from the village on a high concrete bridge completed in 1930. The deep, narrow Salgina flows swiftly in its rocky steep-sided ravine almost 300 feet below the bridge. Under the mists, over the dark forest, the tense white bone of that arch is "one of the most beautiful examples of pure twentieth-century structure... even to the skilled engineer an object of mystery and wonder." The author, a Princeton professor of civil engineering, has traveled to Salginatobel, and he offers his own fine photographic views of the bridge in romantic homage. Its designer was the Swiss engineer Robert Maillart, an outstanding bridge engineer of his time, an engineer-artist whose work seems to express a vision: science and art—efficiency and elegance—are two aspects of one design, integrated "by the connecting link of economy." No one would doubt that in this little corner of the mountains, the democratic, frugal canton of Graubünden, where the elected town leaders sit with the engineers to debate proposals, Maillart's design was the low bid among 18.

Maillart was born near Geneva, and he took a degree in civil engineering in 1894 at the Swiss Federal Technical University, the famous ETH, in Zurich. His grades were high in mathematics and drawing, only fair in bridges and the theory of structures. But the ETH had a curriculum "far more visually oriented than that of engineering schools" today; it still mirrored the great visual style of Carl Culmann, the first professor of civil engineering there, whose classic book of 1855, *Graphic Statics,* dominated teaching worldwide for 50 years and was later to be celebrated in D'Arcy Wentworth Thompson's volume *On Growth and Form.* We follow Maillart through his first jobs to independence as a builder and designer of industrial buildings and bridges, having chosen reinforced concrete (then quite newly successful) as his medium for life. By 1905 the feeling of the little bridges he builds is already akin to the structures of his later life, but it is as the head of a small designing company that he finally realizes his mature masterpieces, between 1928 and his death some 10 years later.

A map shows the sites of the "major bridges" (46 all over Switzerland and one in France), and a dozen are discussed at some length. The volume is not, however, a synoptic study of the designer's work, nor an album of what he has left us. There are such volumes, because Maillart has become conspicuous to the historians of modern art and architecture, who see his wonderful forms as the denial of analysis, the reward of aesthetic genius, beyond all algebraic rule. The point of Professor Billington's book is to appraise Maillart as engineer-artist, whose free choice of forms, inspired by his deep aesthetic sensibilities, made it possible for him to use the simplest formulas for the analysis of stress. "In his ideal of engineering structure the behavior under loading was so simple and easy to visualize that the problems of mathematical analysis practically disappeared." He gave such a form to his deck-stiffened arches that simplifying analytic methods were accurate. The arch was thought of as being loaded quite symmetrically, the cross walls carrying the uniform weight of the deck above along the archway down to the springs of the arch. Indeed, he often made the arches polygonal rather than curved, the changes in slope working against the bending of the arch.

The straight lines help to reduce the cost of the concrete forms, a chief expense of the entire structure. Then the deck is made stiff enough to resist the unsymmetrical loads, the "live loads" of nonuniform traffic. If the deck is made stiff enough against bending, it will transmit its loads almost uniformly to the arch below. "The result is a uniformly loaded arch with axial forces only and a nonuniformly loaded deck with bending forces only." A few pages of simple calculations then set the dimensions to be chosen; direct load tests of finished structures always verified Maillart's designs with surprising success. (He had himself pioneered in the measurement of concrete deflections in a sharply meaningful way.) So armed, Maillart was able to build his finest bridges with curved roadways, three-dimensional yet simple both in analysis and in construction. Essentially polygonal, the members rarely curved in two directions. These methods are still fruitful. His successors are raising some of the finest canyon bridgings we have, in Switzerland and elsewhere, some using his forms, others going beyond them, say with the new development of prestressing. They nonetheless share with Maillart the careful choice of overall shape that goes beyond experience to underlying principles. A maquette shows the bridge at Ganter, near the Simplon Pass, due for completion in 1980. Done by the designer Christian Menn, it has no arch at all, but it would have been welcome to Maillart's eye.

We also learn a little of Maillart as man and as commentator. There is an old picture of his wife, when she was the 19-year-old beauty from Bologna, a tourist he met in a Swiss mountain hotel. With it a more formal one shows the young man Maillart at about that time, natty with pointed beard and mustaches of cantilevered wax elegance! One of his last papers was a critique of a German-built bridge across the Danube at Leipheim, built with explicit credit to him. After a careful comparison of the structures and costs of the German bridge with some of his own he wrote: "Without regard for anything other than keeping within the available budget, the Arve bridge would be found to be a useful object of the purest type. The Danube bridge by contrast has the character of a monument to the German *Reichsbahn;* it aims to be not a pure useful object but rather a representative landmark of the German art of building.... The resulting structure has been made to fit with the aesthetic criterion." We are here at the time of the ascendancy of Albert Speer and the Reich of 1,000 years.

This is a welcome and penetrating study of a wonderful man, and a valuable contribution to the history of ideas. One cannot help recalling another ETH student (he graduated just six years after Maillart) whose powerful work also showed the most fruitful tension between the demands of a stringent mathematical expression and the "free constructions of the human mind." He was Albert Einstein.

The Chivas Regal of Liqueurs.

Chivas Brothers make the world's finest Scotch. And the same renowned Chivas quality and tradition goes into its equally-regal Lochan Ora Liqueur. With a unique taste all its own, Lochan Ora is to be lingered over—sipped slowly, savored fully. It's expensive but, then, good taste invariably is.

Lochan Ora.

The Imported Liqueur from Chivas Brothers.

In simple terms, why every Honda has front-wheel drive.

Have you noticed how more and more car manufacturers are switching to front-wheel drive these days?

We're not surprised. We knew the advantages of front-wheel drive a long, long time ago.

In fact, only Honda has sold all its cars in the U.S. with front-wheel drive and a transverse-mounted engine. (Not to mention having sold more than anyone else too.)

So just what *are* the advantages?

For a start, we've designed a car that's smaller on the outside but with more than enough room inside for both driver and passengers.

This is partly due to the fact that there's no driveshaft running through the passenger compartment. So your passengers have more foot and legroom.

Eliminating the driveshaft also reduces another problem. Because the driveshaft can be a source of noise and vibration.

But the advantages of front-wheel drive don't just stop at improved space utilization and comfort.

Front-wheel drive puts more of the weight on the front driving wheels. That means better traction.

And since driving power is applied in the direction the car is being steered, it helps you through the turns.

We could go on. But the only way to really appreciate our front-wheel drive is to test-drive a Honda yourself.

The Honda Civic. The car that was named Motor Trend magazine's Import Car of the Year.

The Accord. Our luxury car.

And the Prelude. Our idea of a sports car.

They all have front-wheel drive.

So if that's what you're looking for in a car, it's worth remembering that Honda is out in front all the way.

HONDA

We make it simple.

If you have ever taken a luxury sports car through a tight turn, you know the feeling. It's the sense of supreme precision with which this trim, compact camera proclaims its Nikon heritage. A feeling that is borne out by the professional quality pictures the Nikon FE delivers with automatic ease. And one that, unlike other fine things in life, is readily affordable.

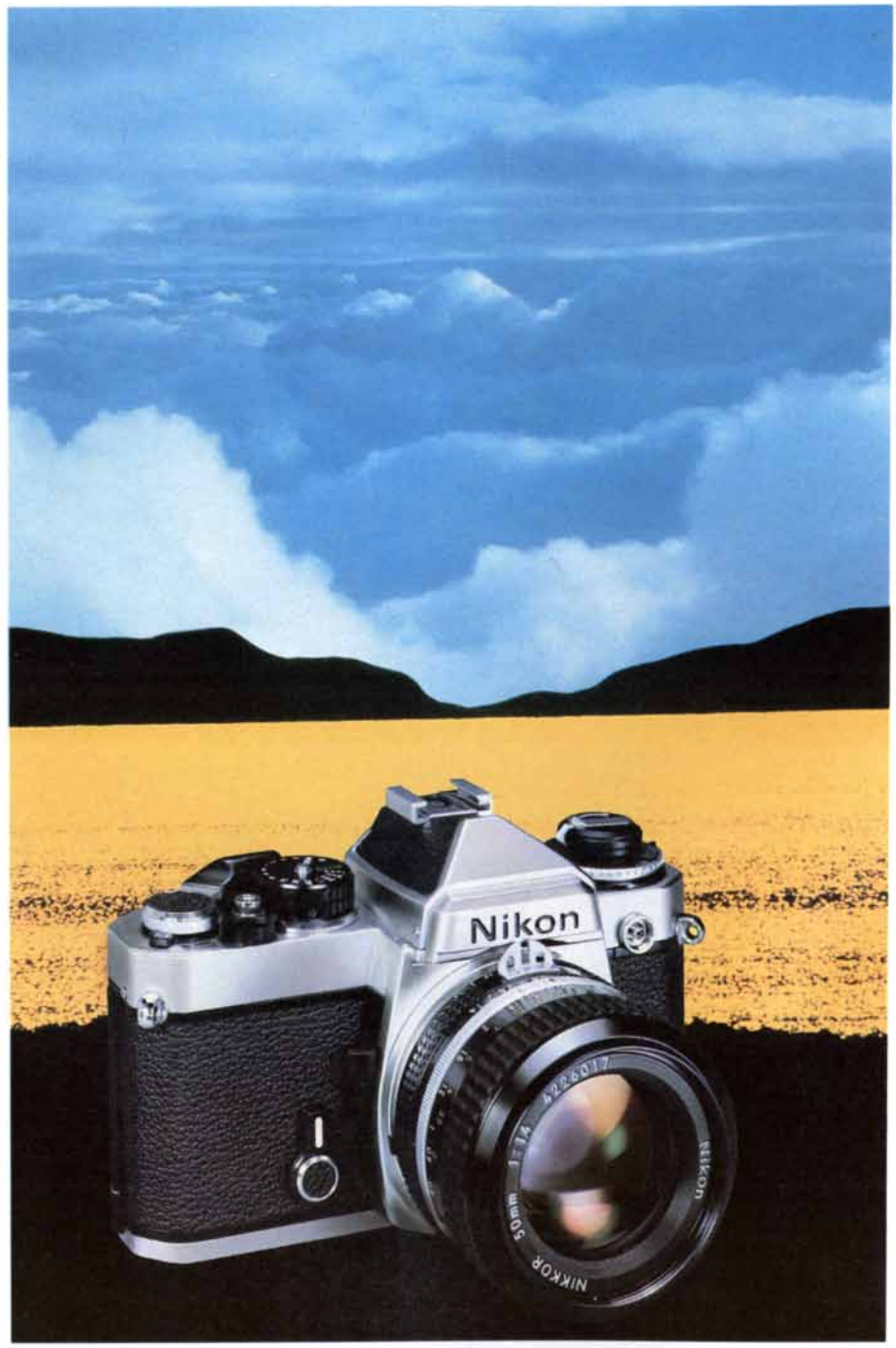
With the Nikon FE, you can simply focus and shoot... and rely on its Nikon electronics to give you sharp, magnificently exposed photographs, automatically. Or, switch to manual operation and enjoy complete creative control over every exposure, more easily than you ever thought possible.

Above all, this is a camera that makes no compromise in its supreme Nikon quality. Stroke the advance lever, and feel the smoothness of precision gearing machined to microscopic tolerances. Press the exposure button, and hear the shutter respond with hushed precision. Look through the bright, silver-coated viewfinder, and see your picture snap into sharp focus with a fingertip touch.

Know, too, that the world's greatest photographic system stands behind your Nikon FE. Add the dynamic firepower of motor drive, at up to 3.5 shots a second. Banish darkness with the ingenious automatic thyristor flash. Explore new perspectives through more than 60 Nikkor lenses, the same superb optics chosen by most professionals for their sharpness and color fidelity.

For the purist:
The Nikon FM
For those who prefer only manual exposure control, the Nikon FM offers the reliable guidance of one-step electronic metering. It's as compact and precisely responsive as the FE and costs even less. At your Nikon dealer.

Nikon Inc., Garden City, New York 11530.



Experience a sense of perfection.
The Nikon FE.

Established 1845 SCIENTIFIC AMERICAN June 1980 Volume 242 Number 6

Genetic Amniocentesis

The fluid that surrounds a fetus in the uterus can now be examined for the prenatal detection of genetic disorders, yet the procedure is being performed for only a tenth of the parents most in need of it

by Fritz Fuchs

Amniocentesis, from the Greek *amnion,* the fetal membrane, and *kentesis,* a pricking or puncture, signifies the insertion of a needle into the membranous sac surrounding the fetus in the womb of a pregnant woman and the withdrawal of some of the fluid in which the fetus is suspended. The fluid is sometimes withdrawn late in a pregnancy to remove the excess that accumulates in the pathological condition called polyhydramnios. Currently it is sampled far more often with an entirely different intent.

In 1955 Povl Riis and I, working at the University of Copenhagen, demonstrated that the sex of a fetus can be determined by staining the nuclei of cells found floating in the amniotic fluid, because the cells are from the fetus and in cells from the tissues of a female the chromatin (the material in the nucleus that accepts the stain) includes a condensation that can be seen as a dark mass: the Barr body. We also were able to determine the *ABO* blood group of the fetus by adding cells from the amniotic fluid to solutions containing red blood cells whose blood group is known and then adding to the solution the antibody to cells of such a group. In the solution in which the two populations of cells are of the same group (both types of cells have *ABO* marker molecules arrayed on their surface) the antibody causes a clumping of cells in which both populations participate.

Such findings led us to predict as early as 1956 that many other features of the genetic makeup of the fetus could be identified by examining the amniotic fluid and the cells floating in it, and that it might therefore be possible to diagnose a number of hereditary disorders well before the birth of an afflicted infant. What we surely did not predict was the rapidity with which the prenatal diagnosis of genetic disorders has progressed since those early years.

The advantage of prenatal diagnosis is clear. Among the numerous fetal abnormalities that can now be detected many lead to debilitating disease and many cause death at an early age. Others cause mental retardation so severe that it precludes a normal life. For most of the abnormalities no treatment now exists, but if they can be detected early in gestation, the pregnancy can be ended. Even those prospective parents who do not consider the termination of a pregnancy acceptable may think it important to know the diagnosis so that they can prepare for the birth of an afflicted infant. Moreover, a large proportion of parents who know themselves to be at risk of bearing a child with a genetic disease no doubt would never undertake a pregnancy if prenatal diagnosis were not available, or would choose abortion automatically if a pregnancy occurred.

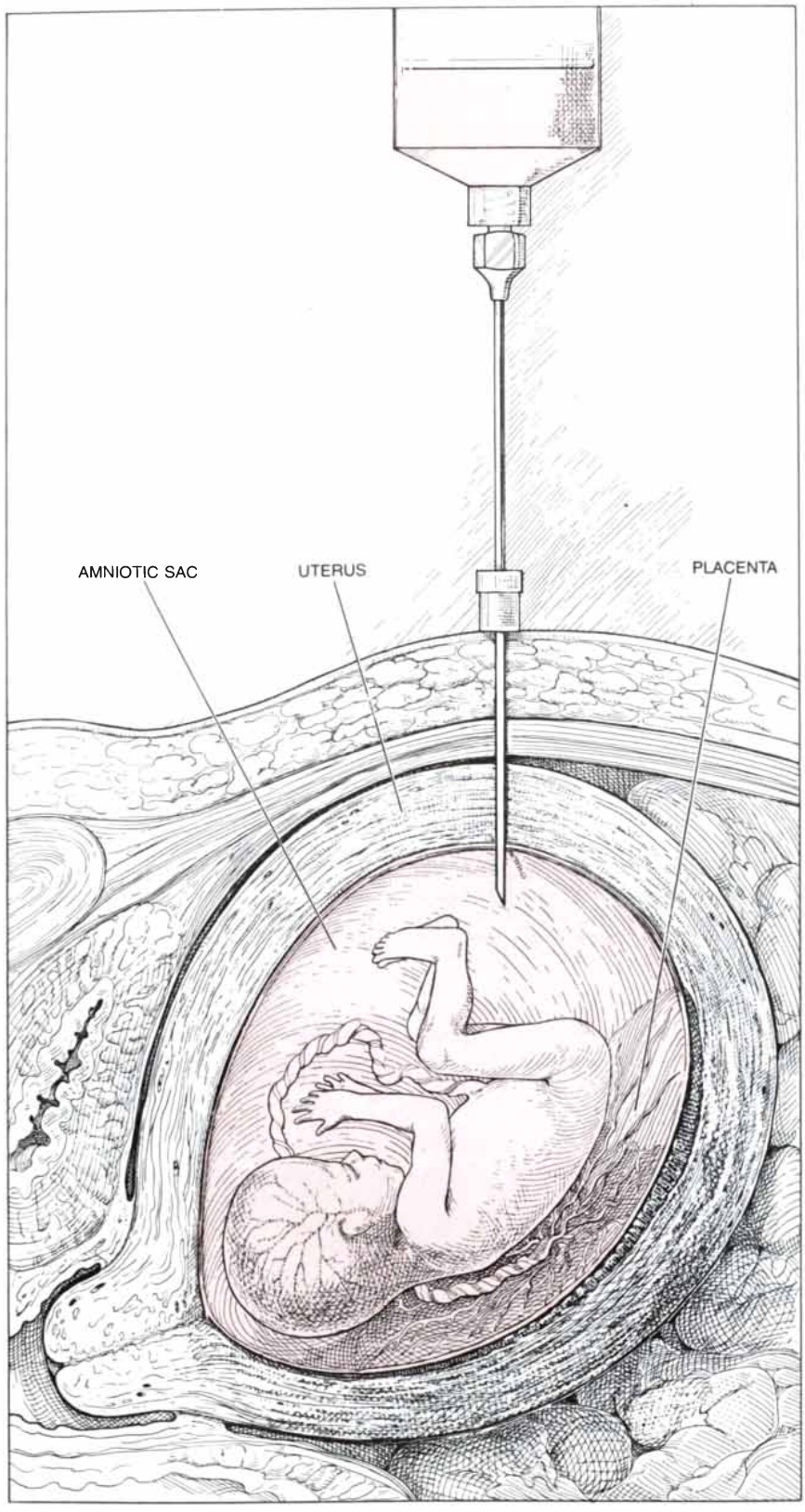
In the U.S. and a number of other countries amniocentesis and the related laboratory procedures are now available in many medical centers. Obstetricians are aware of its benefits and its risks, and public discussion has brought amniocentesis to the attention of at least part of the population. At present, however, only an estimated 10 percent of the women in this country who are substantially at risk of having children with genetic disorders that can be detected by amniocentesis actually have the procedure performed.

The amniotic fluid usually is sampled 16 to 17 weeks after the pregnant woman's last menstrual period. This corresponds to the 14th or 15th week of the pregnancy, a time that is found to be optimal for the procedure in part because the amniotic fluid has then attained a volume of 175 to 225 milliliters (six to eight ounces), from which as much as 25 milliliters can be removed without substantially collapsing the fluid space. The fluid has several sources. Some of it is secreted from the upper respiratory tract of the fetus. Some of it diffuses through the fetal skin. Some of it diffuses through the membranes of the amniotic sac. The most constant source of the fluid is the urine excreted by the fetus.

Suspended in the fluid are live and dead cells. Some slough off from the skin of the fetus. Some are in the urine and in the respiratory-tract secretions. Others slough off from the umbilical cord, from the inner surface of the amniotic sac and from the placenta, to which the umbilical cord is attached. The placenta is an organ interposed between the maternal and the fetal bloodstream. In genetic content the cells from all these sources in essence are fetal cells, because the cord, the sac and the placenta, in addition to the fetus itself, derive from the fertilized ovum.

The fluid is best removed immediately after examination of the image of the fetus in a pulse-echo ultrasonogram. The essence of this technique is that when vibrations with frequencies of from 20,000 to several million cycles per second meet the interface between tissues of different densities, they are reflected. The reflections yield an image on which can be measured the size of various structures. A notably useful measurement is that of the size of the fetus's head, which is well correlated with its age.

Sonography makes it possible to diagnose major structural abnormalities. Oscillations in the sonogram reveal the fetal heartbeat several weeks before it can be detected with an ordinary stethoscope. The technique therefore makes



NEEDLE IS INSERTED through a pregnant woman's abdominal wall to remove fluid from the sac in which the fetus is suspended. The procedure, called amniocentesis, provides samples of the fluid (and of the cells floating in it) for the prenatal diagnosis of genetic disease. The illustration, which is actual size, shows the fetus in the 15th week of pregnancy. It is the time at which the amniocentesis is best performed, in part because the fluid has sufficient volume so that the sample can be taken and in part because the completion of the tests of the fluid and its cells, two to four weeks after the fluid is sampled, leaves open to the prospective parents the choice of having the pregnancy ended if a severe disease is diagnosed. Many of the fetal abnormalities that can be detected by amniocentesis lead to crippling, life-shortening disorders.

possible the early diagnosis of a fetal death. With the aid of sonography a site for the puncture of amniocentesis is selected so that the needle used for the procedure avoids the head of the fetus, and if possible the placenta, and enters an accessible pool of fluid. A problem for which sonography is particularly valuable is the detection of twins and other multiple gestations. With rare exceptions each fetus in a multiple gestation has its own amniotic sac, and so it is necessary to sample the fluid in each sac.

In any case the fluid always is removed by means of a long, thin needle that is inserted through the mother's abdominal wall. Small quantities of the fluid are used for biochemical assays. The remaining fluid is placed in tissue-culture flasks and incubated so that the living cells in the fluid multiply. This requires two to four weeks. If the examination of the fluid and its cells then reveals a fetal abnormality, the pregnancy can still be terminated well before the fetus is viable.

One reason for the culturing is that a large number of cells can then be caught as they divide and their genetic material is condensed into chromosomes. At other times the genetic material is a disorganized tangle that cannot be analyzed. Typically the chromosomes are photographed under a high-resolution microscope and identified according to their size. In a newer technique the chromosomes are stained with dyes that bind selectively to certain parts of individual chromosomes to produce characteristic patterns of banding. The normal human complement of chromosomes is 46. All but two of them are found in pairs. The remaining two are sex chromosomes: they bear the genes that make the child male or female. In the cells of a male one of the chromosomes (designated *X*) is large. The other one (*Y*) is small. In the cells of a female both of them are *X*. It turns out that one of the *X* chromosomes in each cell of a female condenses to form the Barr body.

The group of hereditary diseases that were the first to be diagnosed by amniocentesis consists of the sex-linked disorders, in which the disease is caused by a defective gene that is part of an *X* chromosome. In males the presence of such a defect results in manifestation of the disease because the defective version of the gene is the only copy in each cell. In females, however, a defective *X* chromosome is masked by a normal *X*. The disease can affect a female only if both of her *X* chromosomes are defective, and that is quite unlikely; it requires that the genetic inheritance from her mother include the defective gene and that her father have the disease. It is all the more unlikely in view of the severity of the diseases, most of which are crippling and greatly shorten life. Two examples are hemophilia, in which the blood lacks

certain substances that make it coagulate and thereby arrest bleeding, and Duchenne's muscular dystrophy, a progressive muscle weakness that by early adolescence confines its victim to a wheelchair.

Hence a woman with a defective *X* chromosome is a carrier who will pass the sex-linked defect on to half of her children. On the average half of her male children will suffer from the disease and half of her female children will be carriers. A woman at risk of bearing a child with a sex-linked disease usually knows it, because for many generations some of her male ancestors have been afflicted by the disease. The examination of the chromosomes in cells from the amniotic fluid then reveals the sex of the fetus. The cells can be stained to demonstrate the presence or absence of the Barr body, or the cells can be cultured so that the sex chromosomes can be identified. Since the disease has a 50 percent incidence in the sex at risk (the male), the indication for amniocentesis is certainly quite strong. (It should be added that recent efforts to find a correlation between the sex-linked disorders and some feature of the fetus other than the sex may ultimately make possible the prenatal diagnosis of the sex-linked disorders themselves.)

A second group of disorders that can be detected by amniocentesis consists of disorders caused by gross chromosomal abnormalities, usually an abnormal number of chromosomes but sometimes a major structural defect in a single chromosome. The commonest of these disorders is Down's syndrome, in which the cells of the fetus each have three rather than the usual two of the chromosome designated No. 21. The chromosomal abnormality is called trisomy 21. The consequences are mental retardation and internal malformations that often include congenital heart disease and lead to early death. Typically the infant's head is small and flattened and has mongoloid features such as slanted eyes. Certain other chromosomal abnormalities have clinical features that are equally severe. Still others are compatible with a normal life except that they cause sterility.

Chromosomal abnormalities that are disastrous to a fetus can be the result of an innocuous change in the chromosomes in either parent. That change is a translocation: the displacement of a chromosome, or part of a chromosome, onto a second chromosome. Such a defect may exist in all the parent's cells; if it does, the defect existed in the fertilized ovum from which all the cells arose. Alternatively, the defect may exist in only some of the parent's cells. The cells that have the abnormality are those that arose from a cell in the embryo in which the translocation first occurred. In either case the translocation causes neither loss

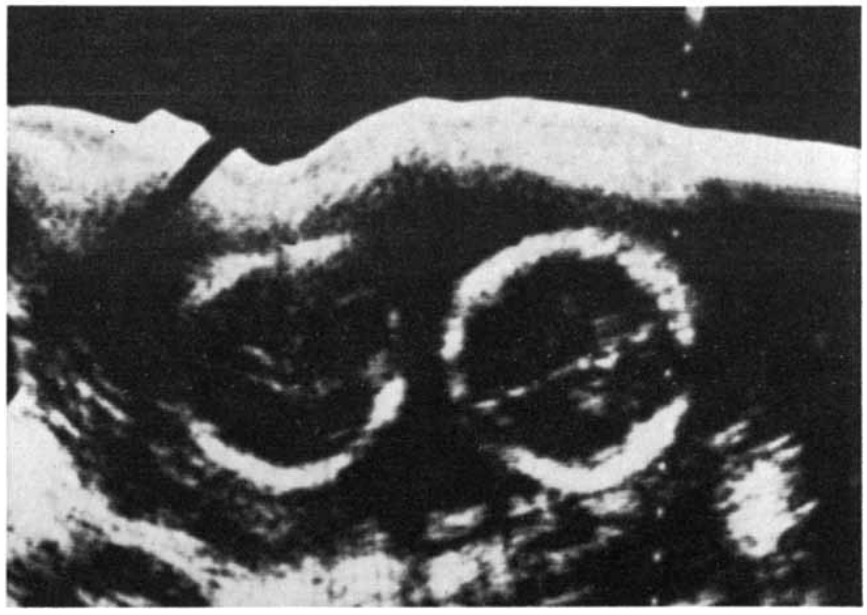
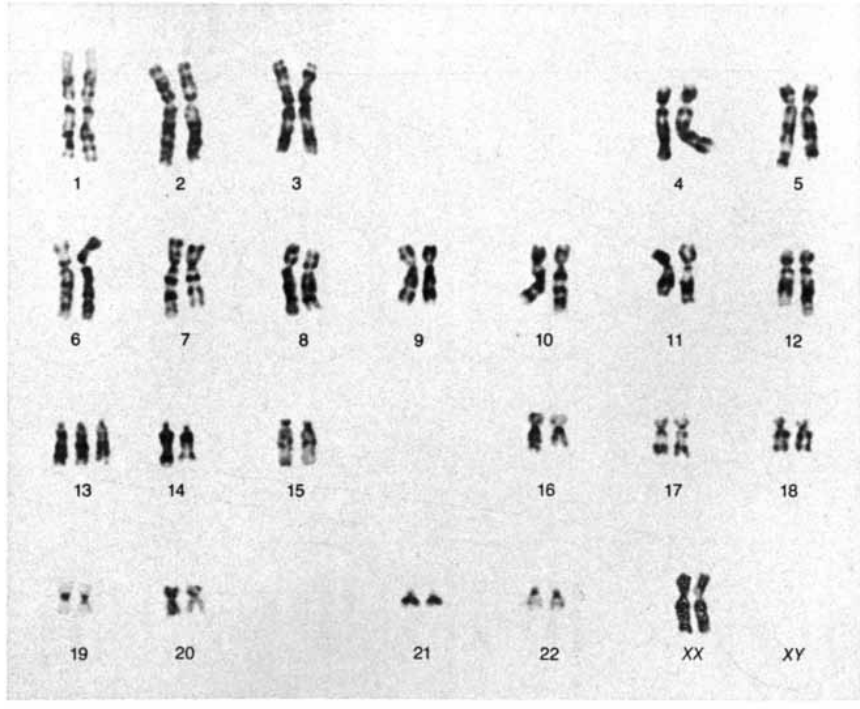


IMAGE OF A PREGNANCY is made by ultrasonography and is viewed before amniocentesis is performed so that the needle reaches an accessible pool of fluid in the fetal sac. The technique constructs the image from high-frequency vibrations, which are reflected at the interface between tissues of different densities. The sonogram shown here is of a pregnancy at 21 weeks. It reveals the gestation of twins. The white ovals defining their heads are caused by reflections of ultrasound at the skull. The white line at the midplane of the head at the right is caused by reflections of ultrasound at the falx cerebri, a thick sheet of tissue between the left and right hemispheres of the brain. A dotted line coursing diagonally downward at the right is placed on the image by an electronic measuring device and is used to measure the size of the fetal head, from which the age of the fetus is judged. The dots are at one-centimeter intervals. The sonogram was made by the Division of Ultrasound at the New York Hospital–Cornell Medical Center.



CHROMOSOMES from a cell in the amniotic fluid are identical with those in the cells of the fetus. The set shown here is from the progeny of a cell in the fluid. The set includes an extra chromosome No. 13; hence the cells of the fetus also have that defect, which is called trisomy 13 and almost always causes spontaneous miscarriage. The presence of two *X* chromosomes (*bottom right*) shows that the fetus is a female. If the child is born, however, her head and brain will be severely deformed and it is likely that she will die before she is six months old. The chromosomes in the illustration were prepared by the Cytogenetics Laboratory of the New York Hospital–Cornell Medical Center. The cell from which they were taken was about to divide, and so each chromosome is present in two copies that join at the structure called the centromere.

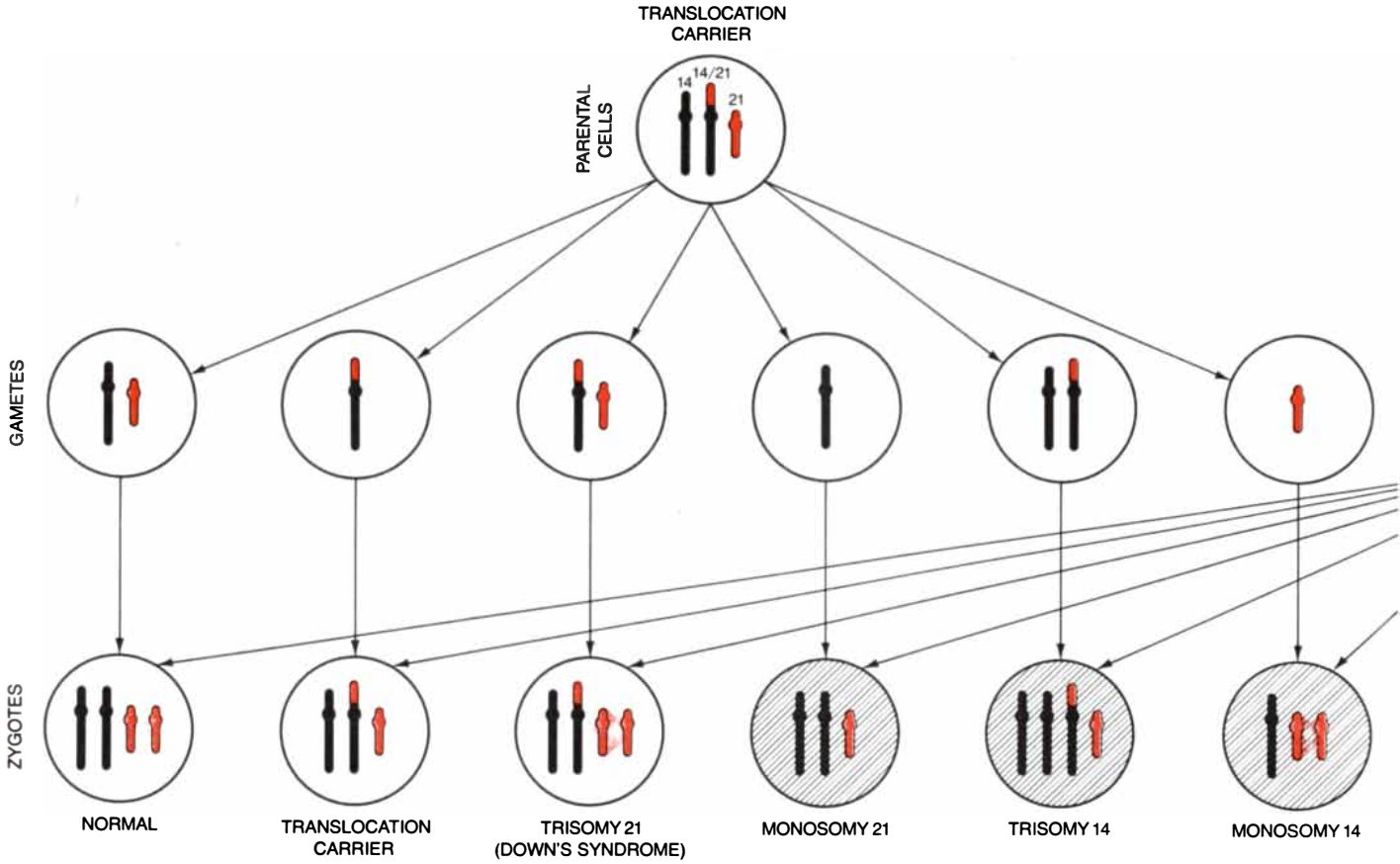
nor gain of chromosomal material in any one cell of the body. Hence the parent does not manifest any disease. The parent's germ cells form, however, by meiosis, a process in which cells divide but their chromosomes do not replicate. Instead they are simply allocated among daughter cells, so that if a chromosome has translocated, one germ cell may get too much chromosomal material and another may get too little. Both conditions are grave. Some fetuses with cells that include 45 or 47 chromosomes are miscarried spontaneously. Others are carried to term and then are born with severe defects.

Trisomies can also occur by mutation. The risk of its happening increases with advancing maternal age, perhaps because all germ cells in the ovaries were formed before the mother herself was born. Germ cells released from the ovary during later years of the mother's fertile period have therefore been exposed to mutagens (mutation-causing agents) longer than those that were ovulated early.

A third group of disorders detectable by amniocentesis consists of diseases caused by the biochemical defects known as inborn errors of metabolism. The inborn error is usually the deficiency of a certain enzyme. It is caused by a mistake in the gene that specifies the structure of the enzyme. Although the incorrect gene itself cannot yet be detected (in most cases the site of the gene, normal or abnormal, in the chromosomal material is not yet known), the defect is revealed by assays of the amniotic fluid or of its cells that show abnormal rates of enzyme activity, abnormal metabolites or normal metabolites in abnormal concentrations. In a few instances the knowledge that a certain disease is caused by a particular inborn error has led to the development of a therapy, but most of the inborn errors entail severe, debilitating diseases that currently are incurable and have symptoms that cannot be alleviated. About 75 inborn errors of metabolism, each of them quite rare but collectively the source of much human suffering, can now be diagnosed by amniocentesis.

An example is Tay-Sachs disease, in which the fatty substance called ganglioside accumulates abnormally and progressively in cells of the nervous system. The consequences include blindness, dementia and paralysis. Usually the child dies before attaining the age of five. The inborn error that causes Tay-Sachs disease is a deficiency of the enzyme hexosaminidase *A*. When heat is applied to the enzyme, it loses its efficacy; with the aid of an assay that is based on this property an examination of skin cells, blood plasma or white blood cells taken from prospective parents reveals carriers of the defective gene. As it happens, carriers are quite rare in the general population, but the incidence is considerable among Jews of eastern European origin. There the incidence may be as great as one person in 30.

Although the precise location of the defective gene is not yet known, it does not lie on a sex chromosome. Moreover, the defective gene is recessive, so that in the chromosomes of the fetus both versions of the gene must be defective to bring out Tay-Sachs disease. To put it another way, if both prospective parents are carriers, the chances are one in four that their child will manifest the disease. Thus amniocentesis is indicated if both of the partners are carriers. An assay of cells from the amniotic flu-



CHROMOSOMAL ABNORMALITY (such as the one shown in the bottom illustration on the preceding page) sometimes is inherited in the manner diagrammed here. The parental cell at the right includes a normal complement (two versions) of chromosome No. 14 (*black*) and chromosome No. 21 (*color*). The parental cell at the left is abnormal. One version of chromosome No. 14 and one of chromosome No. 21 have broken near the centromere. The short arms of the chromosomes have disappeared and the long arms have fused to produce a hybrid 14/21. The defect is called a translocation; it may produce in the parent no sign of disease. When the cell divides to produce germ cells, however, the chromosomes are allocated unevenly. The six possible outcomes for fertilized ova appear at the bottom of the illustration. The three at the right are not found in live births; it appears that the abnormality always induces miscarriage. Of the three at the left

id will then determine whether the fetus has inherited the disease.

The discovery by David J. H. Brock and Roger Sutcliffe of Western General Hospital in Edinburgh that the incidence of certain fetal malformations is correlated with elevated levels of the protein called alpha-fetoprotein (AFP) both in the amniotic fluid and in the mother's blood opened the way for the prenatal diagnosis of a fourth group of disorders. Most of them are defects of the neural tube, the structure in the embryo that becomes the central nervous system. The defects include anencephaly, in which the brain of the infant is partially or completely absent, along with the upper part of the skull, and spina bifida, a defect that leaves the spinal cord covered only by membranes or only by skin and membranes and not by the bones of the vertebral column. Certain other malformations involving the kidneys or the gastrointestinal tract and the abdominal wall have also been associated with abnormally high AFP levels in the amniotic fluid.

AFP is manufactured in the liver of the fetus, from which it is secreted into the fetal circulation in amounts that increase until the 20th week of the pregnancy. From there it passes into the amniotic fluid; it is probably excreted in the urine of the fetus, although it also may diffuse through the skin. Small amounts then diffuse through the placenta and the amniotic sac and enter the maternal circulation.

For anencephaly it is hypothesized that a further path exists: the AFP diffuses through the thin walls of developing blood vessels in the brain of the fetus, which is exposed to the amniotic fluid by the congenital malformation. AFP does not itself cause the neural-tube defects; it is produced in normal amounts in the liver of a malformed fetus. What makes AFP important is that it is the only protein known to exist in the fetus that is not produced in adults. Hence its presence in the mother at levels that seem to be abnormal can be a diagnostic sign.

In pregnant women who have previously delivered an infant with neural-tube defects or who have family members with such defects the level of AFP in the amniotic fluid should be measured. Such women are known to be at greater risk than the general population of bearing an afflicted child. In women not known to be at risk the level of AFP in the maternal blood can be measured in early pregnancy, and amniocentesis can then be performed if the level in the maternal blood is elevated in repeated samples.

There is, however, no sharp demarcation between normal and abnormal maternal levels. Moreover, there are several possible reasons for misinterpreting the measurement, such as the undetected death of the fetus or the miscalculation of its age. The latter is a source of error because the level of AFP considered normal changes with the age of the fetus. In cases of maternal levels deemed to be borderline it therefore becomes important to apply sonography to determine the fetal age and make certain that the fetus is alive before amniocentesis is done.

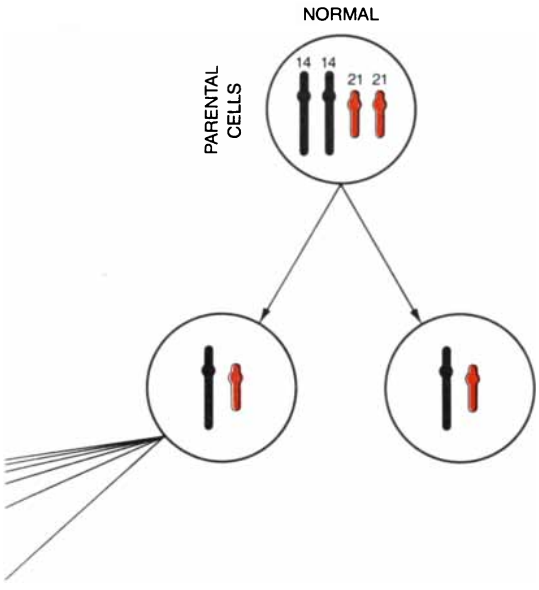
In Britain and in the Scandinavian countries large-scale AFP screening programs for pregnant women have already been instituted. In the U.S. the Food and Drug Administration and the National Institutes of Health recommend further studies before large-scale screening programs are undertaken. Our own experience at the New York Hospital–Cornell Medical Center suggests that screening programs have realized their promise. In our opinion the principal reason for not yet instituting large-scale programs is a lack of widespread expert knowledge and facilities.

It was recognized from the beginning that the insertion of a needle into the amniotic sac and the withdrawal of a sample of amniotic fluid can be associated with certain hazards, particularly to the fetus. It is therefore important to weigh the risks of a genetic disorder against the hazards of the procedure in each individual case.

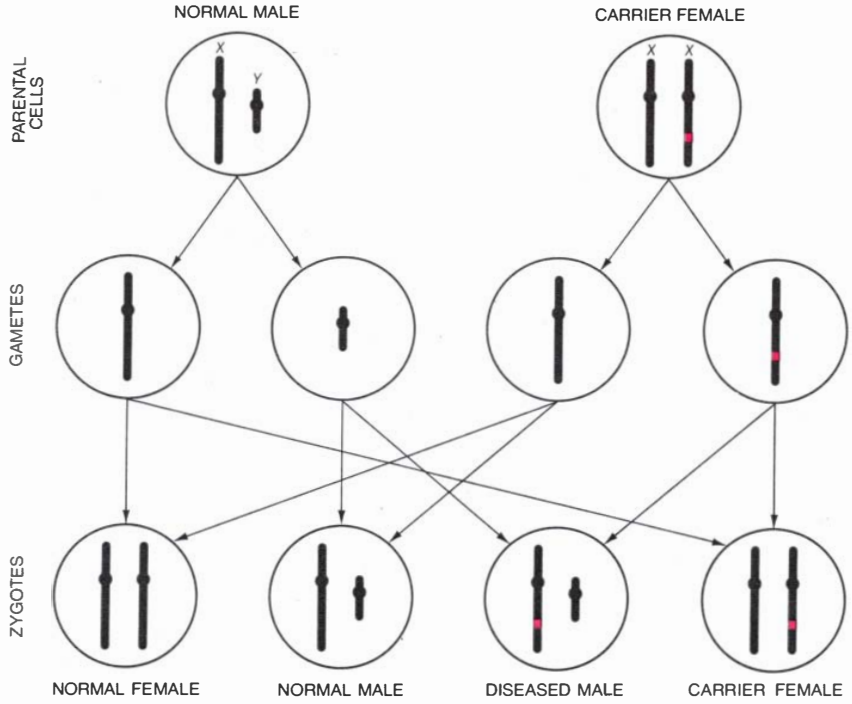
Two major hazards are known. They are the increased risk of spontaneous abortion or rupture of the amniotic sac, which can occur for several weeks following amniocentesis, and the risk of causing in the mother an immune reaction that is directed at the fetus. The reaction is one in which an *Rh*-negative mother (a woman whose red blood cells lack the cell-surface molecules called rhesus factor) develops antibodies that attack the red blood cells in an *Rh*-positive fetus. The possibility arises because the puncture of the placenta by the needle used for amniocentesis is sometimes unavoidable and may enable fetal red blood cells to enter the maternal circulation. The hazard can be prevented, however, by injecting anti-*Rh* globulin into the maternal circulation of an *Rh*-negative mother. This substance is an antibody that destroys the *Rh*-positive blood cells that have found their way into the maternal circulation before they can trigger the immune response. If both the mother and the father are *Rh*-negative, the treatment need not be performed, because in that case the fetus cannot be *Rh*-positive, and so the immune reaction cannot occur.

The risk of amniocentesis, then, is essentially an increased risk of miscarriage. It augments a natural risk of miscarriage, which is estimated to be 1 to 2 percent at the stage of the pregnancy when the amniocentesis is done. In a study published by the National Institutes of Health the total fetal loss (including stillbirths) for 1,040 subjects of amniocentesis and for 992 controls was 3.5 and 3.2 percent respectively. In 1,440 instances of amniocentesis performed at the New York Hospital–Cornell Medical Center from 1972 to 1978 the total fetal loss was only 1.5 percent, and undoubtedly there would have been some losses even if amniocentesis had not been performed. Temporary symptoms that did not entail the death of the fetus occurred in 16 percent of the patients. Such symptoms included lower abdominal pain, leakage of amniotic fluid and vaginal bleeding.

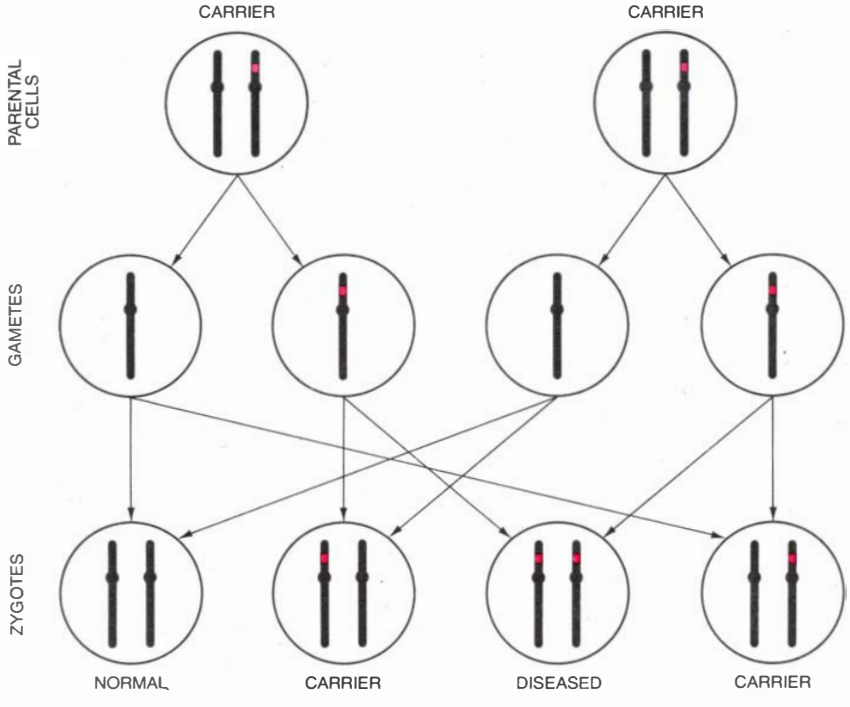
How do these figures compare with the risk of giving birth to a severely diseased child? When amniocentesis is undertaken because of the previous birth of a diseased child, because the mother or the father is a translocation carrier of a chromosomal defect or because the level of AFP in the maternal blood is abnormally high, the chances of detecting a serious abnormality are substantially greater than the increased risk of fetal loss or of serious but nonfatal complications. When it is undertaken because of the mother's age, only if she is 40 or older does the chance of finding a defect definitely outweigh the increased



one outcome is normal and one has the translocation. In the third the presence of an extra chromosome No. 21 (a condition called trisomy 21) causes Down's syndrome, characterized by mental retardation and various malformations. Two-thirds of all fetuses whose cells have trisomy 21 miscarry spontaneously.



SEX-LINKED DISEASE such as hemophilia is caused by a defective gene (*color*) on an *X* chromosome. In the cells of a female the presence of two *X* chromosomes ensures that a normal version of the gene is present. The female is thus a carrier; she manifests no disease. In cells of a male the sex chromosomes are an *X* and a *Y*. Hence if a defective gene is on an *X* chromosome, no normal version is present. Women who are carriers usually know that some of their male ancestors had the disease, and inspection of the chromosomes in cells from the amniotic fluid reveals fetal sex. The chance that a male child born to a carrier will have the disease is one in two.



AUTOSOMAL RECESSIVE DISEASE is caused by a defective gene (*color*) on an autosome: a chromosome other than an *X* or a *Y*. The incidence of the disease thus has no relation to the sex of the fetus. The parental cells at the top of the illustration each have a normal complement (two versions) of an autosome. In one version a gene is defective, in the other it is normal. Hence both of the parents are carriers. The chance that in the cells of their child both genes will be defective is one in four. Such a child will be diseased. In the case of Tay-Sachs disease, which causes mental retardation and early death, a biochemical assay of parental skin cells or blood cells uncovers carriers of the defective gene. If both prospective parents are carriers, an assay of the cells obtained by amniocentesis will indicate whether the disease exists in the fetus.

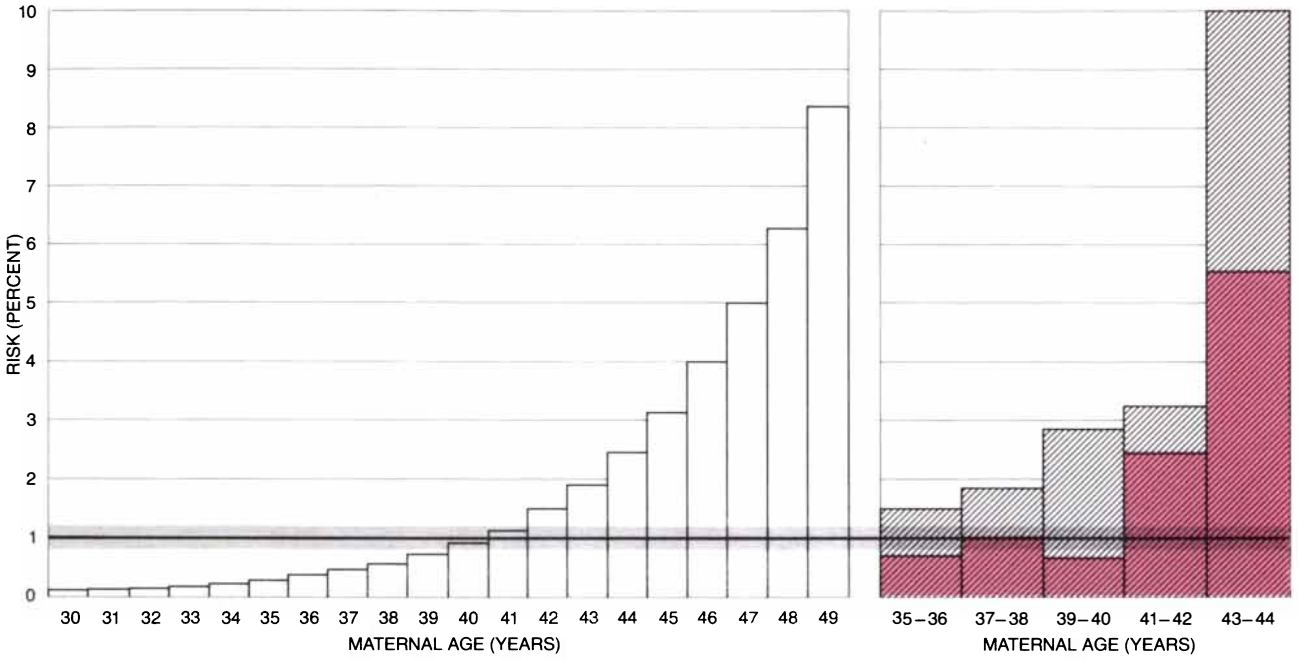
risk to the fetus. If she is between 35 and 40, the risks probably balance.

Most women in that age group decide in favor of amniocentesis, and if they are properly counseled and the local facilities allow, it is certainly reasonable to offer them the opportunity of having it done. For public health, however, amniocentesis raises a difficult question. It can be estimated that not performing it in women whose only apparent risk factor is that they are between 35 and 40 would eliminate two-thirds of the total number of amniocenteses that are currently performed. This would enable the present U.S. health-care facilities to provide amniocentesis to three times as many women who are more substantially at risk. Such a policy, however, simply cannot be instituted within the current system of private medical care.

Some changes are occurring. In the past, for example, it was often pediatricians who had to explain genetic mechanisms and risk factors to parents after the birth of a child with a congenital disease. Now it is obstetricians who have to provide information, because many parents want to know the risk of genetic disorders before they give birth to any children. The issues have become more complex, and to help the obstetricians there has arisen a new group of medical personnel: the genetic counselors. Although their training varies, such counselors have taken special programs designed to give them some knowledge not only of genetics but also of psychology. Before amniocentesis is now undertaken it is often a genetic counselor who explains to the patient (and if possible her mate) the procedure, its purposes, its hazards, its failures, its limitations and its benefits.

In 95 to 98 percent of the patients amniocentesis will rule out the possibility of certain congenital disorders. Nevertheless, it must be made clear to prospective parents that ruling out the disorders for which the amniocentesis is performed is no guarantee of a healthy infant. Moreover, if a genetic disorder is detected, the subsequent need for counseling and support is even greater than before. By the time the results of amniocentesis are available the age of the fetus is 17 to 21 weeks. It is not surprising, therefore, that the psychological effects of an abortion performed for a genetic indication can be severe, particularly in a first pregnancy. In one study done at the University of California School of Medicine in San Francisco depression developed in 92 percent of the women and 82 percent of the men in couples who elected to interrupt a pregnancy, and in four out of 13 families the husband and wife separated. Yet most of the families studied would repeat their course of action and elect abortion over the birth of a defective child.

Failure to tell patients about the pos-



RISK OF CHROMOSOMAL ABNORMALITY in a fetus is known to increase with the age of the mother. The chart at the left shows the empirical risk that a woman will give birth to an infant whose cells have the commonest abnormality: an extra chromosome No. 21. Such infants are born with Down's syndrome. In deciding to do amniocentesis the risk of such a birth must be weighed against the risk of miscarriage, estimated at 1 percent, that the procedure itself entails. The two risks are in balance if the mother is in her late thirties. If she is 40 or older, the risk of miscarriage becomes the lesser of the two. The data are from a study by Ernest B. Hook and Agneta Lindsjö. Colored bars in the chart at the right show empirical probabilities, again by the age of the mother, that the presence of an extra chromosome No. 21 will be discovered by amniocentesis. Many such fetuses are miscarried spontaneously. Hence the bars are higher than those at the left. The bars with hatching at the right show empirical probabilities that any excess of chromosomes (or any deficit) will be discovered by amniocentesis. Those bars are higher still. The data in the chart at the right are from a study by Mitchell S. Golbus and his colleagues.

sibility of genetic diagnosis by amniocentesis has brought legal action for malpractice against obstetricians in recent years. This is not the place to discuss the legal aspects of amniocentesis in detail. Still, it is ironic to contemplate that a small number of plaintiffs in the U.S. have been awarded considerable sums in settlement of some of these cases. Meanwhile approximately 90 percent of the mothers substantially at risk of bearing children with disorders that can be detected by amniocentesis did not receive the benefits of the procedure.

A second legal issue involves the borderline between medical research and clinical practice. If the state of New York, for example, decides to allow and perhaps even encourage the screening of fetuses for neural-tube defects by means of AFP assays and the state of New Jersey does not, will obstetricians in New Jersey leave themselves vulnerable to lawsuit if they fail to tell their patients that the test can be done on the other side of the Hudson River in New York?

The most important aspect of the future of amniocentesis (and prenatal diagnosis in general) is to make the present techniques available to every mother at risk of bearing an abnormal child. Nevertheless, recent discoveries show the ways in which prenatal diagnosis can be expected to develop. For one thing, continuing work will surely increase the number of inborn errors of metabolism that can be detected by amniocentesis. At the same time the list of inborn errors known to exist can be expected to grow as the biochemical disorders underlying other genetic diseases are clarified.

Inborn errors, however, are rare. A more significant prospect is the prenatal diagnosis of diseases of higher incidence. Some examples are thalassemia and sickle-cell anemia, both of which are due to abnormalities in hemoglobin. One approach to the prenatal diagnosis of pathologies of hemoglobin requires the detection of the abnormal hemoglobin itself in samples of fetal blood. Such samples are obtained by inserting into the amniotic sac a needle thicker than the one used for amniocentesis. Through the needle is inserted a slender fiber-optic device that includes in turn a long, thin needle. Blood can then be taken from a fetal artery that the clinician actually can see on the surface of the placenta. The technique, which is called fetoscopy, requires great skill and experience. Even so, it carries a much greater risk to the fetus than amniocentesis.

This approach may, however, become obsolete. In 1978 Yuet Wai Kan and Andrée M. Dozy reported that sickle-cell anemia can be diagnosed prenatally by means of amniocentesis. Their method is based on the use of enzymes that cleave DNA strands at the sites of specific sequences of the nucleotides composing them. The strands are taken from the nuclei of cells in the amniotic fluid. Some of the strands incorporate the gene that encodes the structure of hemoglobin. It turns out that the cleavage of those strands by a particular enzyme produces fragments of one size if the gene is normal and fragments of another size if the gene is defective. The difference reveals the defect. Similar techniques should eventually make possible the prenatal diagnosis of many genetic diseases for which there is currently no method.

To be sure, genetic disorders at present cannot be cured. At the time the fetus first becomes visible by sonography, and hence might conceivably be accessible for genetic engineering, it consists of millions of cells, and copies of the genes, and of any defects in them, are present in every one. Nevertheless, certain inborn errors of metabolism have symptoms that can be alleviated after birth by dietary measures or by the administration of drugs. It is imaginable that such treatment might be applicable to the fetus. Moreover, it is a truism in medicine that the first step in rational treatment is an exact diagnosis, and this is what amniocentesis provides in many cases. The successes of amniocentesis therefore suggest the hope that at some time in the future measures to alter the expression of genes and thereby cure disease might be administered in utero.

Basaltic Meteorites

Eucrites and shergottites are remarkably similar to volcanic rocks on the earth and the moon, but they are from somewhere else. They testify to the long history of volcanic activity in the solar system

by Harry Y. McSween, Jr., and Edward M. Stolper

Among the thousands of meteorites that have been collected and classified a tiny fraction, about 100, evidently crystallized from molten rock somewhere in the solar system about 4.5 billion years ago, possibly no more than 100 million years after the formation of the sun and the planets. What was the source of heat capable of melting rock so soon after the origin of the solar system? And in what kind of body did such melting take place? A still smaller sample of meteorites, only three in number, presents an even greater mystery. The three objects crystallized from molten rock no more than 1.1 billion years ago and were presumably ejected into space by an impact on a body very similar in composition to the earth. Although most meteorites are believed to have come from comparatively small bodies, these three meteorites exhibit properties that indicate their source was a large planet, conceivably Mars. In order to account for such an unlikely source some unusual factor must be invoked, because the impact needed to accelerate a fragment of rock to escape velocity from a body even as small as the moon is so great that no meteorites of lunar origin have ever been discovered.

Meteorites resembling terrestrial volcanic rocks have been recognized and studied for more than a century. They furnished evidence of extraterrestrial igneous processes long before the launching of space missions. It is now known that volcanic processes shaped the evolution of most of the bodies, large and small, in the inner solar system. The maria, or "seas," of the moon, which were sampled by the astronauts of the Apollo missions, were flooded by lava between three and four billion years ago. Photographs made from the Mariner and Viking spacecraft reveal that the great volcanoes of Mars are far larger than the analogous structures on the earth, such as the Hawaiian Islands. The recent Voyager discovery of active volcanoes on Io, a moon of Jupiter, is the first sign of present-day volcanism on a body other than the earth. Observations of Mercury by the *Mariner 10* spacecraft revealed maria similar to those on the moon, and pictures of the surface of Venus made by the Russian Venera landers show rocks that appear to be volcanic in origin. The full extent of volcanic activity on the earth has only recently been appreciated with the recognition that virtually the entire crust of the earth under the oceans is formed from molten rock extruded at mid-ocean ridges.

Volcanic eruptions are the final stage of a process that begins with the melting of rock in a planet's interior, the "source region." The most usual source of the heat that leads to melting is energy released by the decay of radioactive elements. The material in the source region is generally only partially molten, being made up of magma, or liquid rock, and unmelted crystals. The lighter liquid gradually rises above the denser crystals through the action of gravity and collects in magma chambers. The segregation process that drives the liquid upward can take anywhere from hundreds of years to hundreds of millions, depending primarily on the force of gravity, which varies with depth and the planet's size, on the nature of the crystals in the source region, on the amount of liquid produced by the heat available and on the viscosity of the liquid.

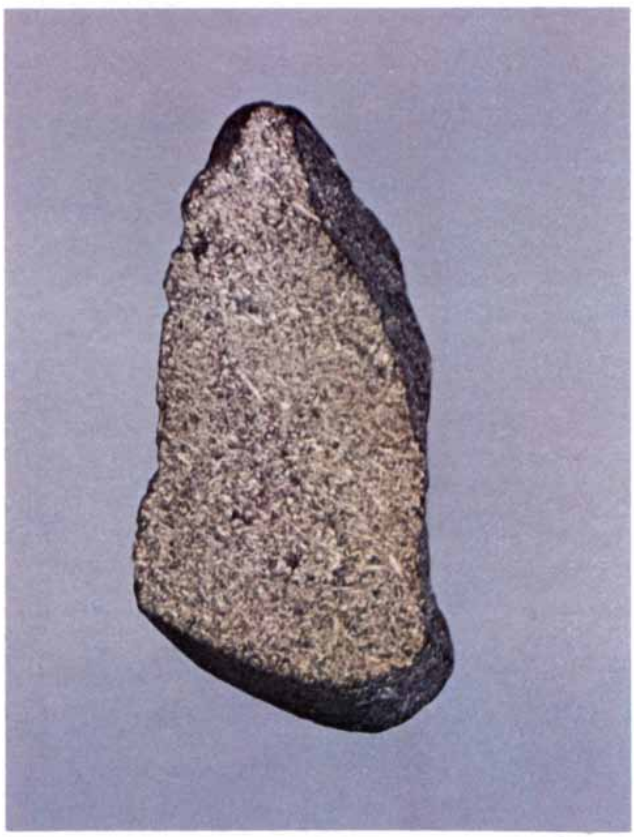
From the magma chambers the molten rock finds its way to the surface through conduits or fractures. On its way to the surface the melt tends to cool and partially crystallize, just as a cup of hot salty water will on cooling gradually precipitate crystals of salt, which grow on the bottom and the sides of the cup. And just as the water in the cup gets progressively less salty as more of the salt precipitates, so too does the composition of the ascending magma change as it cools and crystals settle out of it. Although the salt-water analogy is oversimplified, it illustrates an important point: Most magmas that ultimately erupt have changed substantially in composition as they have cooled on their way to the surface.

The final stage in the igneous process, the stage of eruption, is the only one that can be observed directly. Of course, not all the magmas produced by partial melting in the interior of a planet reach the surface. In many cases the magmas remain trapped and crystallize completely in chambers below the surface.

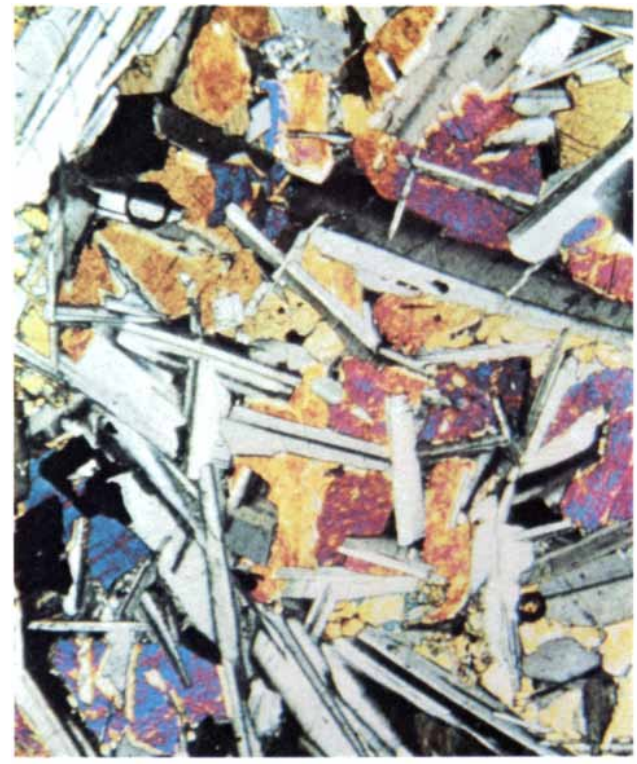
The simple observation of lava flows and volcanoes on the earth or on some other body therefore reveals a great deal about the planet's evolutionary history. At some time before the eruption of lava sufficient heat had to be supplied to partially melt the planet's interior. If the source of heat is assumed to be the decay of radioactive elements, one can infer much about the probable quantity and distribution of those elements. Regardless of the source of the heat it is evident that the liquid was able to segregate from crystals in the source region and find paths for reaching the surface. For example, the apparent absence of volcanic activity on the moon since about three billion years ago does not necessarily mean there has been no melting in the moon's interior since that time; it may only indicate (as has been suggested by Sean C. Solomon and his co-workers at the Massachusetts Institute of Technology) that cooling and contraction of the moon's crust has sealed all the fractures through which liquid could ascend.

Under favorable conditions one can infer features of the mineralogy and chemical composition of the source region by studying the erupted lavas. In other words, one can use the volcanic rocks as probes of a planetary interior. To illustrate how this might be done, consider again a cup of water, this time one with a layer of white crystals visible at the bottom. If one tastes the water and finds it salty, one infers that the crystals are salt. If the water is sweet, one infers that they are sugar. If it is both salty and sweet, one would probably conclude that they are a mixture of salt and sugar. Just as the crystals in the bottom of the cup leave a distinctive imprint on the chemistry of the water, which one de-

EUCRITE, one of a small class of meteorites that crystallized out of molten rock soon after the formation of the solar system some 4.6 billion years ago, appears in these two views. The view at the left shows the black, glassy exterior of the meteorite indicating that it fell at high velocity through the earth's atmosphere. The view at the right shows the sectioned interior of the meteorite. It has a brecciated texture, indicating that the meteorite consists of fragments that were fused together on the parent body from which it was ejected. This particular eucrite is a fragment of the Pasamonte meteorite fall that was observed in New Mexico on March 24, 1933. It is seen half actual size.



SHERGOTTITE, one of an even smaller class of meteorites, is a fragment of lava that solidified somewhere in the solar system no more than 1.1 billion years ago. Only three shergottites are known; this one is the original Shergotty meteorite, which was observed to fall near the town of Shergotty (or Sherghati) in India in 1865. The view at the left shows the exterior of the meteorite, the view at the right the sectioned interior. The interior consists of elongated crystals of the silicate pyroxene that evidently settled with a preferred orientation as the lava cooled in a magma chamber within the parent body of the meteorite. This specimen too is half actual size. It and the eucrite specimen shown in the pictures at the top of the page were photographed at the National Museum of Natural History in Washington.



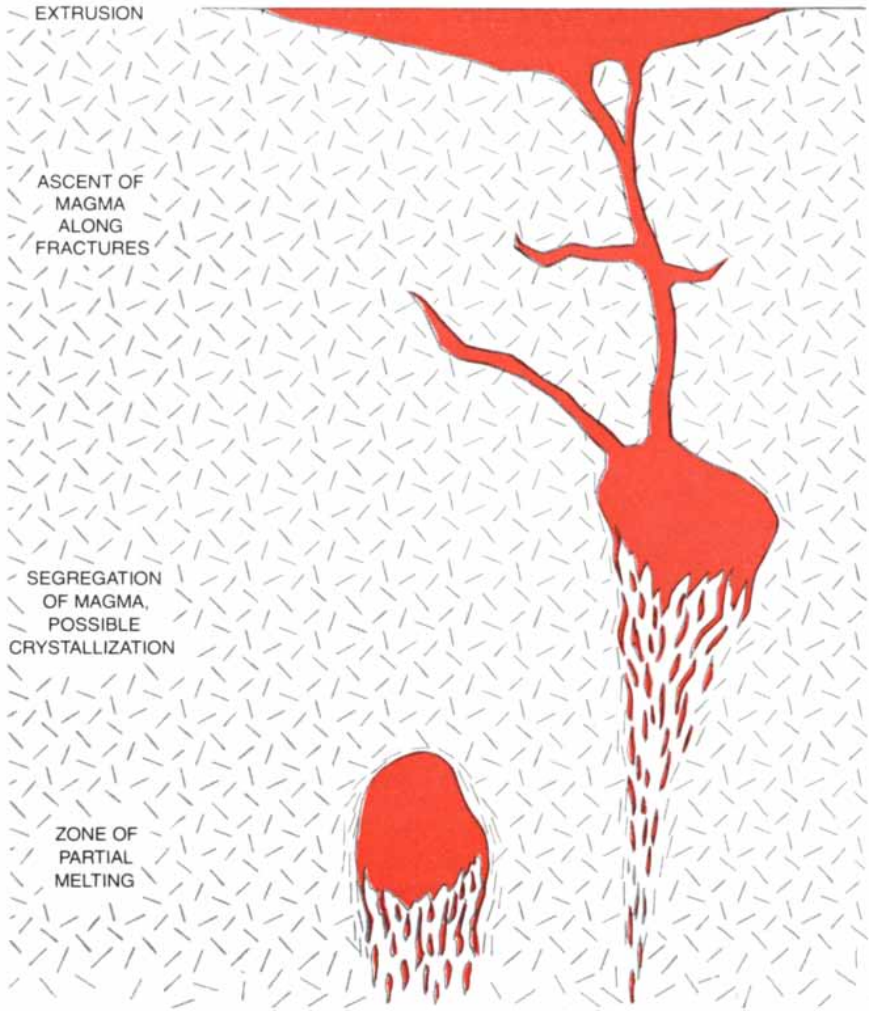
EUCRITES AND LUNAR BASALT are similar in mineralogy and texture, but there are enough differences between them to indicate that the eucrites did not come from the moon. The polarized-light micrograph at the left shows the interior of a eucrite that fell near Juvinas in France in 1821. The specimen consists of elongated grains of gray plagioclase embedded in colored crystals of pigeonite. The micrograph at the right shows the interior of a specimen of lunar basalt. This specimen too contains plagioclase embedded in pigeonite.

SHERGOTTITES AND TERRESTRIAL BASALT are so similar in composition and mineralogy that it is difficult to conceive that the shergottites could have originated elsewhere in the solar system. The case for an extraterrestrial origin is nonetheless compelling. The micrograph at the left shows a shergottite that fell near Zagami in Nigeria in 1962. The micrograph at the right shows a typical terrestrial basalt. The chief difference is that the shergottite contains a glass called maskelynite, which is formed when plagioclase is subjected to intense shock. The maskelynite appears black in the micrograph. The colored crystals are augite and pigeonite. In the micrograph of terrestrial basalt elongated gray crystals of plagioclase are interspersed among colored grains of augite and pigeonite. There is no maskelynite present.

tects through the water's taste, so too do the crystals in the source regions in planetary interiors leave a distinctive chemical imprint on the liquids that segregate from the source regions. Thus if one can find and identify volcanic rocks whose composition was not greatly changed by crystallization as they rose to the surface, and if one is clever enough to recognize the chemical imprint of the crystals left behind in the source region, one can make informed guesses about the mineralogy and chemistry of the parent material in the source regions. It should be added that the crucial step of identifying volcanic rocks that have not changed composition by crystallizing on the way from their source to the surface is difficult and controversial. On the earth, at least, such rocks appear to be rare, so that the rocks one chooses to examine for an imprint of crystals in their source regions must be selected with care.

With this background let us turn to the meteorite samples and consider how they may reveal the thermal evolution of their parent bodies. Most meteorites show no evidence of igneous origin. One large class of meteorites, the chondrites, appear to be mixtures of unaltered minerals that condensed over a wide range of temperatures before the planets themselves formed out of the cloud of dust and gas known as the solar nebula. A small fraction of meteorites, however, are igneous in origin; they are known as achondrites. The term refers to the absence in these specimens of chondrules, the small stony spherules found in chondrites. The achondrites are the only samples of igneous rocks available from outside the earth-moon system. The oldest-known terrestrial igneous rocks were formed about 3.8 billion years ago; many of the achondrites crystallized between 4.4 and 4.6 billion years ago. Although igneous rocks were forming on the earth earlier than 3.8 billion years ago, none have survived because they have all been remelted. Most of the achondrites are thought to have been dislodged by impact from bodies with diameters ranging from 500 kilometers to perhaps as little as 10 kilometers in the asteroid belt between the orbits of Mars and Jupiter. As we shall see, it may even be possible to identify the specific bodies from which some of the achondrites came.

One of the best-studied groups of achondrites are the eucrites, from the Greek *eukritos,* meaning easily distinguished. The eucrites are primarily composed of roughly equal amounts of the minerals anorthite and pigeonite. Anorthite is a plagioclase feldspar, a calcium aluminum silicate with the approximate formula $CaAl_2Si_2O_8$. Pigeonite is a magnesium iron pyroxene with the approximate formula $MgFeSi_2O_6$; typical samples also include a little calcium. Eucrites are texturally, mineralogically and chemically similar to terrestrial basaltic rocks, which are loosely defined as dark, fine-grained rocks consisting largely of plagioclase and pyroxene. In fact, eucrites would probably not easily be recognized as meteorites, even by geologists, if they were not visibly covered with the dark, glassy crust signifying that their exterior had been melted during a fast passage through the earth's atmosphere.



ASCENT OF MAGMA, or liquid rock, through the crust of a planetary or asteroidal body is shown schematically. Rocks in the source region are partially melted by heat generated by the decay of radioactive elements. The melts segregate from residual crystals, and because they are more buoyant they migrate toward the surface. Some liquids remain trapped in magma chambers, where they recrystallize partially or entirely. Other liquid fractions find channels through which they reach the surface, flow out and solidify. If the extruded lava is struck by an impacting body, fragments may be ejected into space and ultimately reach the earth as meteorites.

In spite of the eucrites' resemblance to terrestrial basalts they are distinctive in several respects. The dominant pyroxene in terrestrial basalts is usually augite, a calcium-rich silicate that contains various amounts of magnesium and iron, whereas pigeonite, the dominant pyroxene in eucrites, is poor in calcium. Moreover, terrestrial basalts are significantly richer than eucrites in alkali elements such as sodium, potassium and rubidium and in other volatile elements that would have condensed from the solar nebula at temperatures generally less than about 700 degrees Celsius. Evidently the eucrites originated in planetary bodies formed predominantly from materials that condensed from the solar nebula at higher temperatures than did the materials from which the earth formed. The relative scarcity of volatile elements in eucrites shows up in the composition of the eucrites' plagioclase: it is rich in calcium and poor in sodium, whereas the plagioclase in typical terrestrial basalts commonly has about equal amounts of the two elements.

Terrestrial basalts are also more highly oxidized than eucrites. When iron metal is exposed to oxygen, the two elements combine in various proportions, depending on conditions; the higher the ratio of oxygen to iron, the more highly oxidized the compound. In eucrites one can find unoxidized grains of metal-

lic iron in addition to the ferrous oxide (FeO) in silicate minerals, whereas in terrestrial basalts the iron not contained in silicates is usually in the form of magnetite (Fe_3O_4). In addition to these differences in composition and state of oxidation eucrites are usually brecciated: they consist of angular fragments that have been welded together. The brecciation is thought to have been caused by the impact of other meteorites on the eucritic material while it was still at the surface of its parent body. Presumably it was such collisions that ejected the eucrites from their native surface and hurled them into orbits that ultimately crossed the path of the earth.

The evidence is compelling that the eucrites crystallized from a molten state either in magma chambers or after they reached the surface of their parent body. Can that body be identified? Did only one body in the solar system give rise to eucrites or were there several such bodies? Although lunar basalts closely resemble eucrites, careful study of lunar rocks has disclosed differences that indicate the eucrites could not have come from the moon. In fact, no known meteorites seem to have originated on the moon. This is highly significant, because if no rocks can be ejected from the moon and delivered to the earth in spite of the moon's small size, weak gravity and close proximity, it is difficult to see how meteorites could come from any of the major planets, which are larger than the moon and of course much farther from the earth. It is generally assumed, therefore, that the eucrites are fragments spalled from small bodies in the asteroid belt, as are some other types of meteorites whose orbits were observed before they struck the earth.

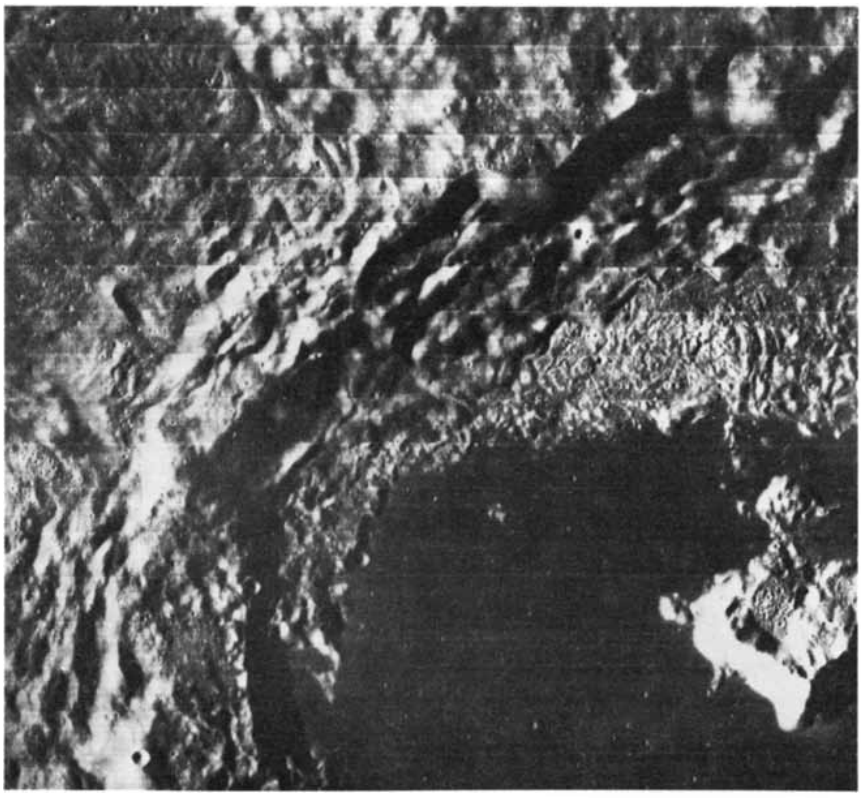
In recent years several laboratories have intensively examined the visible and infrared spectra of sunlight reflected from the surface of other planets and asteroids. Most asteroids with a diameter greater than 50 kilometers have now been surveyed. The reflectance spectra depend on the minerals on the surface of the asteroid and their composition. Hence by comparing the reflectance spectra of asteroids with spectra of meteorites analyzed in the laboratory one can draw inferences about the materials on the asteroids' surface. In some instances the spectra of asteroids have been closely matched with the spectra of known types of meteorites. The only solar-system object with a reflectance spectrum similar to that of the eucrites is Vesta, the second-largest of the asteroids, with a diameter of about 550 kilometers. Although agreement is not universal, most workers believe it is probable that the eucrites are fragments of Vesta, or at least that lavas much like those from which the eucrites crystallized are present on the surface of that asteroid.

If the eucrites came from an asteroidal body, one should be able to infer some of the mineralogy of the source regions in the interior of the body that gave rise to eucritic liquids on partial melting. How does one go about studying a volcanic rock to see what crystals were left behind in its source region? Returning to our previous analogy, suppose in place of a cup of water with white crystals on the bottom you were handed only a sample of water poured from the cup and were asked to identify the crystals left behind. Without the somewhat risky procedure of tasting the water, how would you do it?

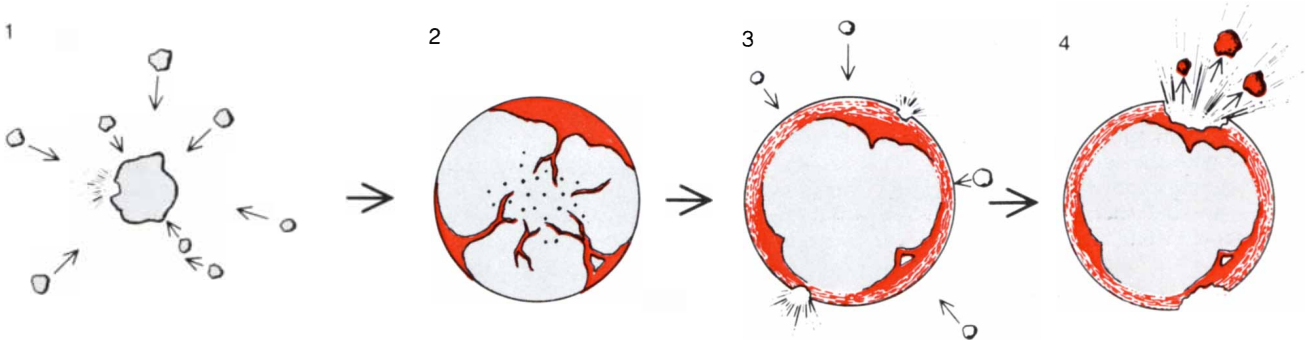
One way is to cool the water slowly below room temperature. As the temperature falls additional crystals will grow on the bottom and sides of the cup as the solubility of the dissolved substances decreases with temperature. If salt or sugar crystals grow, they can be distinguished by their crystal form or by chemical analysis. The important point is that the identity of the unknown crystals left in the cup can be determined by identifying the crystals that grow when the water is slowly cooled. A similar approach can be taken to identify the crystals left behind in the source regions of liquids on the eucrites' parent body. A eucrite sample is put in a furnace and heated until it is completely molten; it is then cooled slowly. The mineral or minerals that first begin to crystallize, that is, those with which the eucritic liquid is in equilibrium, should have the same composition as those left in the source region.

When such experiments are carried out with liquids having the composition of eucritic meteorites, one finds that the liquids are in equilibrium with three types of crystals: olivine (a magnesium-iron silicate with the approximate formula $MgFeSiO_4$), pigeonite and plagioclase. The clear implication is that these three minerals are the ones left behind when the eucritic liquids segregated from their source regions inside the eucrites' parent body.

Several potential problems are associated with this procedure. As we have noted, most lavas have probably cooled and partially crystallized on their way to the surface, so that their original composition has changed. As a result the minerals that first crystallize when such lavas are remelted in the laboratory may not accurately represent the crystals left deep in the source regions. A second problem is that source regions are usually under substantial pressure because of



LAVA-FILLED CRATER ON THE MOON is typical of lunar marias ("seas"). The lava in such craters was released through fractures in the crust when the moon was bombarded by asteroidal bodies early in its history. The picture shows part of the crater Tsiolkovsky, 250 kilometers in diameter, on the far side of the moon. It was made in 1967 by *Lunar Orbiter 3* during a reconnaissance to select landing sites for the Apollo missions. It was made from an altitude of 1,460 kilometers by a photographic system that yields strip images. Lunar north is at the top.



EUCRITES MAY HAVE EVOLVED on one of the larger asteroids such as Vesta, which is believed to have been formed by the accretion of smaller bodies 4.6 billion years ago (*1*). Within the first 200,000 years heat, possibly generated by short-lived radioactive elements, partially melted the body's interior, with some of the liquid reaching the surface as lava (*2*). Meteorites bombarded the surface continually (*3*). Such impacts later ejected fragments of the brecciated lava surface into space (*4*), sending some on a collision course with the earth.

the mass of the rock above them. Since different minerals will crystallize from a liquid at different pressures, one must try to conduct the crystallization experiments at pressures corresponding to the depths of the source regions. Unfortunately the depths are hard to establish, even for terrestrial lavas. If the eucrites came from small bodies such as Vesta, however, the depth uncertainty is a minor concern; the pressures are fairly low even in the center of such bodies.

What clues do such crystallization experiments yield about the gross composition of the eucrites' parent body? Although the experiments suggest that olivine, pigeonite and plagioclase were left behind, they do not specify the proportions of the three minerals in the residual material. The same liquid would be in equilibrium with a residue containing 99 percent olivine crystals or only 1 percent. Luckily other chemical imprints in the liquids can help to set limits on the relative proportions of minerals in the residue. The concentrations of trace elements, such as the rare earths lanthanum and europium, in the eucrite samples are particularly useful for this purpose. Guy J. Consolmagno and Michael J. Drake of the University of Arizona have concluded from rare-earth data that eucritic liquids could have been produced by a 5 to 15 percent partial melting of peridotite, a rock composed mostly of olivine with lesser amounts of pyroxene and plagioclase.

Peridotite is also believed to form the bulk of the earth's upper mantle, the source region for most terrestrial basalts. Because the earth's mantle is at pressures much higher than those in the eucrites' putative parent body certain mineralogical differences are to be expected. For example, in terrestrial peridotites the aluminum-bearing phase usually takes the form not of plagioclase but of garnet or spinel, minerals that form at high pressure. Nevertheless, terrestrial peridotites have much in common with the peridotites that may have given rise to the eucrites. In both peridotites olivine is the dominant mineral, the principal pyroxene phase is poor in calcium and the principal aluminum-bearing mineral is less abundant than olivine and pyroxene.

There are, however, important chemical differences between eucrites and terrestrial basalts that cannot be attributed to differences in pressure between their respective source regions. The eucrites' parent body is depleted in alkalis and other volatile elements compared with the earth's upper mantle. Moreover, the earth's upper mantle contains some high-calcium pyroxene and the eucrites' source regions contain little, if any. The earth's upper mantle is also probably more strongly oxidized than the eucrites' source. In these three respects the source region that gave rise to the eucrites resembles much more closely the source region for basalts found on the moon than that for basalts on the earth.

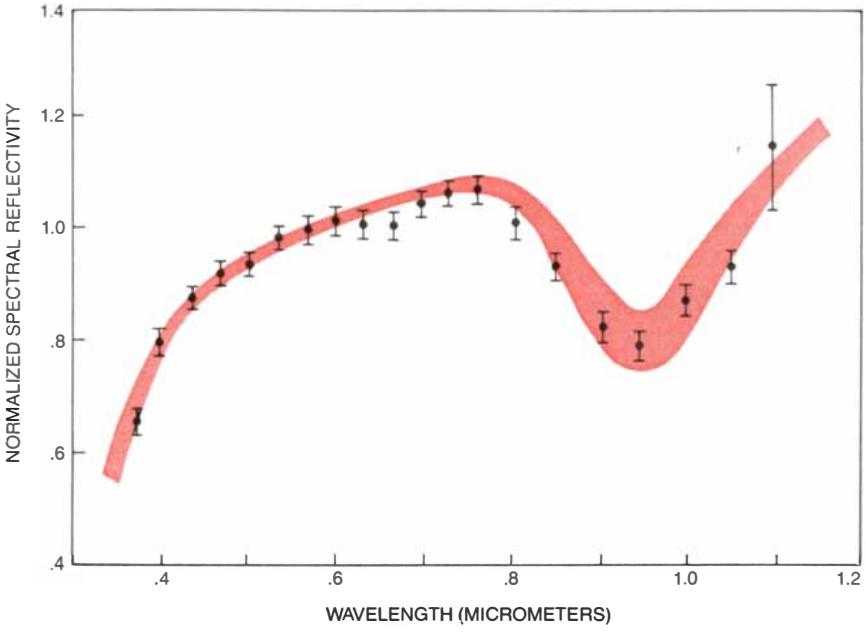
The most remarkable feature of the eucrites is their great age. The ages of rocks can be determined by accurately measuring the amount of a radioactive isotope, such as rubidium 87, in the rock and comparing that value with the amount of some stable isotope into which the radioactive parent decays. In the case of rubidium 87, which has a half-life of 47 billion years, the stable end product is strontium 87, an element with one more proton and one less neutron. Corrections must be made, of course, for the amount of strontium 87 that was initially present in the magma. Once the rock crystallizes no more rubidium can be added and the radiometric clock is started. Such radiometric determinations establish that the eucrites all crystallized from liquids between 4.4 and 4.6 billion years ago, that is, no more than 200 million years after the formation of the sun and the planets. The oldest rocks so far brought back from the surface of the moon are about 4.2 billion years old; the oldest rocks on the surface of the earth are some 400 million years younger. How could the heat required to melt eucrites, about 1,150 degrees C., be generated on a small body so early in the history of the solar system?

The heat could not have been supplied by the slow decay of the radioactive isotopes of potassium, uranium and thorium, which ultimately generated the heat for melting the interior of the earth and the moon. It has been suggested, however, that bodies much smaller than the earth and the moon could have been heated quite rapidly by the decay of the short-lived radioactive isotope aluminum 26. The idea has gained support from recent work by Gerald J. Wasserburg and his co-workers at the California Institute of Technology, who have identified an excess of magnesium 26, the decay product of aluminum 26, in samples of the Allende meteorite, a chondrite that has not undergone melting and so retains the characteristics of the primitive solar nebula. Two other possible heat sources have been suggested: heating of the eucrites' parent body by the impact of falling objects and heating by the electromagnetic field of the juvenile sun.

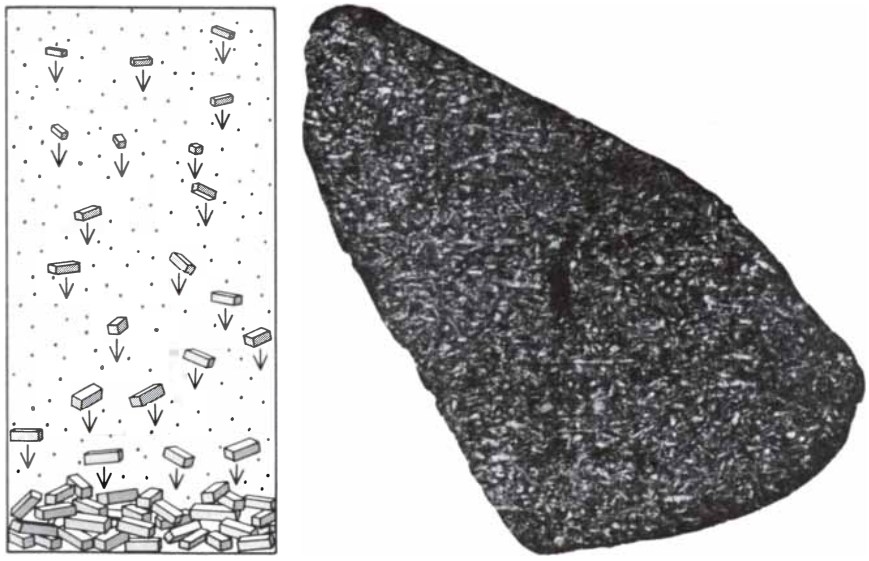
The following general picture of the evolution of the eucrites' parent body seems plausible. An asteroidal body, perhaps Vesta, formed some 4.6 billion years ago. Mineralogically it was a peridotite with a chemical composition similar to that of chondritic meteorites. In this respect it resembled the peridotite mantle of the moon more closely than the mantle of the earth. Soon after the asteroid formed, or perhaps even during its formation, its interior was partially melted, possibly by the heat of a short-lived radioactive isotope. The molten rock segregated from the source regions, leaving behind as residual crystals olivine, low-calcium pyroxene and plagioclase. Liquids destined to become eucrites migrated toward the surface, some erupting as lava flows. Igneous activity ended within the first 200 million years after the body's formation.

From the very beginning the asteroidal body was bombarded by objects of all sizes. The impacts brecciated the newly formed lava crust and ultimately ejected fragments from the surface, putting them on an ultimate collision course with the earth.

A second important group of achondrites are the shergottites, named for a meteorite that fell near the town of Shergotty (or Sherghati) in the Indian state of Bihar in 1865. A second meteorite of the same type fell near Zagami in Nigeria in 1962. A third (and the only other one known) was discovered only three years ago on an ice sheet in Antarctica. All three apparently crystallized from molten rock no more than 1.1 billion years ago. An unusual feature of the shergottites, which is what originally attracted attention to them, was the nature of the plagioclase glass that constitutes nearly half of their mass. This glass has the composition and appearance of plagioclase but lacks the long-range atomic periodicity that characterizes crystalline materials. Known as maskelynite, the glass forms when plagioclase is shocked by impacts to pressures of 300,000 bars, or some 4.5 million pounds per square inch. It recrystallizes readily to plagioclase if it is heated to 400 degrees C. for more than a few hours. The shergottites show maskelynite and pyroxenes intergrown in textures typical of igneous rocks. It is therefore apparent the shock that converted the plagioclase into maskelynite took place after the shergottites had crystallized from the molten state.



ASTEROID VESTA AS SOURCE OF EUCRITES is suggested by the close correspondence between the reflectance spectrum of the asteroid (*black bars*) and the laboratory reflectance spectra of typical eucrites (*colored band*). The reflectance spectra of virtually all the several hundred catalogued asteroids with a diameter larger than 50 kilometers have now been measured. Only Vesta, at a diameter of about 550 kilometers the second-largest asteroid, has a spectrum matching that of the eucrites. The dip in both curves at about .95 micrometer corresponds to a strong absorption band of pigeonite, a member of the pyroxene family of silicates.



ORIENTATION OF PYROXENE CRYSTALS in the Shergotty meteorite suggests that the material of the meteorite crystallized slowly in a magma chamber below the surface of the parent body. The diagram at the left shows schematically how elongated crystals of pyroxene tend to settle at the bottom of a magma chamber in a preferred orientation. The photograph of the meteorite at the right has been oriented so that its pyroxene crystals are aligned more or less horizontally, as they presumably were when they settled out of the magma a billion years ago.

Except for the presence of maskelynite, and unlike the eucrites, the shergottites are virtually identical with typical terrestrial basaltic rocks. Both contain substantial amounts of augite in addition to pigeonite, and both contain magnetite, which is evidence that both evolved at higher oxidation states than the eucrites. The maskelynite in shergottites, like the plagioclase in terrestrial basalts, contains roughly similar amounts of sodium and calcium. This is in contrast to the plagioclase in eucrites, in which the abundances of these elements differ from those in terrestrial basalts.

The shergottites also differ from the eucrites in that the composition of the liquids from which the shergottites crystallized was changed before the liquids solidified into rock. Such compositional change, termed differentiation, can occur in conduits as the liquids cool on their way to the surface or in magma chambers where cooling proceeds slowly. Crystals that form early and are denser than the liquid may settle slowly to the bottom of a magma chamber and pile up in preferred orientations. Such accumulations of augite and pigeonite crystals can be seen in the shergottites.

The original Shergotty meteorite and the new Antarctic find have been dated radiometrically by Laurence E. Nyquist and his co-workers at the National Aeronautics and Space Administration's Johnson Space Center in Houston, who applied techniques that had been developed for the dating of moon rocks. They determined that both meteorites evidently crystallized from liquids between .65 and 1.1 billion years ago. The uncertainty in the age arises from the shock event that created the maskelynite and reset some of the radiometric clocks, but the shergottites are certainly among the youngest extraterrestrial rocks known.

The reflectance spectra of the shergottites do not match the spectra of any of the known asteroids. The shergottites are so similar to terrestrial basalts

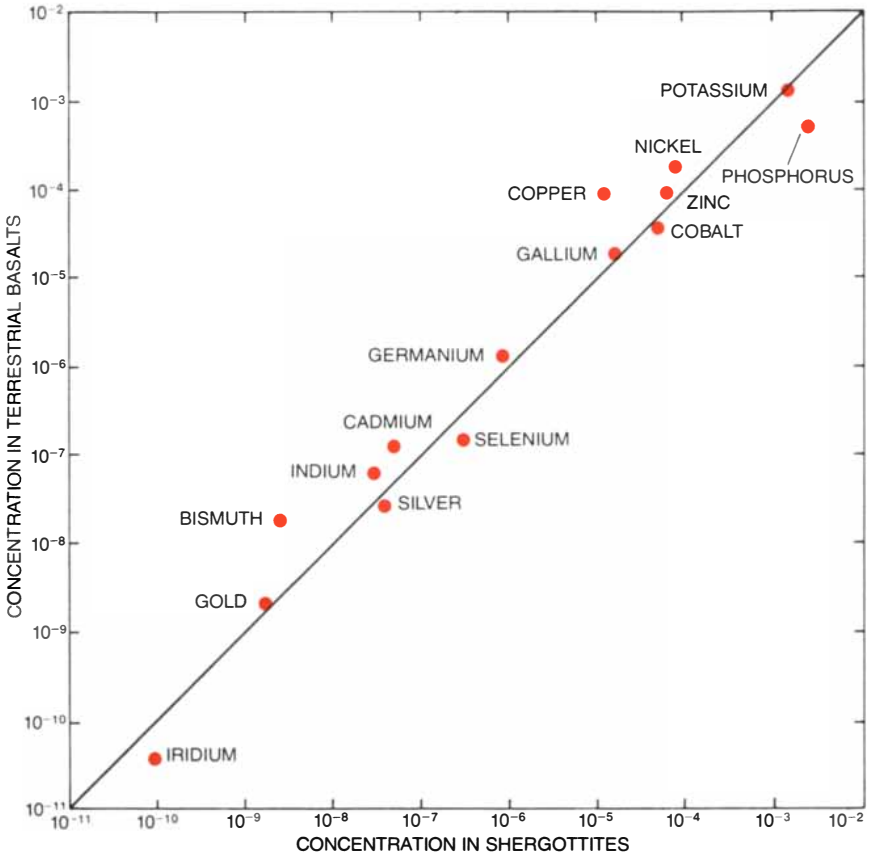
that the chemical composition of their source regions must be very similar to that of the upper mantle of the earth. The evolution of the earth's upper mantle has been quite complex. It has been partially melted repeatedly, yielding the magmas that make up the earth's crust. The concentrations of elements such as nickel and cobalt in the source regions of terrestrial basalts may have been established by interaction between the earth's mantle and its metallic core when the core formed early in the earth's history, an event surely not duplicated in detail elsewhere in the solar system. Yet nickel and cobalt are present in virtually the same concentrations in the shergottites and in terrestrial basalts. How is it possible that another body in the solar system could yield basalts so similar to those on the earth?

Could it be that the shergottites are not meteorites at all but simply pieces of terrestrial basalt? That would explain both their earthlike composition and their young ages. There are strong reasons to doubt this possibility. First, the Indian and Nigerian shergottites were actually seen to fall, and they have a glassy crust that formed when they passed through the atmosphere. Second, they contain chemical evidence in the form of short-lived radioactive isotopes that they were bombarded by cosmic rays in space for several million years. Therefore if the shergottites are terrestrial rocks, they must have been ejected from the earth by an impact of considerable force and placed in "parking" orbits capable of holding them for several million years before allowing them to reenter the earth's atmosphere. Although ejection by impact would account for the conversion of plagioclase into maskelynite, a terrestrial explanation seems rather farfetched.

Perhaps the most telling objection to a terrestrial origin is small but significant chemical peculiarities of the shergottites. For example, they are richer in iron and manganese than typical terrestrial basalts, and in this respect they are similar to the eucrites. Moreover, terrestrial basalts contain small but measurable quantities of water and the shergottites contain none. Finally, Robert N. Clayton and his colleagues at the University of Chicago have detected small differences between the isotopic composition of oxygen in shergottites and that in terrestrial basalts.

If the shergottites did not originate on the earth, where did they originate? If they are derived like the eucrites from a small asteroid-size body, how could such a body have been heated sufficiently for partial melting to have occurred as recently as 1.1 billion years ago and perhaps only .65 billion years ago?

Short-lived radioactive isotopes such as those invoked for the heating of a body the size of Vesta to the point where it could produce eucrites some 4.5 billion years ago would have decayed by a billion years ago. Long-lived radioactive isotopes, on the other hand, such as those that contribute to the heating of the earth today, would be ineffective in heating a small body because such a body would not have enough insulating capacity to trap the heat and prevent its being lost into space. The relation between planetary size and insulating capacity yields a rough correlation between the size of a body and the duration of its volcanic activity. The recent Voyager missions to Jupiter have revealed one important exception to this correlation: the Jovian moon Io, which is only slightly larger than the earth's moon, is still volcanically active. The



SIMILARITY OF SHERGOTTITES AND TERRESTRIAL BASALTS extends to minor and trace elements, suggesting that the source region of the shergottites bears a remarkable resemblance to the upper mantle of the earth. The 15 elements whose concentrations are plotted here differ widely in their properties and geochemical behavior. For example, whereas bismuth melts at 271 degrees Celsius, iridium melts at 2,410 degrees. On solidifying, nickel concentrates preferentially in a metal phase, cadmium in a sulfide phase and germanium in a silicate phase. Elements that fall along the diagonal line have the same abundance in both types of material.

MINERAL		SHERGOTTY METEORITE (PERCENT)	MARTIAN SOIL (ADJUSTED PERCENT)
SILICON DIOXIDE	SiO_2	50.4	53.9
FERROUS OXIDE	FeO	19.3	19.7
CALCIUM OXIDE	CaO	9.6	6.7
MAGNESIUM OXIDE	MgO	9.3	10.0
ALUMINUM OXIDE	Al_2O_3	7.0	6.8
TITANIUM DIOXIDE	TiO_2	.9	1.0
POTASSIUM OXIDE	K_2O	.2	.1

COMPARISON OF SHERGOTTITES AND MARTIAN SOIL discloses striking similarities between them, provided that the composition of the Martian soil is recomputed with sulfur and chlorine removed. It seems likely that these two elements represent "contamination" by volcanic gases in the samples of Martian soil that were analyzed by the Viking landers. The samples actually contained about 3 percent sulfur and 1 percent chlorine. These volatile elements tend to escape and are present in typical terrestrial and lunar basalts only in minor amounts.

apparent heat source is Io's gravitational or electromagnetic interaction with its giant planet. For a body as small as an asteroid one possible source of energy capable of melting rock as recently as a billion years ago might be an impact with another body. That such an impact could give rise to a melt with the composition of a shergottite, however, is hard to demonstrate.

Nevertheless, if the shergottites are indeed fragments of an asteroid, it means there is a small body in the solar system with chemical characteristics that have been thought unique to the earth or at least to a planet of comparable size. Regardless of the size of the parent of the shergottites it is now clear that many of these characteristics are not uniquely terrestrial. If the parent body of the shergottites is of asteroidal size, it could mean that the shergottites' parent body and the earth's upper mantle formed from similar materials early in the history of the solar system. In this case many of the chemical features of earth rocks previously thought to reflect uniquely the earth's complex evolution were actually inherited from the building blocks from which the earth agglomerated. Conceivably, then, the shergottites' parent is a leftover building block of the type from which the earth's upper mantle formed.

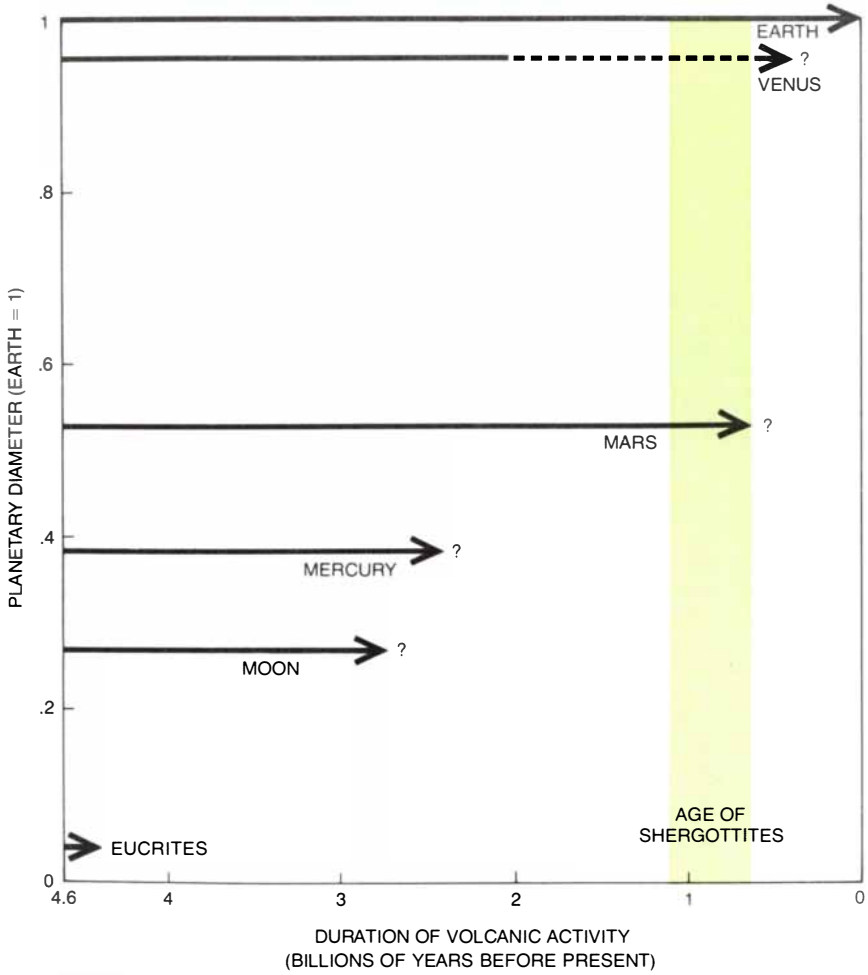
If neither the earth nor an asteroidal body is a credible source of the shergottites, what alternatives remain? We believe the still active Jovian moon Io can be dismissed on two counts. Recent measurements suggest Io's surface is so rich in sulfur and sodium that the composition of its volcanic products would be utterly unlike that of the shergottites. The second objection is that any fragments of Io that might be dislodged by the impact of other bodies would be quite unlikely to escape from the immense gravitational pull of Jupiter.

The only alternative source of the shergottites that we find appealing is Mars. Mariner and Viking photographs have disclosed the existence of giant volcanoes on the Martian surface. From the small number of impact craters on some Martian lava flows one can estimate that the planet was probably volcanically active as recently as half a billion years ago and may even be active today. The great objection to Mars as a source of shergottites is the total absence of meteorites from the moon. An impact capable of ejecting a fragment of the Martian surface into an earth-intersecting orbit would seem to be even less probable than such an event on the moon, in view of the moon's smaller size and close proximity to the earth.

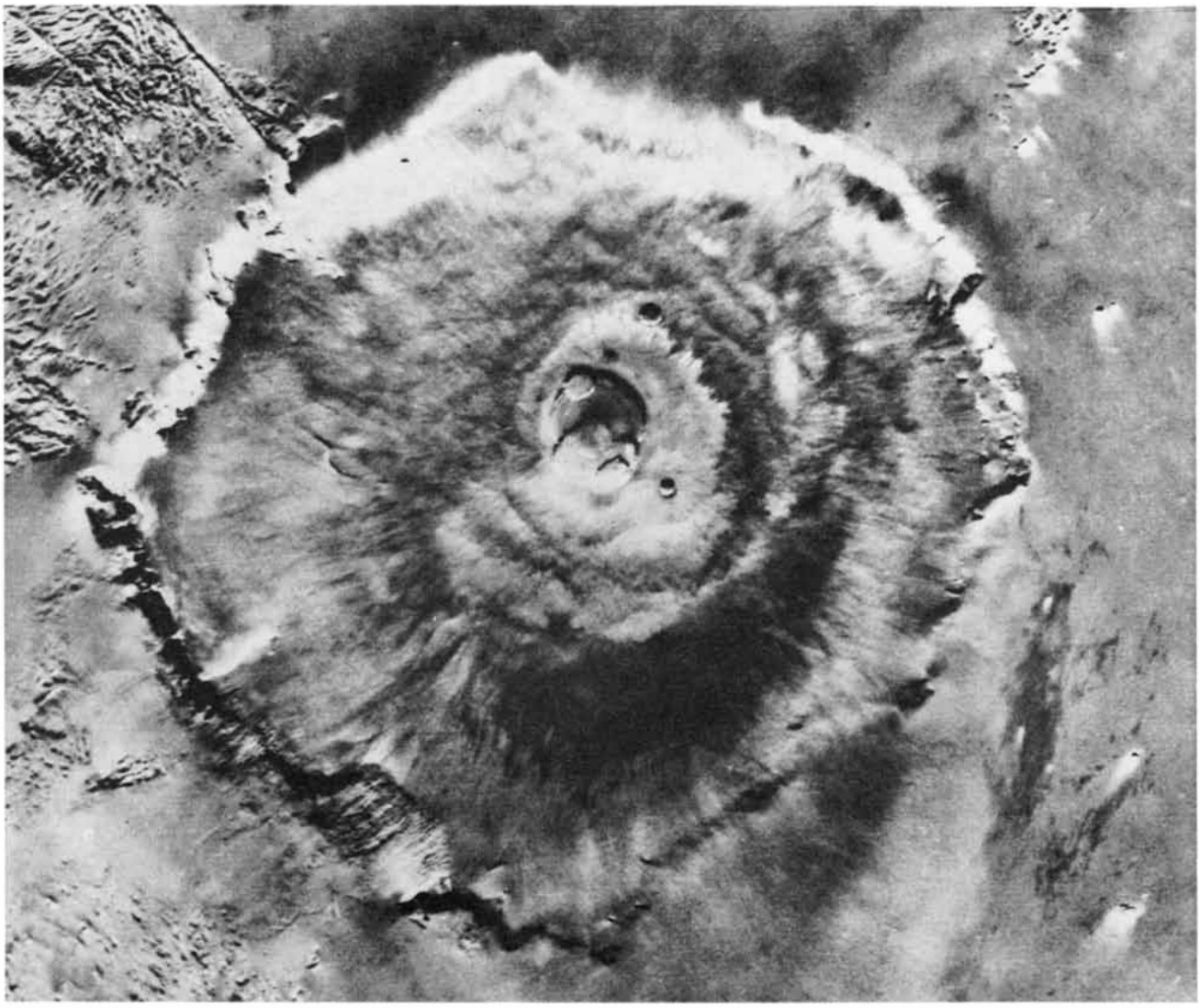
The Martian case is not hopeless, however. George W. Wetherill of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington recently suggested that permafrost ices stored below the surface of Mars may alter the planet's impact characteristics. If the ices were to be rapidly vaporized by an impacting object, the expanding gases might help ejected fragments to reach escape velocity.

There is one last intriguing bit of evidence that may link the shergottites to Mars. The two Viking spacecraft that landed on Mars made quantitative analyses of the planet's soil at two sites and found it to be fairly rich in sulfur and chlorine. This has generally been interpreted to mean the soil samples examined do not represent fresh igneous rock but are samples that have been altered by weathering processes. If one assumes that the sulfur and chlorine are indeed weathering artifacts and subtracts those two elements from the soil analyses, one finds that the chemical composition of the Martian soil quite closely matches the chemical composition of the shergottites. Only in calcium oxide do the two samples deviate from each other by more than 10 percent [*see bottom illustration on preceding page*].

It may be a long time before geologists have in their hands an unmistakably identified sample of Martian soil or rock and longer still before they can examine an unmistakably identified piece of Vesta or some other large asteroid. Meanwhile meteorites will continue to fall and challenge geologists and geochemists to divine their origin. The search for the sources of the eucrites and shergottites illustrates the kind of detective work that is necessary.



DURATION OF VOLCANIC ACTIVITY on a planet or a planetoid may be related to the size of the body. Venus, which is only slightly smaller than the earth, is obscured by clouds, but radar imaging techniques have disclosed the presence on its surface of volcanolike structures. Approximate dates for the cessation of volcanic activity on Mars and Mercury can be estimated from counts of craters. The youngest rocks brought back from the moon crystallized about 2.8 billion years ago. The eucrites came from a parent body, possibly Vesta, in which molten rock appeared no more than 200,000 years after the formation of the solar system 4.6 billion years ago. Mars was apparently still volcanically active at the time when the shergottites crystallized from molten rock between .65 and 1.1 billion years ago and may even be active today. Apart from the earth the only body in the solar system that has visibly active volcanoes is Jupiter's moon Io, a discovery made last year by the Voyager spacecraft. Only slightly larger than the earth's moon, Io appears to be heated by tidal forces arising from its proximity to Jupiter.



LARGEST VOLCANO ON MARS, Olympus Mons, appears in a photograph made in 1977 by the *Viking 1* orbiter. Far larger than any similar structure on the earth, Olympus Mons is some 27 kilometers high and about 600 kilometers across at the base. It was built up by eruptions of low-viscosity lava. Olympus Mons may have been active no more than 500 million years ago, and it may even be active today.

SURFACE OF MARS, photographed on May 18, 1979, by the *Viking 2* lander, is littered with rocks that clearly solidified from the molten state. The site is Utopia Planitia in the northern hemisphere of Mars. It is early morning and the rocks have a light coating of frost, which is thought to be a mixture of water ice and frozen carbon dioxide. Such rocks might well have the characteristics of shergottites.

Computer Backgammon

Backgammon is a good test of principles of artificial intelligence. BKG 9.8 is the first computer program to defeat a world champion at any board or card game

by Hans Berliner

Last July my backgammon-playing computer program BKG 9.8 defeated the world champion, Luigi Villa of Italy, by the score of 7–1 in a $5,000 winner-take-all match in Monte Carlo. It was the first time a computer program had beaten a world champion at any board or card game. Before the match Paul Magriel, the former world backgammon champion who had provided some of the expert knowledge that went into the development of BKG 9.8, estimated that the program had between a 35 and a 40 percent chance of winning. I had thought he was overly enthusiastic. The program did get the better of the dice rolls, but it also played with great accuracy and imagination and clearly emerged the victor. Unlike the best programs for playing chess, BKG 9.8 does well more by positional judgment than by brute calculation. This means that it plays backgammon much as human experts do.

My work on computer backgammon is part of the large branch of computer science called artificial intelligence, which aims at developing programs capable of doing things that if a human being were to do them, he would be considered intelligent. Investigators in artificial intelligence have always been interested in games because intelligence is needed to play them well. The rules of a game are precisely defined and there are usually standards of performance, so that it is often possible to pit a program directly against human competitors under controlled conditions. In this way the capacity (and hence the intelligence) of the program can be accurately measured.

For six years I worked on a chess program that I hoped would approach the game the way a human chess master does. I was reasonably well qualified to do so. For some 15 years I was one of the top 12 players in the U.S., and in 1968 I won the world correspondence-chess championship. One kind of chess program is the searching program, which is designed to investigate all possibilities to a certain depth. In the course of my work on computer chess I encountered several kinds of methodological problems with which searching programs had great difficulty. One problem is called the horizon effect, which arises when a program searches deeply enough to discover a difficulty in the play but then acts as if the difficulty did not exist. Actually the program recognizes the difficulty, but it postpones it by finding another line of play interspersing perhaps two insignificant but forced moves in that branch of the search. Since all the branches are investigated to the same depth, the search is terminated before the problem is discovered in that particular branch. As a result the program acts as though it has permanently avoided the difficulty. If it had pushed a little deeper into the branch, it would have encountered the same problem.

The fact that human experts would never make this kind of mistake indicates they have a different way of approaching the game. They organize the moves into events. As long as an important event remained unexplored in any branch the expert would not terminate his search. By looking not at events but at moves the programs misplayed certain straightforward positions.

Building positional judgment into a program was also extremely difficult. Chess masters can agree that a certain attack is worth, say, two pawns. An enormous amount of information goes into such judgments, and it is remarkable that quantitative values can be put on them. Many people would doubt that any program could possibly do such a thing. It seemed to me that introducing rules to enable a program to make such judgments would involve an incredibly large (perhaps impossibly large) number of rules to specify under what conditions a certain feature of a position is good and just how good it is. As a result I decided to examine how variables corresponding to significant features of a position could be combined into arithmetical functions to create fine shades of difference in output. Chess was not suited to such an investigation because too much of the judgment process involves playing out alternatives to see which features come to fruition in a particular position. What I wanted was a domain where it is possible to compare two situations and make a judgment about which one is the better without having to worry about the exhaustive analysis that chess positions require. When I became acquainted with backgammon, I realized it had the desired properties, and I set out to develop a backgammon program.

Let me briefly describe the rules of backgammon for those readers who are not familiar with the game. Backgammon is a dice game in which a player tries to move all 15 of his pieces out of his end of the board before his opponent does. The board consists of 24 "points," or triangles, divided into four quadrants: inner and outer "tables" for each player. The initial position of the pieces is shown in the illustration on page 66. The pieces are moved from point to point according to the numbers a player rolls on a pair of dice.

If the numbers on the dice are not the same, the player either uses each number to move one piece or uses the total of the two numbers to move one piece. Each number is considered individually, so that when the player uses both numbers to move one piece, he makes not one move but two separate moves. For example, if one die shows a six and the other a two, a single piece may first be moved six points and then two points (or first two points and then six points). When a piece is moved to a point for the first move of a two-move play, it is said to touch down on that point.

If the numbers rolled on the dice are the same, the player uses that number four times. For example, if he rolls two twos, he can either (1) move one piece a total of eight points, (2) two pieces four points each, (3) two pieces two points each and one piece four points, (4) one

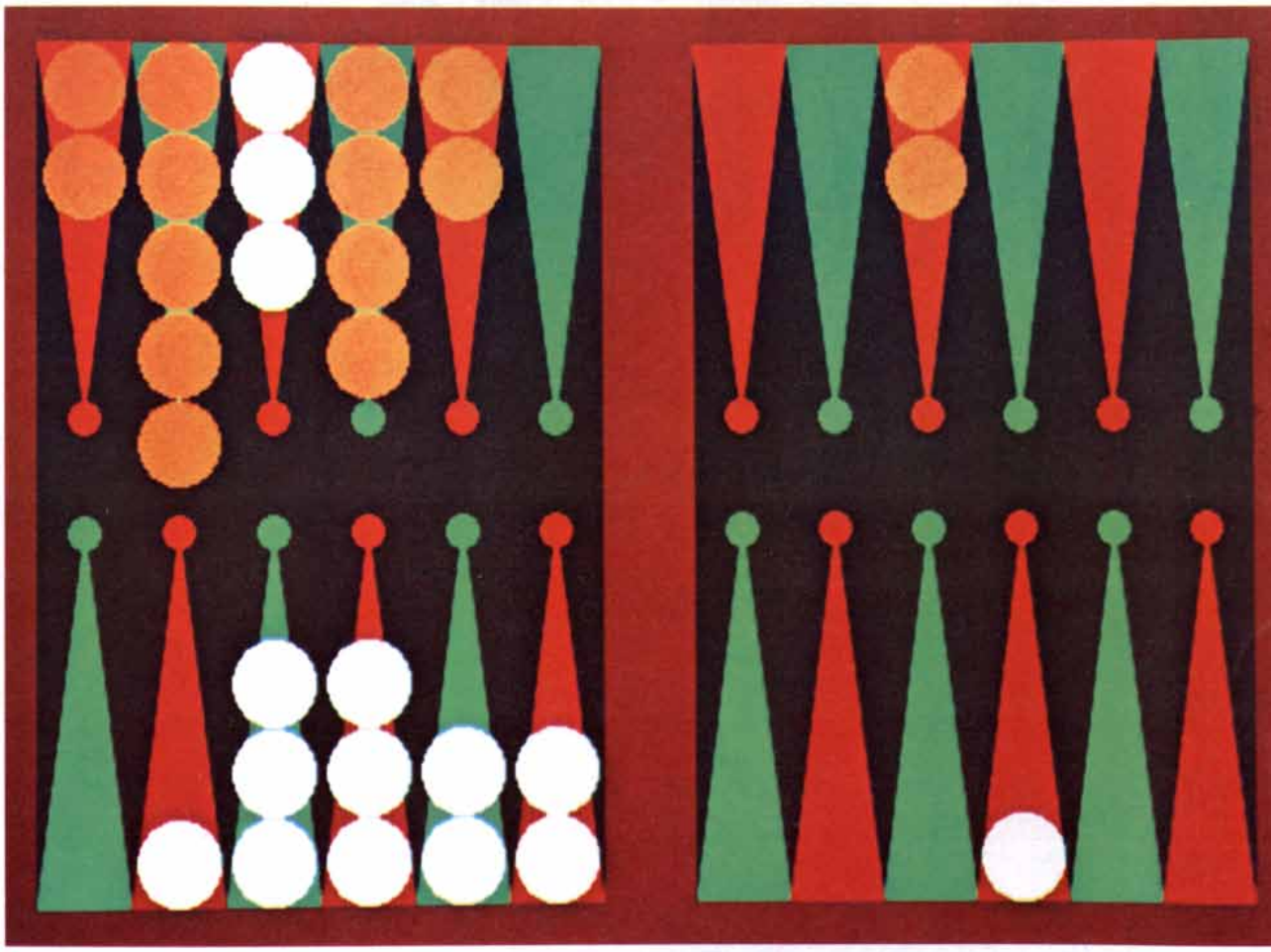
piece six points and one piece two points or (5) four pieces two points each.

When at least two pieces of one side occupy a point, the point is said to be made, and none of the opponent's pieces can touch down or land there. A made point is quite useful because it not only blocks your opponent's progress but also serves as a base for your own pieces. When a point has only one piece on it (called a blot), it is "hit" (sent off the board) when an opposing piece touches down or lands there. The hit blot, which is put on the bar that divides the inner and outer tables, must be reentered at the beginning of the board before the player can move another piece.

Once a player has moved all 15 pieces onto his inner table, he can begin bearing them off the board according to the numbers on the dice. The winner is the first player to bear off all his pieces. There are three kinds of victory: a normal one for an agreed stake if the loser has borne off at least one of his pieces, a gammon for twice the stake if the loser has not borne off any of his pieces and a backgammon for three times the stake if the loser has not borne off a piece and has at least one piece in his opponent's inner table or on the bar.

What makes backgammon an exciting gambling game is an additional device called the doubling cube. On any turn before a player throws the dice he can propose a doubling of the stake by turning the doubling cube to the face marked 2. His opponent can either decline the double, in which case he concedes the game and gives up the stake, or accept the double, in which case the game is played out for twice the stake. The player who accepts a double gets possession of the doubling cube, which means that he is the only one who can next propose a doubling of the current stake. The number of redoubles in games between good players is usually small, the value of the cube seldom going above 4.

Such is the nature of the game I set out to program. The basic element of any game-playing program is a move generator that takes an input position and generates all the legal moves (and only the legal moves) that can be played in that position. Next the program decides what moves it will examine further. A typical chess program investigates all the legal moves that can be made beyond a given position. The possible continuations are arranged in the form of a tree diagram. One branch of the tree is followed until the program encounters a reason for terminating the search. The program then applies an evaluation function to the terminal position to arrive at a quantitative value that expresses which player is in a better position and by how much. The program selects its move by comparing this value



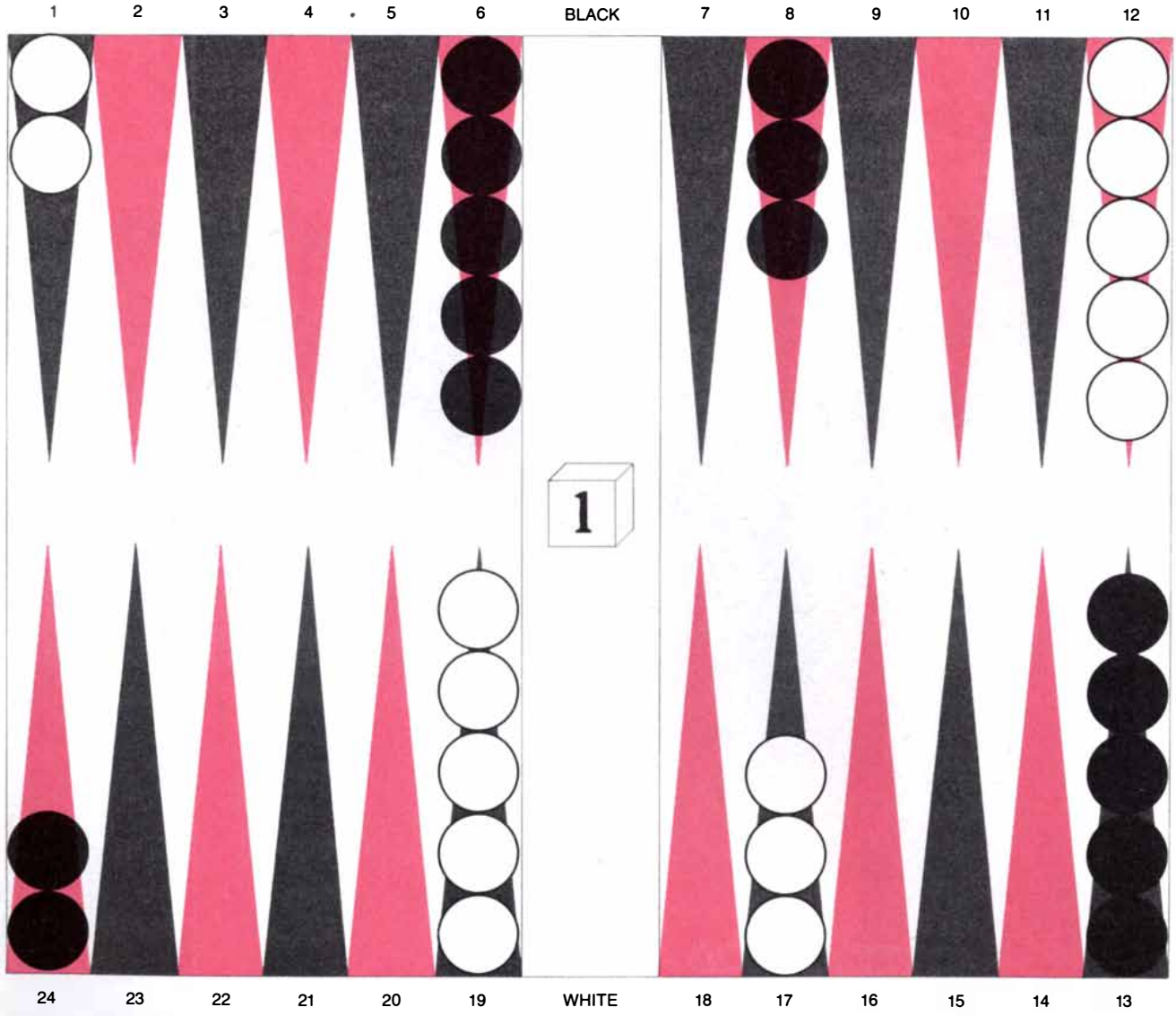
COLOR VIDEO DISPLAY shows a critical position in the first game of the $5,000 winner-take-all backgammon match between the author's computer program BKG 9.8 and the world champion, Luigi Villa of Italy. The program had the orange pieces and moved counterclockwise; Villa had the white pieces and moved clockwise. To win the game a player must first move all his pieces onto the six "points," or triangles, in his home quadrant of the board and then move them off the board before his opponent does. The program's home quadrant is at the top left; Villa's home quadrant is at the bottom left. The program is ahead in the position shown because the world champion still had to move the three white pieces at the top left 16 points before they could be in his home quadrant. The position is analyzed in more detail in the top illustration on page 69. The color video display was provided by the Three Rivers Computer Corporation of Pittsburgh.

with the values it has assigned to other branches.

In chess programs the branches are usually followed to a prearranged maximum depth. The branching factor for chess (the average number of moves that can be made beyond each node in the tree diagram) is about 35, and it is possible for a fast program to search to a depth of six plies in the three minutes per move that is allotted in tournament play. In backgammon, however, the branching factor is more than 400: there are 21 possible rolls on each move and some 20 ways of playing each roll. Such a large branching factor indicates that an exhaustive search would not be the right way to design a backgammon-playing computer program.

What my program does is to generate all the legal moves in the game position and evaluate them without searching. The program selects the move with the highest evaluation and makes it in the game. The evaluation function considers such factors as the safety of the pieces, the extent to which the pieces are blockaded, the degree to which either side is ahead in the race to bear pieces off and so on. The doubling cube is also controlled by the evaluation function, which decides whether a double should be offered and whether an offer made by the opponent should be accepted or declined.

To construct an effective evaluation function calls for testing various approaches in actual programs. The evaluation function in my first program was based on a linear polynomial in which each term represented a particular feature of a backgammon position and the



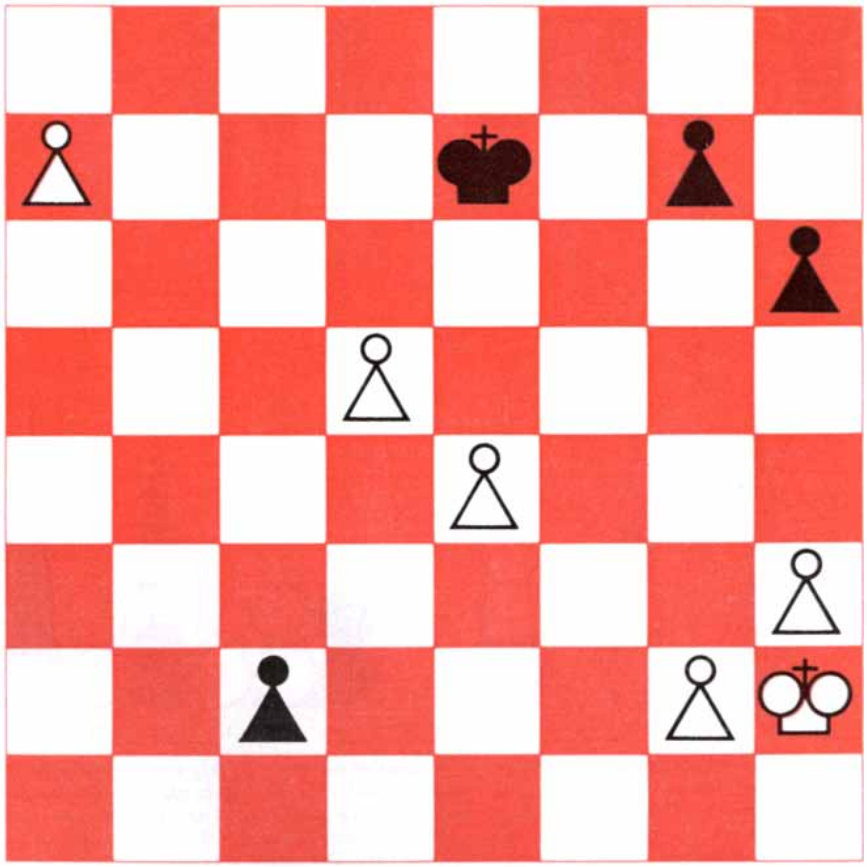
STARTING POSITION of a backgammon game shows the pieces arranged symmetrically. The board consists of 24 red and black points that are divided into four quadrants: Black's inner "table" (consisting of the points numbered 1 through 6), Black's outer table (the points 7 through 12), White's outer table (the points 13 through 18) and White's inner table (the points 19 through 24). The pieces are moved from point to point according to the numbers rolled on dice. The white pieces move clockwise so that they follow the points in ascending order; the black pieces move counterclockwise so that they follow the points in descending order. The notation used to represent backgammon moves is easy to understand. For example, 7–10 means a piece is moved from the 7 point to the 10 point. The cube on the bar that separates the inner tables from the outer ones is called the doubling cube. The 1 indicates that the game is being played for the original stake. On any turn before a player throws the dice he can offer to double the stake by turning the cube to the face marked 2. The other player must accept or reject the offer. If he accepts, the game is played out for twice the original stake. If he declines, the game is over and he pays the original stake. Once a player accepts a double only he can offer the next one, which would quadruple the original stake.

constant coefficient of the term indicated the importance of that feature. The sum of the linear polynomial gave the value of the position. This approach was limited by the fact that the constant coefficient could represent only the average importance of the feature. It was a limitation that frequently prevented the backgammon program from making expert judgments.

My next effort was to divide the backgammon positions into classes, each of which had a somewhat different evaluation function. This approach led to an improvement in the program's playing strength, but it too had a drawback. The relative values of two positions in different classes were sometimes inaccurate because the evaluation functions yielded significantly different values for positions near the common border of the classes where the values should have been quite close.

For example, suppose the program has to choose between a move leading to a blockading game (in which the relevant considerations are making points, leaving blots and hitting blots) and a move leading to a running game (in which the opposing armies of pieces have passed each other, so that the only consideration is which army is ahead in the race). Moreover, in the blockading game each side must evaluate the potential running game that would come about if the armies were to suddenly disengage. Since the running game is completely different from the blockading game, the program has difficulty comparing the two. The roughness of boundaries between the two kinds of game, which occasionally led to serious errors in judgment, seemed almost impossible to remedy.

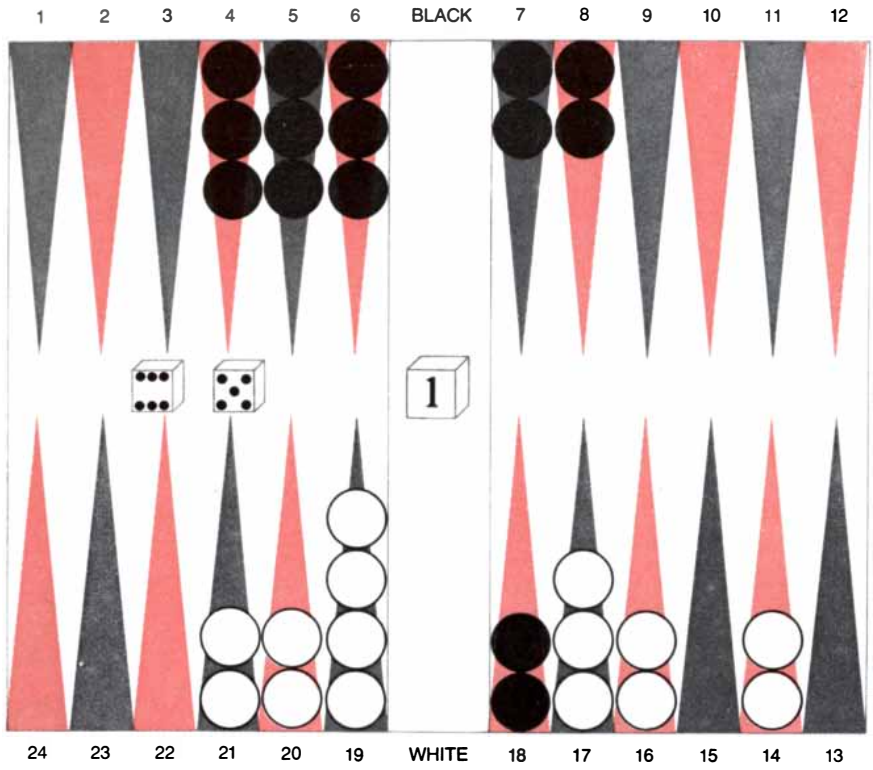
The next attempt at an evaluation function proved to be much more successful. To overcome the problem of the rough boundaries the positions were not divided into classes. Instead the evaluation space of all the positions was warped in such a way that in certain parts of the space a particular feature could be more important than it was in other parts. The transition in importance from one part of the space to another part was made to be smooth. Moreover, the transition depends on the other features present. This means that the importance of a particular feature is a nonlinear function. The features that control the transitions are called application coefficients; they are special slowly changing variables that replace the normally constant coefficients in the linear polynomial evaluation function. Since the application coefficients vary slowly and smoothly, they can provide a great deal of context but avoid the rough boundaries between different contexts. We called this new approach SNAC, for smoothness, nonlinearity and application coefficients.



KING-AND-PAWN END GAME is typical of the kind of position computer programs that play chess could not cope with. This position is an example of what is called the horizon effect: the program believes it has solved a problem that in fact it has only succeeded in postponing. The program, which was playing White, was designed to choose a move in the position after investigating all possibilities to a depth of three plies (two moves for White and one move for Black). The program finds the line of play 1 P-R8(Q) P-B8(Q), 2 Q-N7 ch. (say) and correctly judges that it is ahead by two pawns and winning. It also finds, however, that by playing 1 P-Q6 ch. KxP, 2 P-R8(Q) it comes out a queen ahead, and so the program clearly prefers this continuation to the preceding one. The fact that on the next move Black will also make a queen escapes the program's notice, since it has been told to search only to a depth of three plies. On the program's next turn it will realize that the intended P-R8(Q) will not put it a queen ahead because of P-B8(Q), and so it again invokes an artificial remedy: 1 P-K5 ch. KxP, 2 P-R8 ch. This scenario seems absurd to human players because they approach the game in a different way. They look not at moves but at events. The queening of the black pawn is an important event, which the program noticed. As long as an important event has not been explored in a branch of the tree, a human expert would continue to study the position before making a move.

The SNAC approach enabled the BKG program (the BKG stands for backgammon) for the first time to make accurate use of the vast amount of knowledge that was by now built into it. The earlier versions of the program had been limited in their ability to apply this knowledge. Each SNAC function is in effect a microstrategy for accumulating or avoiding certain features of a backgammon position. The coefficient indicates the applicability of the strategy. As a result BKG can simultaneously investigate any number of the 30 or so strategies for which it has SNAC functions, keeping track of exactly how important each strategy is in the particular position. At any point in the game some strategies may be ignored completely, others raised to the highest level of significance and still others given only moderate consideration. The approach allows a gradual shifting of strategic priorities without a sudden aberration of performance as new demands arise.

The structure and content of the program were evaluated under controlled conditions in three ways: by giving it problems from standard instructional texts, by pitting it against other programs and by having it play against human competitors. The record of the BKG program both in solving backgammon problems from texts and in playing actual backgammon games showed a marked improvement after the introduction of SNAC, in spite of the fact that the program had gained little addi-



BACKGAMMON POSITION is typical of the kind of position an early version of the BKG program could not handle well. Black has rolled a six and a five that can be played in two fundamentally different ways: running both pieces from the 18 point (18–12 and 18–13) or moving two other pieces. The first way (leading to a running game) disengages the armies of pieces, so that the rest of the game becomes a straightforward race. The second way (leading to a blockading game) leaves the armies entangled, so that considerations such as making points, leaving "blots" and hitting them are quite important. The program could have adequately compared two running-game alternatives or two blockading-game ones. Yet since the running game and the blockading game are different, the program had trouble deciding which formation is better.

tional knowledge of the game. In competition BKG was trouncing the best available commercial backgammon-playing microprocessor 78 percent of the time. Without SNAC, BKG had beaten the microprocessor only 56 percent of the time. When Magriel played against the program for the first time, he was surprised at how well it did. He subsequently helped us to refine the algorithms bearing on the doubling cube and to evaluate the program's overall performance.

The real test of BKG's strength came in May, 1979, when BKG 9.7 (the numbers stand for successive versions of the program) played in a small private tournament of intermediate-level players in California and won its first two matches before losing to the ultimate winner of the tournament. Without SNAC, BKG had not done well in tournaments. In the spring of 1978 the program had been eliminated from an intramural competition at Carnegie-Mellon University after it had lost its first two matches to weak players.

	BEFORE SNAC	WITH SNAC
TEXTBOOK PROBLEMS	45%	66%
AGAINST BEST COMMERCIAL MICROPROCESSOR	56%	78%
AGAINST EARLIER VERSIONS OF ITSELF	37.9%	62.1%
AGAINST HUMAN PLAYERS	0–2	3–1

TABLE OF PERFORMANCE RESULTS shows that the program did much better when the polynomial evaluation function it used to judge the strength of a backgammon position had smooth nonlinear functions and application coefficients (designated SNAC). In the polynomial each term represents a feature of a backgammon position, and the nonlinear coefficient of the term shows the importance of the feature. The fact that the coefficient is not constant but varying means the importance of a feature changes according to other features in the position.

The fateful week in Monte Carlo when the program would be pitted against the world champion was only a month later. Before the contestants could meet, the best human competitors had to play among themselves for the world title, which Villa eventually won.

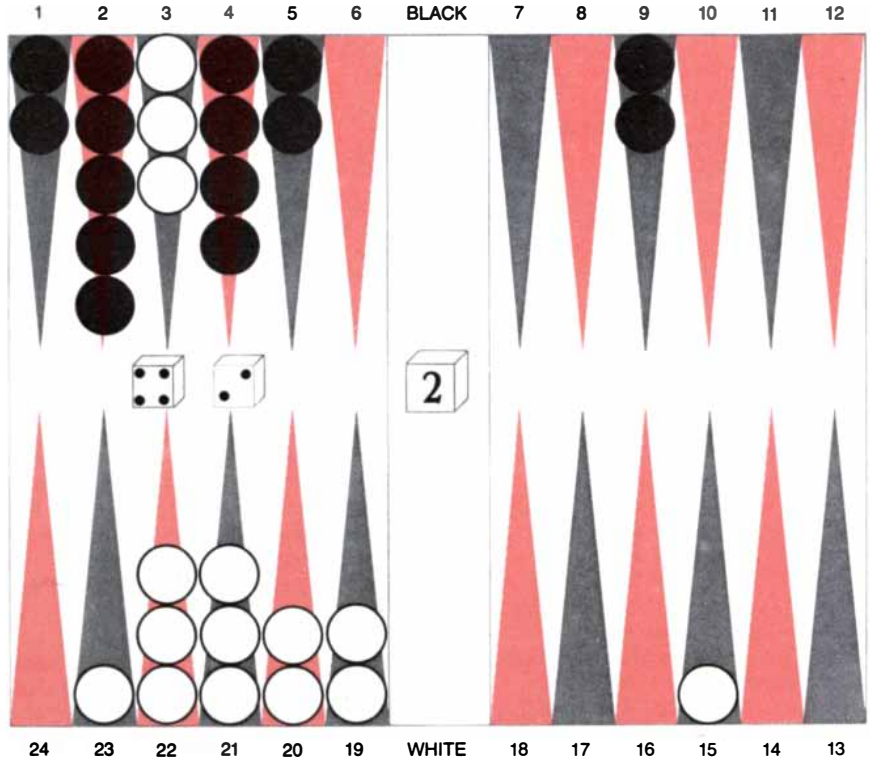
The BKG 9.8 program, running on a PDP-10 computer at Carnegie-Mellon, was connected by satellite to a mobile robot in Monte Carlo. Not much was expected of the programmed robot, dubbed Gammonoid by the tournament organizers. Although the organizers had made Gammonoid the symbol of the tournament by putting a picture of it on their literature and little robot figures on the trophies, the players knew that existing microprocessors could not give them a good game. Why should the robot be any different?

This view was reinforced at the opening ceremonies in the Summer Sports Palace in Monaco. At one point the overhead lights dimmed, the orchestra began playing the theme of the film *Star Wars* and a spotlight focused on an opening in the stage curtain through which Gammonoid was supposed to propel itself onto the stage. To my dismay the robot got entangled in the curtain and its appearance was delayed for five minutes.

The match between BKG 9.8 and the champion took place at 11:00 P.M. on the last day of the tournament. Each side put up $2,500 so that the contest would be a meaningful one. To convince the spectators that the program's dice rolls were honest the tournament director appointed an assistant to roll for the robot. The match, which was held in the Winter Sports Palace, was being carried by closed-circuit television to a room with seating for 200. Magriel was ready to provide a play-by-play commentary, but even with this added attraction the attendance was disappointingly low.

In the first game BKG 9.8 got off to a good start. It doubled appropriately at an early point, when Villa had to accept, and it skillfully nursed its advantage to get into a position where it had almost won. The top illustration on the opposite page shows a key position near the end of the game. The program rolled a four and a two and was forced to leave a blot. Which blot would it leave? It could move a piece from the 5 point to the 1 point and a piece from the 4 point to the 2 point, leaving a blot on the 5 point that could be hit in 11 ways (by any dice roll with a two in it). It chose to move two pieces from the 9 point to the 5 and 7 points, leaving a blot on the 7 point that could be hit in 13 ways (by any roll of four or a roll of a three and a one).

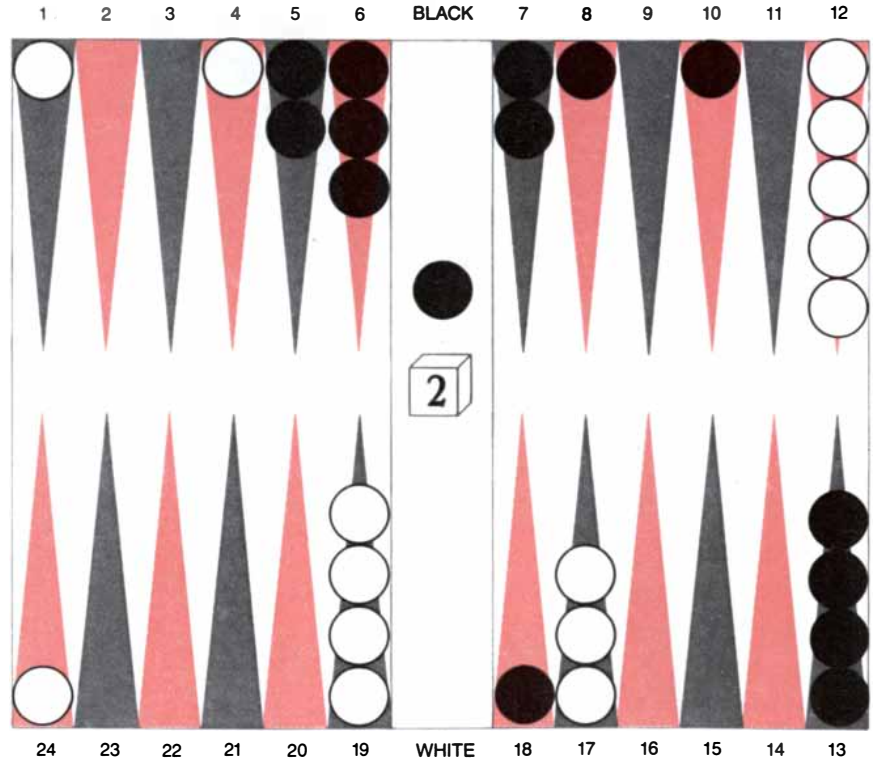
The BKG program has a function that counts the numbers of ways a blot can be hit, and so it completely understands the present risk of getting hit. It also has SNAC functions that measure the future risk of getting hit as a function of the various kinds of formations and the probability of those formations' immediately breaking up. The two plays between which the program chose differ in the balance between present risk and future risk, but the SNAC functions are well tuned for this kind of situation, and so the program has no trouble deciding which play is better. It understands that it has chosen the move with the greater present risk. Yet it also recognizes that if it had made the safer play, it would soon have had to move the pieces on the 9 point. Then it would probably have been forced to leave a blot, because the nearest friendly point is far from the 9 point. Therefore the program prefers to take a slightly greater risk immediately and do away with the long-term problem altogether. This play is certainly the correct one, which any expert should make without thinking, but it is not the kind of thing computer programs are supposed to be able to do, taking an apparently ill-advised action because it is well advised in the long run. After BKG had made the move Villa was unable to hit the blot, and BKG went on to win smoothly, making the score 2–0.



BKG ROLLED A FOUR AND A TWO in this position from the first game of its match with Villa. The program (*Black*) had the advantage but was forced to leave a blot. It played 9–5 and 9–7, leaving a blot on the 7 point that could be hit by 13 dice rolls. The apparently safer play of 5–1 and 4–2, leaving a blot on the 5 point that could be hit only by 11 rolls, is inferior because it leaves two pieces on the 9 point that could become exposed later when they must move.

The second game was a pivotal one in the match. Again the program got off to a good start, and to keep his chances alive Villa hit one of BKG's pieces in his own inner board. This brought about the position shown in the bottom illustration at the right, with the program having the next move. Here BKG made an extremely imaginative double that Villa declined. The program realized that it already had a slightly better position and that if its next roll was good (any roll with a one, particularly a roll that enables the piece on the 4 point to be hit), it could easily swing the game very much in its favor. In that case it would be too late to double because Villa would decline, thereby depriving BKG of the possibility of gammoning him. The experts applauded the double, although they also thought Villa should have accepted it. He declined because he was hoping things would go his way in the subsequent games. The score was now 3–0, and more spectators began to come into the television room.

Villa got off to a good start in the third game. He built up a strong position and doubled at a time when it was appropriate for BKG to decline. The program accepted, however. Villa was now on his way to winning the doubled game, but through a series of unfortunate rolls he was forced to leave an exposed blot as he was bearing off his pieces. The program was not able to hit the blot immediately, but Villa was forced to leave



BKG DOUBLED in this position from the second game of the match. The double was a good one, and Villa declined it. The question of doubling comes down to deciding whether one's position is too weak, too strong or just right. If the position is too weak, the opponent will accept the double. If it is too strong, he will decline, losing only the original stake and not twice the stake, which he could have lost if the double had not been offered and he had been gammoned.

another blot two rolls later. This time BKG got a good number, hit one of Villa's pieces and went on to win by redoubling him when his position was hopeless. This made the score 5–0. The television room was now full of spectators, who groaned and cheered as the game swung back and forth between the combatants. It was like the semifinals and finals of the world championship, when the room was packed with aficionados who argued about which moves were best and which side was in the better position.

At this point I was quite pleased with the way things were going. In my fondest dreams I might have hoped for five or six points in a losing contest. Yet here we were, leading 5–0 with an excellent chance of winning the match. I had worried that an expert might be able to play in some strange way that would entice the program into unusual situations where it would blunder seriously. Of course, a great deal had been done to try to prevent this possibility. It was nonetheless on my mind, although it never came about.

In the fourth game Villa quickly got an advantage and doubled early, hoping to recoup some of his losses if he could go on to win. The BKG program, however, chose to play it safe and keep its dominating lead by declining the double. It was a close decision whether or not the program should have declined. The score was now 5–1, and the crowd in the television room was ready to see Villa make a comeback.

The fifth game was the most interesting and fateful of the match. BKG played most aggressively in the early stages, and as a result two of its pieces were hit and sent back. The program made the best of this loss of time by establishing a back game: an exceptionally strong defensive formation in which two defensive points are held in the opponent's home board. This meant that Villa's victory in the game, if there was to be one, would be a long way off. The central concept of a back game is to lure the opposing pieces forward as fast as possible in the hopes of eventually hitting a piece and sending it back. For this strategy to succeed it is necessary to have a good defensive position with one's own pieces not advanced too far. Otherwise it will not be possible to contain the piece that is sent back.

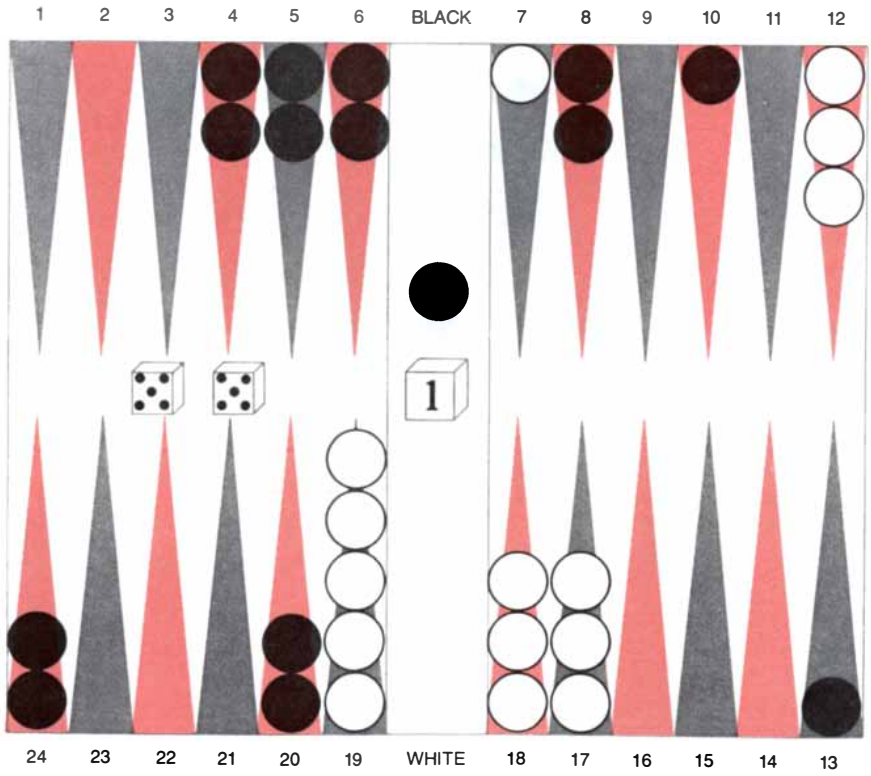
Both sides played well for several moves, and then BKG rolled an unfortunate double five in the position shown in the illustration below. As a result the program had to advance its pieces faster than it would have liked. It showed its excellent command of the position by playing two pieces from the 8 point to the 3 point and one piece from the bar to the 15 point, leaving three blots that could be hit. Of course, the program would not have minded at all if the blots had been hit; that would have slowed the advance of its own pieces and would have put it in a better position to hit one of Villa's pieces. Moreover, the blots were ideally situated to obstruct the mobility of Villa's forces, which could not afford to be hit because the program had already achieved a good defensive formation.

Several moves later BKG had to play a five and a one in the position shown in the top illustration on the opposite page. The obvious play was to move a piece from the 13 point to the 7 point in the hope that this piece would be hit as Villa's last piece on the 2 point tried to escape. If the piece had been hit, the program would have had more time to plan its defense. The program rejected this move, however, for the sensational one of moving a piece from the 13 point to the 8 point and a piece from the 3 point to the 2 point.

Although this move destroyed part of BKG's defensive formation, it was an aggressive double-edged continuation that was judged to be correct by the watching experts. The conception is as follows. If Villa hit one or both of the blots in BKG's home board, then BKG would gain time to improve the effectiveness of its back game. On the other hand, if the blots were not hit, BKG would have a chance to establish an even stronger defensive position, making it more difficult for Villa's back piece to escape from the program's pieces that contained it. In essence BKG's outstanding play gave it not one but two ways to win. Nevertheless, the play was risky, and Villa, with much to gain and little to lose, doubled and BKG accepted.

Villa immediately hit a blot as he brought in his piece and started moving his forces home. The program now rolled another two fives, again forcing it to advance its pieces faster than it would have liked. A few moves later came another critical moment. BKG had to play two twos in the position shown in the bottom illustration on the opposite page. Here a player who is not an expert might be tempted to maintain his back game by playing a piece from the 22 point to the 20 point and two pieces from the 6 point to the 2 point and the 4 point. BKG realized, however, as most experts would, that a back game is useless without a strong home-board position. In fact, it risks being gammoned.

Therefore BKG moved a piece from the 3 point to the 1 point and three pieces from the 22 point to the 20 point. This play abandoned the back game and started a race for the home board in order to limit the program's losses to a doubled game. Soon BKG was reward-



BKG ROLLED TWO FIVES in the fifth and final game of the match. The program played 8–3, 8–3 and bar-15, leaving three blots. If the blots were hit, BKG would have more time to reinforce its back game: the holding of the 24 point and the 20 point in Villa's inner table.

ed unexpectedly for its good play. In the next 12 turns for each side the program's designated dice thrower outrolled Villa by 31 pips (4.3 pips is the standard deviation for a single roll), achieving a position in which it had about a 20 percent chance of winning. At that moment out of its dice cup came two sixes, which enabled the program to take off its last four pieces, winning the game and the match.

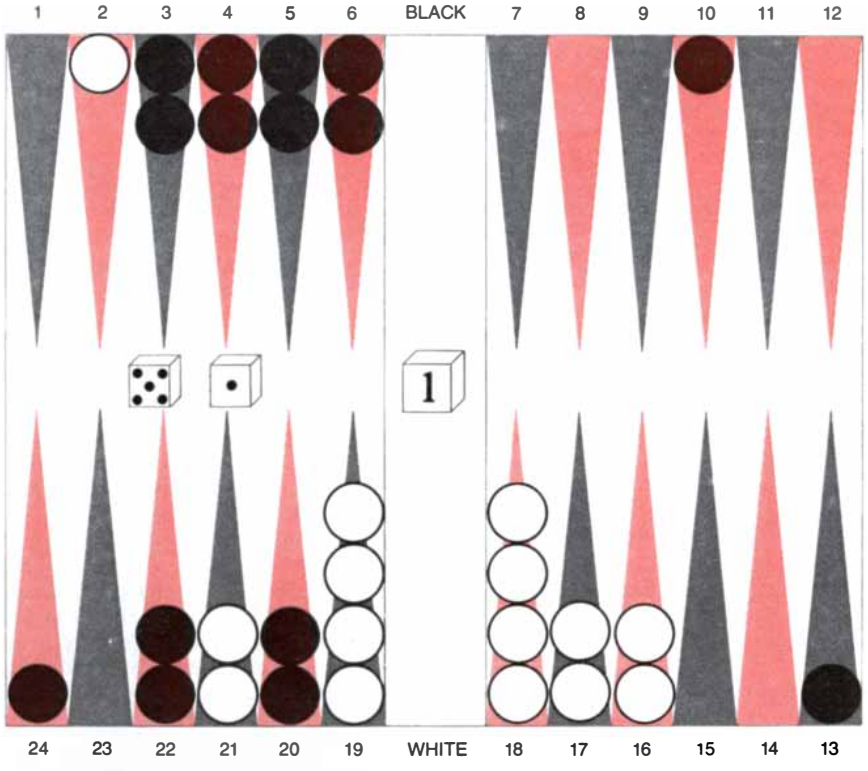
I could hardly believe this finish, yet the program certainly earned its victory. There was nothing seriously wrong with its play, although it was lucky to have won the third game and the last. The spectators rushed into the closed room where the match had been played. Photographers took pictures, reporters sought interviews and the assembled experts congratulated me. Only one thing marred the scene. Villa, who only a day earlier had reached the summit of his backgammon career in winning the world title, was disconsolate. I told him that I was sorry it had happened and that we both knew he was really the better player.

Several weeks later I analyzed the games in some detail at Carnegie-Mellon. There was no doubt that BKG 9.8 played well, but down the line Villa played better. He made the technically correct plays almost all the time, whereas the program did not make the best play in eight out of 73 nonforced situations. Only one of these mistakes, however, gave the program any trouble. An expert would not have made most of the errors the program made, but they could be exploited only a small percent of the time.

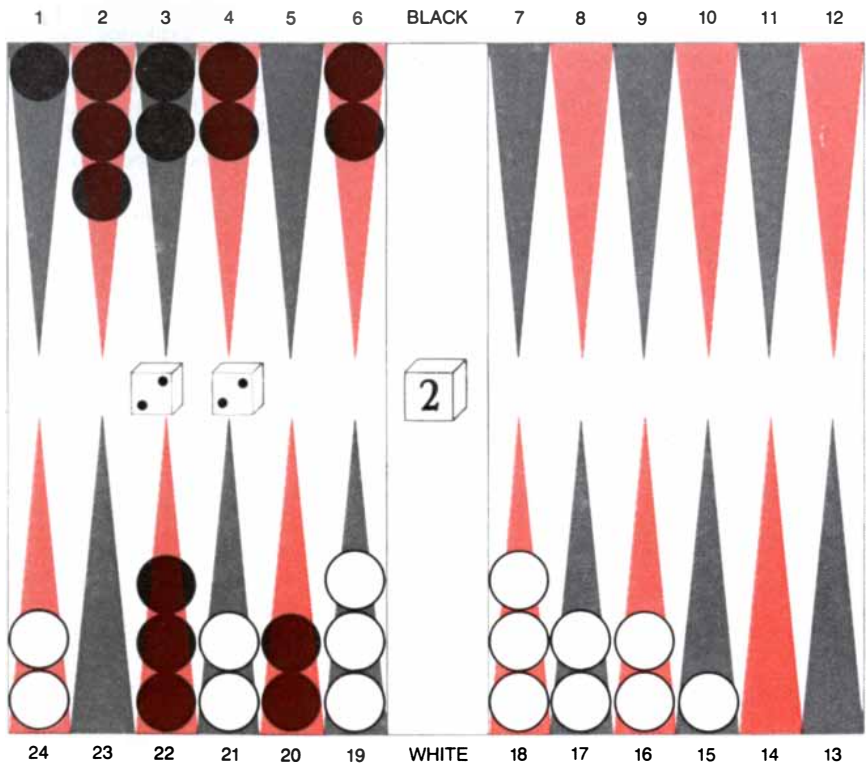
BKG 9.8 shined brightly when it came to exercising imagination. Someone who did not know whether the program was playing White or Black might have thought it was the human competitor who was making the sparkling plays and the machine the stodgy ones. In the match the dice had the final say, and they spoke for BKG 9.8.

The BKG program will now be developed in two areas. First, I plan to build more knowledge into it. Second, I want to make it into a teaching program that will ultimately be able to perceive its own weaknesses and modify itself to correct them. The first task will take time but does not seem to be too demanding. BKG 9.8 already seems to know most of what is important in backgammon. Although the accuracy of its knowledge is high, there are places where the values of the application coefficients of functions can be improved somewhat and where additional knowledge could be beneficial. My co-workers and I are currently proceeding along these lines.

There are many problems of back-



BKG ROLLED A FIVE AND A ONE in this position in the last game. The program made the sensational play of 13–8 and 3–2. If any of BKG's blots were hit, it would have more time to build up its back game. On the other hand, if they were not hit, it would be able to make points in its home board, making it more difficult for Villa's piece to come back in and then escape.



BKG ROLLED TWO TWOS in this position in the final game. By making the plays 3–1, 22–20, 22–20 and 22–20 the program correctly abandoned its back game and started moving its army of pieces home, in the hope of not getting gammoned. Although the program was the underdog in the race, it got lucky rolls and ended up winning the doubled game and the match.

gammon such as the correct way of bearing pieces off the board that can be solved completely by numerical analysis with the aid of computers. One of my students has developed a complete data base for all positions with 15 pieces or fewer in the home board. The data base provides the expected number of rolls (accurate to five decimal places) that are required to bear off all the pieces. Given this information, it is possible to determine the best move for any dice roll in any bearing-off position. The data base, however, has 54,000 entries, so that it would be wasteful of computer resources to keep it in the program. Yet it seems possible to develop a few rules that would incorporate all the bearing-off knowledge. We are now in the process of developing a program that will generate its own rules and test and modify them until it eventually homes in on a small set of rules that will capture all the information in the data base. These rules will then be included in the BKG program.

Another problem that is solvable is the one of when to double. In the final analysis doubling comes down to deciding whether your position is too good to double, not good enough or just right. The crucial issue is how the position will have changed by the next time you have a chance to double. Since 21 different rolls are possible for each side before the next opportunity arises to double, 441 possible situations must be considered, assuming of course that all of them can be evaluated correctly. Nevertheless, it is usually possible to organize the situations into groups, each of which can be evaluated. If it turns out that your position would be too strong to double at the next opportunity for most of the 441 situations, then you should do so immediately. On the other hand, if the chances are that your opponent would accept a double now as well as the next time, then you should wait, because he might get lucky and roll good numbers as you roll bad ones. Expert human players approach doubling in much the same way that BKG will. If the program gets accurate inputs to its doubling equations, however, it should be able to outclass human competition in this phase of the game.

Situations sometimes arise in backgammon for which there are no well-developed models. These situations are usually referred to as situations requiring judgment. The program does quite well in this domain because of the success of the SNAC functions. It can nonetheless be improved in several places. I plan first to generate a large number of similar situations requiring judgment and then to tune and augment the affected functions until they yield the correct response in every case. This task could be a painstaking one that would be better done automatically, but I do not yet know how to do it that way.

It seems SNAC functions are the proper means of capturing the characteristic that human beings call judgment. They make it possible to respond to small changes in stimuli with small changes in behavior, and this is exactly what judgment (as opposed to logical deduction) is about. I think SNAC functions could be exploited successfully in computer applications ranging from aesthetics to everyday decision making in business. In any reasonable implementation it will of course be necessary to identify the important variables and their interactions and to tune the resulting functions.

The next five years should see remarkable advances in computer game playing. The current era of powerful game-playing programs began in July, 1976, when Chess 4.5, developed by David J. Slate and Lawrence R. Atkin of Northwestern University, won a tournament of Class *B* chess players in California. (On the official ranking scale Class *E* goes from 0 to 1,199, Class *D* from 1,200 to 1,399, Class *C* from 1,400 to 1,599, Class *B* from 1,600 to 1,799, Class *A* from 1,800 to 1,999, expert from 2,000 to 2,199 and master from 2,200 on up. The median rating of all U.S. tournament players is 1,362.) Since then Chess 4.5 has won the Minnesota Open Championship and has beaten experts and masters at "blitz" play (where each side has five minutes for the entire game).

Another strong chess program is Belle, developed by Ken Thompson and Joe Condon of Bell Laboratories, which incorporates special hardware specifically designed to carry out chess calculations. Soon it will be upgraded to conduct tree searches of many millions of nodes within the time limit of three minutes per move, a search that staggers the imagination. When the knowledge of Chess 4.5 is combined with the upgraded hardware of Belle, the program will, I am confident, play chess at the master level. SNAC functions may even help the program to develop a greater sensitivity to what is important in a given position.

Things look even brighter for computer backgammon. My program plays at the Class *A,* or advanced intermediate, level. When the improvements I have mentioned are introduced, I think the program will play all stages of the game at an expert level and will be able to do certain things better than any human competitor could in a short period of time without any mechanical or memory aids. At that point it should be difficult for the best players in the world to beat the program. I hope to eventually make BKG into a learning program that will get stronger by studying its own games.

Many people consider games such as backgammon and chess to be essentially frivolous. The results achieved in computer game playing, however, are certainly comparable to anything else that has been done in the field of artificial intelligence. The work on computer chess has led to major progress in techniques for searching a tree with many nodes and for breaking down a task for parallel computation. And the work on computer backgammon has led to better ways of organizing knowledge and making judgments.

USER: "What stage is the game in?"

PROGRAM: "You are winning and you are in the process of bearing off."

USER: "What does my advantage consist of?"

PROGRAM: "You are ahead in the running game."

USER: "What should I try to do?"

PROGRAM: "You should lift your blockade and try to get your men home safely."

USER: "What do you mean by blockade?"

PROGRAM: "The degree to which your opponent's pieces are blocked in."

USER: "What does that depend on?"

PROGRAM: "The number of men that are in front of a set of points you have made and the difficulty of passing those points."

USER: "How strong is my blockade?"

PROGRAM: "It is moderately strong."

DIALOGUE BETWEEN HUMAN PLAYER AND BKG will be possible in the future. The human player will select his questions from a list, and the program will formulate its answers by examining its own knowledge base and the set of possibilities in the current game position.

On photography, the three Rs, and articulateness

That right-brain/left-brain business has become fashionable doctrine. Vast numbers of words are spilled about it. Those words are mostly spilling out of the left sides of brains, if we understand the doctrine itself, which we may not. We feel more comfortable making judgments in the field of chemical engineering than in neuroanatomy or psychology. We would steer quite clear of this subject but for the fact that the major product of our chemical engineering finds one of its uses in preparing children for adulthood.

In pre-TV days little was spent on special help for kids who were finding it especially hard to learn how to read and write. It was assumed they would be making their way with their muscles. That has become very hard to do. So special arrangements are made. Oddly enough, the special classes consist mostly of little boys. Whatever the adult result, development schedules in the brain seem to differ between the sexes in childhood.

If Albert Einstein were eight years old now, he might well be in one of those classes as a non-intellectual despite latent power enough in the spatially reasoning right side of his brain to discover special relativity. Little Albert did it without TV stimulating that nonverbal right brain. Classmates similarly slow in the left sides of their heads would tend to turn into young men whose every statement will sound more or less alike because they will have too few words (and even fewer mathematical equations) with which to express their thoughts.

The schools and the traditions of scholarship favor the user of words. If overexposure of children to the pictures on the tube is causing the trouble and is too hard to prevent, pictures, *if under control of the child himself,* are seen by many educators as also the cure.

Overcoming verbal handicap is the price of admission to the world as now constituted, where writing advertisements for large companies beats felling large trees by hand axe. To help overcome it, photography is used in many schools to transfer strength from the overstimulated right brain to the underdeveloped left brain, even if the educators who offer evidence of the effectiveness of their techniques for doing this do not all rely on brain-splitting to explain their results.

Though the use of photography to encourage literacy in children represents a very small part of our business and probably always will, we have plenty of material to send you about the techniques and the evidence. It may help in confrontation with taxpayers who claim that a hickory stick works better than a camera for driving the three Rs into young heads.
Write Jim Sucy, Education Markets, Kodak, Rochester, N.Y. 14650.

SCIENCE AND THE CITIZEN

Taking Time from Research

Twelve years after the U.S. Supreme Court finally invalidated a state "monkey law" (an Arkansas statute) on Constitutional grounds the assault on the teaching of Darwinian evolutionary theory is alive and well. There are signs, however, that members of the scientific community, including college and university professors, are beginning to fight back after having left the effort to high school biology teachers for many years.

The current creationist drive is aimed at achieving "equal time" for the creationist view both in textbooks and in class instruction. The drive is led not by theologians (no major sect of even the most fundamentalist Protestant persuasion is formally identified with the effort) but by creationist engineers and scientists (for the most part physical scientists). In order to avoid First Amendment problems they insisted for a time that what they espoused was not a biblical doctrine but "scientific creationism"; having been challenged on the ground that creationism is not by any test a scientific theory, leaders of the movement now tend to argue that neither creationism nor evolution is scientific, but that creationism is better supported by scientific evidence than evolutionary theory is. A favorite tactic is to cite disagreements among scholars on narrow issues in evolutionary biology as proof that evolutionary theory and its subtheories are in serious question.

Legislation requiring equal time for creationism has been introduced in several states. In Iowa such a bill was vigorously opposed by the Iowa Academy of Science last year and died in committee; it was defeated in committee again this year even after it had been amended to merely allow creationist teaching, but it may be reconsidered. A Georgia bill passed in both houses in different forms but failed in conference. Similar versions of a new model bill specifically defining scientific creationism as a valid scientific theory, to be taught whenever evolutionary theory is presented, were introduced this year in Florida, Illinois, New York and South Carolina. In New York the bill is unlikely to emerge from committee.

Another approach for creationists is through local school boards and state education agencies. In 1970 the California State Board of Education was prevailed on to include language in its "science framework" for the public schools to the effect that "several theories," including "creation in scientific terms," are necessary to explain the origin of life. Science teachers succeeded in getting that language eliminated (see "Science and the Citizen," July, 1979). Now individual creationists and the Creation-Science Research Center in San Diego have gone to court in an effort to compel the board of education to revise the framework. In New York the State Education Department has been seeking the opinion of individual scientists and the New York Academy of Sciences on a request that creationist instruction be included in a new science syllabus in preparation.

The creationist drive has been coordinated by the Creation-Science Research Center, the Institute for Creation Research and members of the Creation Research Society. The countereffort has generally been conducted by individuals. The major scientific professional societies have not played a significant role. What coordination there has been has been supplied by the National Association of Biology Teachers (N.A.B.T.), whose membership is largely made up of high school and junior-college teachers (although it also includes college and university faculty members). Whereas creationists welcome opportunities to expound their views, most professional biologists, geologists and anthropologists have tended to think that debating with creationists or countering their views merely dignifies what the scientists consider to be a nonscience. They appear to find it hard to take the creationist threat seriously.

According to Wayne A. Moyer, executive director of the N.A.B.T., however, "the problem won't go away." In an editorial in the March *BioScience* he warned that "we face a highly organized, well-financed effort to legislate creationism—a religious doctrine—into public education. And if creationists are successful, the next target will be state-financed institutions of higher education." Moyer wrote that individuals "opposing this effort to introduce theology masquerading as science into biology classrooms ... desperately need the support of professional biologists." And he urged the necessity of a mechanism to enhance cooperation among those resisting creationist penetration of the schools: a "national information network" to inform the public about evolutionary theory, to monitor and publicize creationist activities and to rebut creationist arguments.

Science courses presenting the creationist view have been taught at some colleges and universities. Faculty members have sometimes complained that a nonscience has no place in a science curriculum, but college administrators (and the American Association of University Professors) have tended to shy away from the issue for fear of infringing on "academic freedom." Most college teachers have not been willing themselves to deal with a nonscience in the classroom. Recently, however, William Thwaites and Frank T. Awbry, professors of biology at San Diego State University, decided the academic community's "unwritten policy of total aloofness" was counterproductive. They are teaching a course ("Evolutionism v. Creationism") in which they present the evidence for evolution and the antievolution view is presented by leading creationist spokesmen. The two biologists have encouraged their teacher-training students in particular to take the course. "We know they are going to run into creationist arguments" on the job, and "we would rather they heard these arguments as students before hearing them as teachers from a student or a parent." As Awbry put it, "we hate to take time from research but it's got to be done."

MXed Reviews

According to the U.S. Air Force, last year's decision by the Carter Administration to proceed with the development of the MX mobile-missile system will, given the continued support of Congress, result in economic benefits for the nation as well as military ones. For example, the environmental-impact statement prepared by the Air Force for the Full Scale Engineering Development (FSED) of the MX predicts that FSED expenditures of approximately $1 billion per year for the next five years will generate some 130,000 new jobs nationwide. The Air Force projection is for the development of the missile alone and does not include its "basing mode." Current plans envision the initial deployment later in the decade of 200 MX missiles, shuttling back and forth within a vast maze of railroads, roads and concrete shelters in the southwestern U.S. The projected cost of the entire system, in constant 1979 dollars, is put at $33 billion.

How reliable are such official estimates of the economic impact of the MX program? An independent analysis done recently by the New York–based Council on Economic Priorities suggests that they are "far too optimistic." Writing in *Arms Control Today,* the newsletter of the Arms Control Association, economist David Gold, director of military research for the council, reports that the preliminary results of his group's evaluation "indicate that the Air Force has overstated the gains from the project, and understated or even ignored substantial costs."

According to Gold, the econometric models on which the Air Force projections are based were used to compare the job-generating capabilities of MX

You can never thank your father enough, but at least you can give him Chivas Regal.

12 YEARS OLD WORLDWIDE • BLENDED SCOTCH WHISKY • 86 PROOF • GENERAL WINE & SPIRITS CO., NEW YORK, N.Y.

MEETING THE DEMANDS OF SOCIETY IS NO EXCUSE FOR BUILDING A BORING CAR.

If one accepts the dismal prophecies emanating from the automotive community, it appears we are destined to suffer a generation of thoroughly boring automobiles.

Cars so utterly debilitated by societal necessities, safety regulations and anti-pollution paraphernalia that they no longer will be the least bit interesting to drive.

There is, however, one rather encouraging note of optimism.

All this doomsaying neglects to take into account the obsessive determination of the engineers at BMW in Munich, Germany to build extraordinary automobiles.

Against all odds, the BMW 528i not only satisfies the laws of the land and the demands of the gas tank, it does so without ever once violating our conviction that extraordinary performance is the one rational justification for owning an expensive car.

FEW CARS PERFORMED THIS WELL BEFORE POLLUTION CONTROLS.

Expensive luxury sedans have never received great kudos for their capacity to perform with efficiency and agility.

Quite the contrary. "Expensive sedans," writes Car and Driver magazine, "tend to ride like pillows when you cruise them and squeal like pigs when you push them."

A bit caustic perhaps. But, an analysis that makes the performance statistics of the BMW 528i seem all the more remarkable.

Round a particularly hair-raising curve and the legendary BMW suspension system—independent on all four wheels—flexes with a resiliency that makes one feel as if the car were built into the roadway. A sensation that results from highly advanced suspension technology and the virtually perfect integration of man and machine.

Press the accelerator and the 528i's fuel-injected, 2.8-liter, overhead cam engine responds in a manner that can only be described as exhilarating—even by pre-pollution control standards.

Yet, the 528i (with standard transmission) delivers 18 EPA estimated mpg, 30 estimated highway mileage and, based on these figures, an estimated mpg range of 295 miles and a highway range of 492 miles.

(Naturally, our fuel efficiency figures are for comparison purposes only. Your actual mileage and range may vary, depending on speed, weather and trip length. Your actual highway mileage and highway range will most likely be lower.)

And, curious as it may seem, the BMW 528i is the only luxury "sports" sedan in its price class that offers a surgically precise five-speed manual gearbox as standard equipment (automatic is available of course).

LUXURY NEEDN'T BE MERELY A FACADE.

One's appetite for luxury would have to be insatiable indeed to imagine an appointment or convenience lacking in the 528i.

AM/FM stereo cassette, full-power accessories, air conditioning, and a good deal more, are all standard equipment.

Yet each and every facet has been strategically engineered to help eliminate the enormous strains and pressures of driving.

Its seats are anatomically shaped buckets. Its front seats are so thoroughly adjustable that it is all but impossible not to find a comfortable driving position.

All vital controls are within easy reach. The tachometer, speedometer and ancillary instruments are large, well-marked and totally visible.

All in all, in a time of lowered automotive expectations, amidst increasing mediocrity, the engineers at BMW have actually improved the BMW 528i.

If you find the notion of owning such a car more than a little intriguing, we suggest you phone your nearest BMW dealer and arrange for a thorough test drive at your convenience.

THE ULTIMATE DRIVING MACHINE.

BMW. MUNICH, GERMANY

THE MARK™ T/A®

Introducing the high performance Radial T/A that adds elegance and superb handling to magnificent machines.

From BFGoodrich,® The Mark™ T/A® radial. The newest member of America's first family in high performance radials. The ones more people buy than any other.

With The Mark T/A, you possess more than an elegant radial. Its appearance complements any quality machine. You ride with the assurance of superb handling, tough durability, straight tracking, and a tread designed to offer excellent wet traction.

The DuroGard® folded belt system wraps The Mark T/A radial in a network of strength, while the dual compound tread resists heat build-up and provides a commanding grip on the road.

Ride T/A radials. Ride number one.

USA ♥ T/A™

BFGoodrich

#1 IN HIGH PERFORMANCE RADIALS.

expenditures at different levels of national unemployment. Assuming an unemployment rate of 8 percent over the next five years, the Air Force model predicts that FSED expenditures would add between 88,000 and 126,000 new jobs to the economy. If the national unemployment rate were to be as low as 4 percent, however, the model predicts that there would be between 15,000 and 22,000 additional jobs. The wide range of results, Gold points out, "implies that the effects of FSED expenditures depend heavily on the state of the economy, a conclusion that is hardly surprising." Nevertheless, he adds, "it is a conclusion that should have precluded the Air Force from releasing an estimate of job creation that is outside the upper bound of the highest range of their own estimates."

More important, the article continues, "an effect such as job creation cannot be analyzed in isolation. Every expenditure has an opportunity cost. Every billion dollars that is spent on the MX is a billion dollars not spent on education, or housing, or consumer goods, or business investment in plant, equipment and research. The employment generated by the MX system should be compared with the employment that could be generated if the same money were to be spent in some alternative fashion."

In the past few years a number of studies comparing the economic impact of military spending with that of other kinds of spending have found that in general a rise in military spending does generate new jobs but that significantly more jobs would be created if the money were to be spent elsewhere, by either the Government or the private sector. The current investigation by the Council on Economic Priorities indicates that the MX program would be no exception to this rule. Estimates of the number of jobs created per billion dollars of expenditures on the MX missile and on five alternative projects (solid-waste treatment, railroad reconstruction, day care, solar energy and mass transit) were compared by Gold and his associates, using the "jobs-impact coefficients" derived from the input-output model of the U.S. economy developed by the Bureau of Labor Statistics. The data obtained so far reveal that every one of the five alternatives would generate more employment than the MX program. In other words, the comparisons show that MX expenditures will probably result in a net loss of jobs.

Furthermore, Gold predicts, the MX is likely to cost far more than current Air Force projections would have it. In contrast to the widely quoted figure for system costs of $33 billion, which has already been adjusted to remove the effects of inflation, he cites reports that the Congressional Budget Office has projected system costs, in current dollars, to be $63 billion for the life of the project, including operations and maintenance after the system is fully deployed. "The CBO is now revising its inflation projections for the 1980's upward, which will again raise the estimate of dollar outlays. If the $33 billion estimate is accepted, Congress and the public are likely to be surprised when the budget outlays rise far above that figure."

In conclusion Gold remarks: "It appears that the Air Force has been willing to conduct analyses, and widely publicize the results, of economic impacts that they see as supportive of the MX system, but they are unwilling to analyze impacts that might cast doubt on the system's economic efficiency."

Death in Britain

The 15-year decline in the U.S. death rate from coronary heart disease continues to fascinate and puzzle epidemiologists, particularly in Britain, which almost alone among the "high coronary" countries has not shared in the downturn. Between 1968 and 1976 the age-adjusted death rate in the U.S. from ischemic heart disease (the term now preferred for coronary heart disease) fell by 21 percent. Remarkably, the decline has affected men and women, whites and blacks, young and old. The largest decline, 26 percent, has taken place among black women. The decline can hardly be an artifact of reporting, because the death rate has fallen for all components of the broad category "major cardiovascular diseases"; indeed, the U.S. death rate from all causes declined 18.6 percent in the decade ending in 1978.

A recent editorial in the British medical journal *The Lancet* observes that in Australia, Canada and Finland, countries where cardiovascular deaths have traditionally been high, deaths from ischemic heart disease have been dropping. Perhaps equally surprising, the coronary death rate seems to be falling even in the "low coronary" countries: Japan, Switzerland, Italy and France. In England and Wales, in contrast, after an early hint of a dip in the curve the mortality figures, says *The Lancet,* "have remained depressingly constant. Among middle-aged men, for example, in 1968 the chance of an American dying from ischemic heart disease was some 40 percent higher than the chance of an Englishman dying. By 1976 the American figures were actually lower than the figures in England and Wales." The only sizable decline in mortality from ischemic heart disease has taken place among British physicians, who have probably reduced their cigarette smoking more than any other group.

The Lancet reviews the possible explanations for the American experience but reaches no strong conclusions. The effect of coronary-bypass surgery, for example, must be "tiny," and "the claims for the benefits of coronary-care units have been moderated by the negative results of randomized controlled trials." *The Lancet* suggests that in the U.S., at least, there has probably been a decrease in the incidence or severity of the artery-clogging disease believed to give rise to a predisposition to heart attacks: atherosclerosis. It cites a recent report from New Orleans that compared two autopsy series 10 years apart and found a reduction in the severity of atherosclerosis among white males, although not among black males.

If the reduction in atherosclerosis is a general phenomenon, some credit must probably be given to the increased use of polyunsaturated fats in the American diet, a response to the theory that high consumption of saturated fats raises the level of cholesterol in the blood and that those high levels in turn accelerate the clogging of the coronary arteries. Between the 1950's and the 1960's, although there was no general decrease in the per capita fat consumption in the U.S., there was an increase in the proportion of fat calories consumed as polyunsaturates. *The Lancet* observes that international diet statistics are not accurate enough to prove a correlation between lower saturated-fat consumption and lower coronary disease but that "the trends are in the direction predicted by the diet-heart theory both in the U.S.A. and in Australia, Canada and Finland." Japan, however, does not fit the theory. In that country the mortality from ischemic heart disease, historically low, continues to decline in spite of an apparent 200 percent increase in saturated-fat consumption combined with a smaller increase in the consumption of polyunsaturates. In Switzerland the picture is also anomalous.

The Lancet finds that trends in smoking fit the heart-disease trends even less well. In the U.S. smoking has increased among women at the same time that it has been decreasing among men, yet it is women who have shown the greater decline in mortality. In Britain the clear decline in smoking among men has not yet been followed by a general decline in heart attacks, with the notable exception of the subgroup of physicians. In the U.S. the vigorous treatment now accorded high blood pressure probably contributed somewhat to the reduction in heart attacks. The growing attention to physical fitness may also be playing a role, but *The Lancet* observes that if this "were *the* crucial factor, [it] would mean that nonwhite women had increased their physical activity more than white men, [which] seems unlikely." On balance, *The Lancet* concludes, "it is tempting to believe that a combination of these changes—diet, smoking, physical activity, treatment of blood pressure—have contributed to the improved heart-disease pattern in the U.S.A. The stability of heart-disease rates in England and

Wales might be due either to respectable scientific doubt concerning these preventive efforts or to simple apathy."

Laetoli Hominid No. 18

When did *Homo sapiens* come into existence? Estimates have been vague, ranging from more than a million years ago to as little as 50,000 years ago. They are still imprecise, but an analysis of an early human fossil found four years ago in East Africa may well help to narrow the range. The analysis indicates that modern man had begun to evolve from his precursor *Homo erectus* between 150,000 and 90,000 years ago.

The fossil specimen was discovered at the site of Laetoli in Tanzania by Mary Leakey and her associates. It is a much fragmented but remarkably complete skull vault and upper jaw. Its 22 pieces were found where they were eroding out of an ancient stream-formed bed of sediments; the high and low boundaries of its age are provided by its geological context.

Mrs. Leakey and two co-workers in the anatomy department of St. Thomas's Hospital Medical School in London have published in *Nature* a preliminary description of the specimen: Laetoli Hominid No. 18. The open sutures of the skull vault suggest that L.H. 18 was between 18 and 30 years old at the time of death; the state of wear of the one surviving upper molar tooth indicates that the age at death was closer to 30 than to 18. The estimated cranial capacity is 1,200 cubic centimeters, greater than the *Homo erectus* average of less than 1,000 c.c. but less than the *Homo sapiens* average of 1,350 c.c. (The *sapiens* range is from 1,200 to 1,800 c.c.)

L.H. 18 shows a mixture of modern and archaic anatomical features. On the modern side is a rounded profile of the back of the skull and the general expansion of the cranium that is reflected in its substantial cranial capacity. On the archaic side is a markedly projecting brow ridge, a receding forehead and an overall heaviness of the bone. The investigators conclude that subject to further anatomical analysis L.H. 18 should be considered an early East African example of modern man.

Half a Billion More

Evidence that photosynthetic bacteria inhabited a shallow-water site in what is now Western Australia some 3.5 billion years ago has been presented by the Precambrian paleobiology research group of the University of California at Los Angeles. The finding adds another 400 to 500 million years to the record of life on the earth and strongly suggests that the planet's first organisms arose even earlier.

The evidence consists of a finely banded chert stromatolite, a structure that is formed by the growth and metabolic activity of microorganisms both in the remote past and at present. It was discovered in 1977 by J. S. R. Dunlop, then a graduate student at the University of Western Australia, in a remote desert area of that state nicknamed the North Pole by 19th-century miners. Malcolm R. Walter of the Australian Bureau of Mineral Resources, one of the 15-man U.C.L.A. research group, has analyzed the stromatolite and concludes it was produced by filament-shaped colonial bacteria that to judge from the thickness of the narrowest growth bands measured no more than 20 micrometers at least in one dimension. A living example of such an organism is *Chloroflexus,* a photosynthetic green bacterium that builds stromatolites in hot springs.

Whatever the true identity of the microscopic life forms, environmental variability would have exposed them to the atmosphere intermittently, and the daily variation in temperature would have been extreme. Their survival in spite of possible ultraviolet radiation suggests that the earth had already developed a protective ozone screen.

Discussing the discovery in *Nature,* Walter, Dunlop and R. Buick, one of Dunlop's colleagues at the University of Western Australia, point out that the microorganisms obviously had developed some strategy for coping with the danger of burial by sediment, because it was the application of this strategy that led to the growth of the stromatolite. Whether the mechanism was a response to the attraction of sunlight, as it is among less ancient stromatolite builders, is not apparent. The three investigators conclude that even at this very early stage in earth history "a community of organisms existed that was adapted to life in an adverse, fluctuating environment."

Computer Typography

At various eras in the history of printing, the type from which letters and other symbols are reproduced has been carved of wood, cast in metal and recorded as a photographic image; today the form of each character is often stored as a pattern of binary numbers in the memory of a digital computer, to be called up as needed on the screen of a cathode-ray tube. Whatever the medium of representation, however, the letterforms themselves have been designed in much the same way: by making a carefully proportioned pen-and-ink drawing of each character at an enlarged scale. Laying out a complete typeface in all its variations of size and style is an arduous task, and today the craft has few practitioners.

An alternative method of type design has recently been introduced by Donald E. Knuth of Stanford University. Knuth is a mathematician and computer scientist, and his work on typography was inspired in part by the observation that "mathematics books and journals do not look as beautiful as they used to." His response was to construct two special-purpose computer languages, one for the design of typefaces and the second for the composition of text from the type thereby created.

The type-design language, called METAFONT, defines the letterforms mathematically. It is not the first application of mathematics to typography: from the 15th through the 17th centuries there were sporadic attempts to create alphabets by purely geometrical methods, namely by constructing the letters with a straightedge and a compass. METAFONT, with access to the calculational capabilities of a digital computer, brings greater resources to the task. The goal is not to find a single equation that would describe, say, the letter "g." Instead the type designer is expected to specify a few points in the outline of the letter and perhaps the orientation of lines at some of the points; the computer program then connects these dots in a designated sequence, either with straight lines or with "pleasing" curves. Of course, the mathematical definition of a pleasing curve is subject to different interpretations; Knuth has selected a family of curves called cubic splines, which allow each segment of a curve to be determined by a different cubic equation.

The basic tools of the language are "pens" and "erasers," which can have various shapes, sizes and orientations. The curve that connects the specified points is the path traced by the center of a pen or of an eraser. By this means the calligraphic effects common to many typefaces are readily reproduced. For example, the letter "o" can usually be described as the form generated by a wide but flat pen, held at a constant angle as it travels an oval path; the resulting line is thin where the pen moves parallel to its long axis and thick where the pen moves perpendicular to the axis. In those typefaces called Modern (which derive ultimately from the work of Giambattista Bodoni, the 18th-century printer) the thinnest sections lie at the top and the bottom of the "o," so that the inner bowl of the letter is aligned vertically. In an Old Style typeface the bowl tilts slightly to the left. METAFONT expresses the distinction between these forms in terms of a single parameter, namely the orientation of the pen.

Designing a single character is probably more difficult, or at least more time-consuming, with METAFONT than it is by hand. The advantages of the automated system become apparent, however, in the design of a complete font of type: a set of all the uppercase and lowercase letters, numbers, punctuation marks and other symbols needed in a single size and a single style. In a manual design the requirement that all these characters be

GRAND AWARD. THE ONLY 12 YEAR OLD CANADIAN WHISKY.

12 years. That's how long this Canadian whisky takes.

12 years to allow a blend of the finest whiskies to marry perfectly. To achieve an unrivaled smoothness. And an absolutely remarkable richness of taste.

Grand Award. No other Canadian whisky tastes like it.

No other is presented at 90.4 proof.

And in the tradition of items of rare and exceptional quality, *only a limited amount of Grand Award is available each year.*

AT LAST, A CAR THAT'S SLOW FROM "F" TO "E" IS FAST FROM 0 TO 50.

It's not surprising that Renault Le Car will take you a long way on a gallon of gas. What is surprising is how quickly it will do it.

With its high-performance, aluminum-head engine and front-wheel drive, Le Car gets you up to highway speeds without anxiety. In fact, *Motor Trend* clocked it from 0 to 50 in only 10.4 seconds.

But perhaps the most pleasant surprise about Renault Le Car is not how quickly it goes, but how comfortable you feel along the way. In a passenger compartment with more room than a Honda Civic or Datsun 210 hatchback.† Cushioned by four-wheel independent suspension and Michelin steel-belted radials, for a smooth, level ride *Motor Trend* says "would do credit to far larger, more expensive cars."

Visit one of the hundreds of Renault dealers from coast to coast. For an economy car that gives you more than just economy.

*Remember: Compare these 1980 EPA estimates with estimated mpg for other cars. Your mileage may vary, depending on speed, trip length, and weather. Your actual highway mileage will probably be lower. California excluded. †Based on 1980 EPA data.

RENAULT LE CAR

WE BUILD MORE INTO ECONOMY CARS THAN JUST ECONOMY.

Imported by American Motors

compatible in certain of their dimensions and in their style necessitates many careful measurements. With METAFONT compatibility can often be ensured simply by establishing beforehand the values of a few parameters, which then apply to all the characters in the font. Moreover, a typeface consists of more than a single font. To be useful it must be available in various sizes, and it is often desirable to have fonts in which the lines have different average weights or the characters have different average widths. For any font in a roman typeface a compatible italic font is usually required; also needed are fonts of specialized letters and symbols, such as small capitals and mathematical signs. Because of these variations designing a typeface by hand requires drawing some dozens of fonts, each one made up of about 90 characters. In METAFONT many of the derived fonts can be generated as mathematical transformations of a single standard font. Indeed, because such transformations can be made quickly and applied simultaneously to all the characters, the designer is free to experiment in ways that would have been impractical with a hand-drawn typeface.

The typefaces generated by METAFONT are ultimately stored in digital form, as an array of 1's and 0's representing areas to be black or white on the printed page. In a computer-controlled typesetting machine the pattern of binary digits modulates an electron beam, which paints the character on the screen of a high-resolution cathode-ray tube. The images of successive characters are transferred from the screen to photographic film and from there to a printing plate. The second of Knuth's computer languages facilitates this process of type composition.

The language is called TEX, a name that is to be read as the Greek letters tau epsilon chi and therefore pronounced "tech." It allows characters to be entered from a keyboard much like that of a "video typewriter" or word-processing system; the output, however, is not like that of a typewriter. Instead the text appears set in the type fonts specified by the user, in a form that can be transferred directly onto plates for printing. The columns of type are justified, or made even, at the left and right margins, and where a word must be divided and hyphenated at the end of a line the division between syllables is determined automatically by the program.

A number of computer programs for the composition of type have been available for more than a decade. (The type in SCIENTIFIC AMERICAN is set by one of them.) The most notable distinction of TEX is that it is well suited to the composition of mathematical expressions and other kinds of notation more complicated than a linear sequence of characters. (Printers refer to text of this kind as "penalty copy" because of the added cost of setting it in type.) In TEX each character is represented by a rectangular box, whose dimensions are part of the typeface specification. The boxes are pasted up in a two-dimensional array to form a page of type, and their vertical positions can be specified in the same way and in the same detail as their horizontal positions. Hence superscripts and subscripts are easily placed; indeed, equations and tabular matter can be composed with little more difficulty than ordinary text.

Knuth describes the two languages in *TEX and METAFONT: New Directions in Typesetting,* a user's manual published jointly by the American Mathematical Society and Digital Press. All the fonts employed in the book were designed by Knuth with METAFONT, and the type was composed with TEX.

Dead Sea Doubts

Over the 33 years that have passed since Bedouins found scrolls in caves at Qumran near the Dead Sea many scholars have expressed support for the hypothesis that the scrolls are from a library maintained in the first century B.C. by an ascetic Jewish sect, the Essenes, who are described in the writings of Josephus and Pliny the Elder and are thought by some theologians to have had an influence on Jesus. In a recent issue of *Proceedings of the American Philosophical Society* Norman Golb of the University of Chicago summarizes a case against the Essene hypothesis and suggests an alternative.

The case in favor of the hypothesis is as follows. The Dead Sea scrolls include books of the Bible and of the Apocrypha and also other works that had not been known, among them a manuscript scholars named the Manual of Discipline. They are written in ancient Hebrew. Near the caves in which these works were found are ruins called Khirbat Qumran. Excavation there uncovered a building with many large rooms. In one room, measuring four by 13 meters, were found tables, benches and inkwells containing dried ink. A cemetery with more than 1,000 graves was discovered nearby.

The ruins are taken to have been a monastery of the Essenes, whom Pliny described as "a solitary people... who live without women" near the Dead Sea. It serves as corroboration that the precepts expressed in the Manual of Discipline match well with those of the Essenes, as given by ancient writers. The scrolls, then, were placed in the caves by the Essenes to keep them from the Romans, who occupied the putative monastery in A.D. 68, a time that marked the end of the sect, by dispersion or by massacre.

The case against the hypothesis has several aspects. For one thing, the thousands of fragments of leather or papyrus found, along with longer manuscripts, in the caves near Khirbat Qumran are now thought to be the remnants of as many as 800 different scrolls. Hence the scrolls that seem to be Essenic in character (notably the Manual of Discipline) are a small minority. As it happens, no doctrine of celibacy appears in any of the manuscripts, including the Manual of Discipline. Moreover, the opening of 43 graves in the cemetery at Khirbat Qumran revealed seven that were those of women and four that were those of children. Supporters of the Essene hypothesis counter that these graves are in auxiliary cemeteries and that the writings of Josephus suggest the existence of an Essene subsect in which marriage was allowed.

A second argument concerns the discoveries (in 1951, 1960 and 1961) of documents in the vicinity of the Dead Sea other than scribal copies of spiritual literature. They include letters, deeds and contracts; they refer to known historical events, notably Jewish revolts against the Romans, and they name specific places in the Judean wilderness. Golb finds it striking that no such letters and documents, personal or official, have been found at Qumran near the ruins that are said to have been a principal habitation of the Essenes for as long as 200 years.

A third argument is that both Timotheus I of Seleucia, a Syrian writing in approximately A.D. 800, and Origen, an Alexandrian writing in the third century, note discoveries of Hebrew manuscripts in the Judean wilderness near Jericho. There are in fact caves closer to Jericho than the ones at Qumran, but if the manuscripts were discovered in them, then the secreting of manuscripts in caves was a widespread practice, not confined to the vicinity of the supposed Essenic ruins. From 1963 to 1965 excavations were made at Masada, the mountaintop fortress south of Qumran near the southwest coast of the Dead Sea that was defended by the Jews from A.D. 72 to 73 in a last stand against the Romans. Fragments of 14 scrolls were discovered. One is a manuscript called Songs of the Sabbath Sacrifice, a work that was also found at Qumran.

To Golb the discoveries of manuscripts in the Judean wilderness, including those found near Khirbat Qumran, imply an effort by the Jews in the first century to preserve the religious and other literature of Jerusalem at a time of subjugation by the Romans. "The surmise is reasonable," he writes, "that those charged with hiding artifacts of importance would have sought to do so in areas not yet controlled by the Romans; but by the summer of A.D. 68 the only such territory was that portion of Judea lying to the east and south of [Jerusalem]—that area, in other words, where Hebrew scrolls were discovered in the third, eighth and 20th centuries."

The Functioning of Blood Platelets

These small bodies act to stop the flow of blood from a wound. The interactions of their contents with substances in the blood plasma and in tissue play complex roles in health and disease

by Marjorie B. Zucker

In a smear of human blood viewed under the light microscope one sees smoothly discoid red blood cells, a variety of gaudily stained white cells and perhaps some rather unprepossessing little bits of granular matter: platelets, the smallest formed elements of the blood. The red cells transport oxygen; the white cells function in various ways to protect the body against foreign substances and to dispose of cellular debris. The platelets play a central role in hemostasis: the stoppage of blood flow. They clump together to form a plug that temporarily seals any break in a blood vessel. And substances in the platelets and on their surface contribute, along with many other substances in the blood plasma and the blood-vessel wall, to the intricately orchestrated formation of a permanent plug—or, under different circumstances, to the formation of a thrombus that can obstruct circulation and cause a heart attack or a stroke.

Where the existence and some of the functions of the red and white cells were recognized in the early days of microscopy, the very existence of platelets was not firmly established until near the end of the 19th century. It was soon clear that they were implicated in hemostasis and blood clotting, but their fundamental role in the process came to be understood only in the late 1940's and the 1950's [see "Blood Platelets," by Marjorie B. Zucker; SCIENTIFIC AMERICAN, February, 1961]. Since then much has been learned about the physiological and biochemical details of platelet function and about what goes wrong when platelets either fail to do their job or do it too well, at the wrong site.

Platelets and Their Contents

If some fresh blood is mixed with an anticoagulant to keep it from clotting and is allowed to settle, a little more than half of it is found to be plasma, a yellowish, protein-rich liquid. Most of the rest is accounted for by red blood cells; the white cells and the platelets together make up only 1 or 2 percent of the volume. Every cubic millimeter of blood contains about a quarter of a billion platelets (compared with only some 7,000 white cells), so that there are about a trillion platelets in the blood of an average woman with four liters (a little more than four quarts) of blood. Platelets are not cells; they are fragments of the giant bone-marrow cells called megakaryocytes. As each megakaryocyte matures, its cytoplasm (the material outside the cell nucleus) breaks up to form several thousand platelets, which are roughly disk-shaped objects about half or a third the diameter of a red cell but with only about a thirteenth of its volume.

Lacking nuclei, platelets have no DNA and very little ability to synthesize proteins; once they are released from the marrow they age slowly in the circulation and die in about 10 days, if they are not consumed before that in the line of duty. Yet they have an active metabolism, carried out by enzymes in the cytoplasm and the intracellular organelles known as mitochondria, that supplies the energy required for their functions.

When platelets are seen in a stained blood smear under the light microscope, they look grainy, and the electron microscope reveals a variety of well-defined organelles. A circumferential band of long microtubules just inside the external membrane serves as a skeletal frame that maintains the roughly discoid shape. There are numerous open vesicles, or membranous channels, some of which are connected with one another and with the surface of the platelet, much like the channels of a sponge, to form what is called the surface-connected system. In addition to the mitochondria and small accumulations of glycogen (the storage form of the sugar glucose), several other kinds of granules are visible. These are membrane-enclosed sacs whose contents are secreted when platelets are stimulated.

The various types of granules can be separated by disrupting the outer membranes of platelets carefully and subjecting the resulting suspension of organelles to centrifugation in a sucrose density gradient: a tube containing a sucrose solution that is increasingly concentrated at successively lower levels. The various granules move toward the bottom of the tube until they reach a level at which the sucrose density matches their own; there they stop, so that the heaviest granules are at the bottom of the tube, the fragments of the outer membrane are near the top and other components are fairly well segregated into bands between the top and the bottom. Each band can be examined by electron microscopy and chemical analysis.

The granules that look densest in micrographs turn out to be the heaviest ones. They contain a concentrated mixture of the amine serotonin, calcium and two adenine nucleotides: adenosine diphosphate (ADP) and adenosine triphosphate (ATP). The last two do not take part in metabolic activity as do the ADP and ATP in the cytoplasm of most cells (and of platelets); they do not exchange with the nucleotides in platelet cytoplasm and granule calcium does not exchange with the cytoplasmic calcium. Nor does the granules' serotonin (which is synthesized by cells in the wall of the intestine and is taken up from the circulating blood through the platelet's outer membrane) exchange with the serotonin that is a major chemical transmitter in the brain.

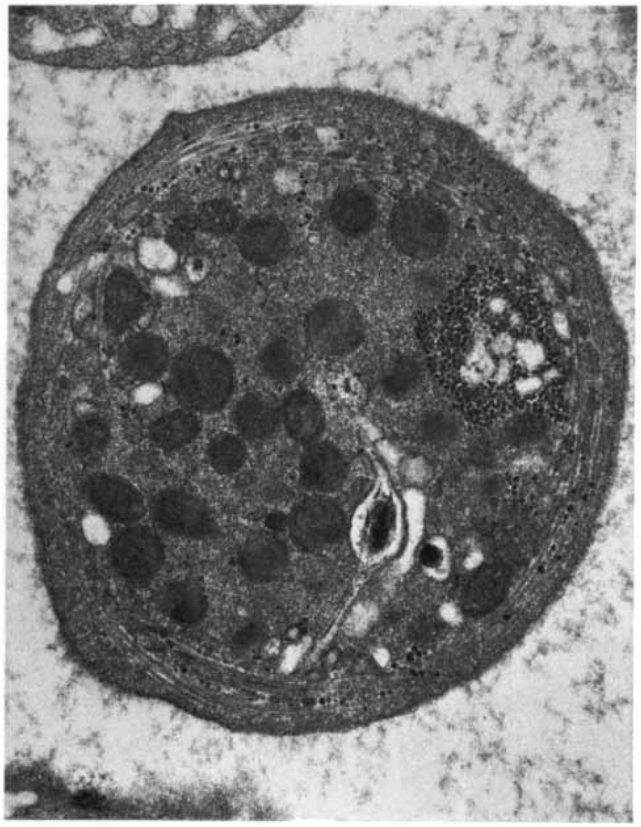
The alpha granules, lighter and more numerous than the dense ones, contain a variety of proteins, which are probably synthesized in the megakaryocytes. Some of these proteins are found only in platelets. They include platelet factor 4, which counteracts the anticoagulant agent heparin, and a potent growth stimulant called platelet-derived growth factor. Others are similar to—or perhaps identical with—plasma proteins that are active in the clotting process, such as fibrinogen and an agent called factor V. Platelets also have a third kind of granule: lysosomes, which are found in most

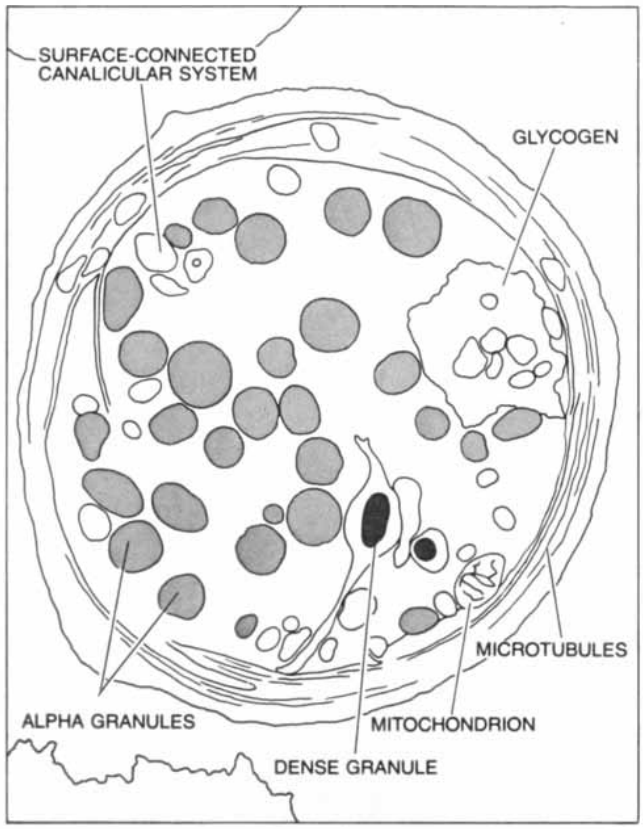
cells and contain enzymes that break up proteins and complex carbohydrates.

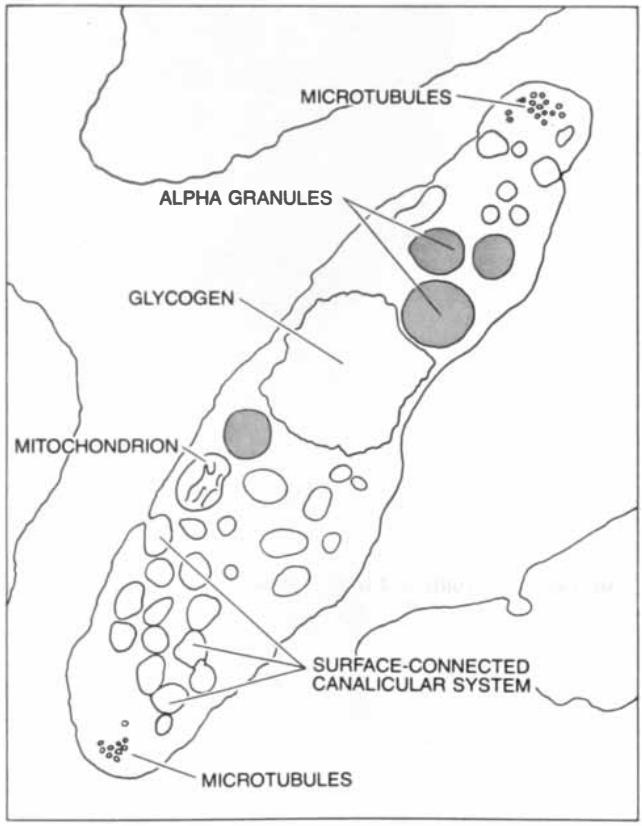
Hemostasis

Platelets contain more of the contractile protein actomyosin than any cells other than true muscle cells, and they contract somewhat as muscles do. Their contractile activity is most apparent in the test-tube process of clot retraction. Fresh blood put in a tube clots in about 10 minutes to become a red, jellylike mass. Then, for an hour or so, the clot becomes smaller and serum, a clear yellow liquid, is extruded. The fraction of the blood that actually solidifies to form a clot is the plasma protein fibrinogen. It is converted by the enzyme thrombin into strands of fibrin, which form a web that traps platelets and blood cells; trapped red cells form the bulk of the mass and make it red. The trapped platelets are stimulated, also by the thrombin, to contract, and in contracting they pull together the fibrin strands to which they have adhered, forcing out the serum (plasma minus fibrinogen). This process of clot retraction is dramatic as a test-tube demonstration, but it has no precise counterpart within the body. Holes in blood vessels are plugged not by fibrin and

PLATELET BLOCKS GAP in a capillary in this electron micrograph made by Hans R. Baumgartner of F. Hoffmann–La Roche & Co. in Basel. The cross section, which shows sections of four red blood cells as well as the platelet, is enlarged 13,000 diameters. The capillary had been artificially dilated, so that two of the thin endothelial cells lining it separated (*bottom*), exposing the subendothelium to the blood. Platelets, which do not adhere to the endothelial lining of a blood vessel, do adhere to collagen, a constituent of subendothelium. A single platelet has done that here, blocking the gap. In the absence of platelets the leakage of blood between endothelial cells in very small blood vessels such as this one can produce pinhead-size hemorrhagic spots called petechiae in the skin. Breaks in larger blood vessels, which have much thicker walls than this capillary has, are plugged by an aggregation of large numbers of platelets (*see illustration on page 96*).





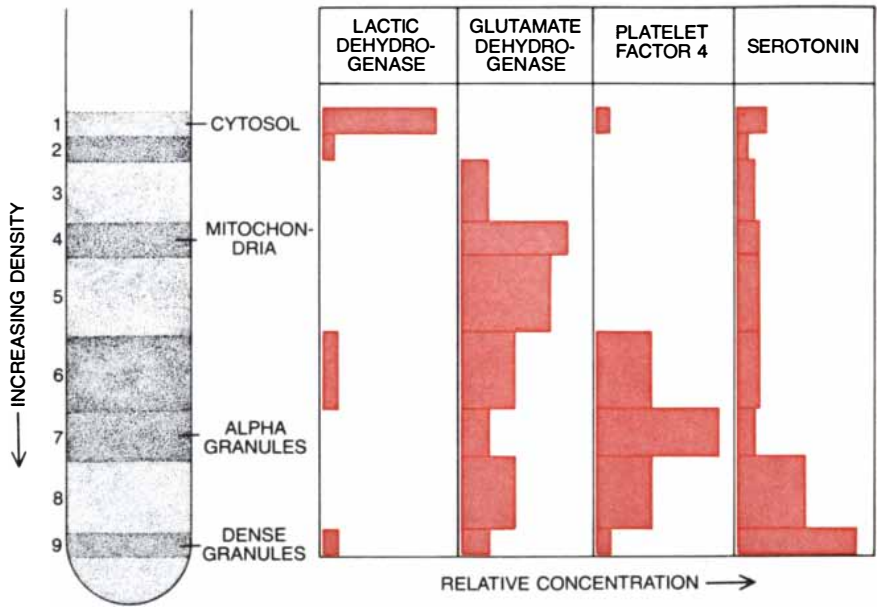


PLATELET GRANULES and other structures are prominently displayed in electron micrographs made by James G. White of the University of Minnesota Medical School and are identified in the drawings. The two sections, in different planes of the disk-shaped platelets, are enlarged about 30,000 diameters. Some of the open vesicles form a surface-connected system. Microtubules frame the disk. The mitochondria are energy-transducing organelles; glycogen, a storage form of glucose, is a source of energy. The dense granules and alpha granules contain various substances that are secreted when platelets are stimulated and that promote the formation of platelet plugs.

red cells but by a mass of platelets without red cells.

Intact blood vessels have a continuous thin lining of overlapping endothelial cells, so that during normal blood flow the platelets do not come in contact with the blood-vessel wall itself. When a vessel is cut, blood flows out through the wall, one of whose constituents is collagen, the insoluble fibrous protein that accounts for much of the body's connective tissue. Platelets in the flowing blood adhere quickly to collagen, and then other passing platelets adhere to them; within a minute a hemostatic plug builds up. Next the contractile process demonstrated in test-tube clot retraction probably comes into play, compacting the platelet mass and extruding materials secreted by the platelets.

A second process is also at work. The cut blood-vessel wall (like other injured tissue) contains "tissue factor," which initiates blood clotting. The exposure of the blood to tissue factor sets in motion a complex series of reactions whereby the plasma protein prothrombin is converted into thrombin. As in the test-tube demonstration, the thrombin in turn converts fibrinogen into fibrin. The fibrin formed at the site of the injury supports and reinforces the platelets in the hemostatic plug, and it also solidifies blood that remains in the wound channel. In what follows, however, I shall be dealing largely with platelet function and the platelet plug rather than with the overall process of clotting.



GRANULES and other platelet fractions are separated from one another by centrifugation in a sucrose density gradient, in which increasingly dense material collects in bands at successively lower levels in the tube (*left*). The major component of four of the levels, determined by electron microscopy, is indicated. The four columns of horizontal bars show the relative concentrations of four chemical constituents of platelets at each level. Lactic dehydrogenase, an enzyme found in cytoplasm, is concentrated in the liquid supernatant; glutamate dehydrogenase is a mitochondrial enzyme. Platelet factor 4 is in alpha granules, serotonin in dense granules. Data are from studies done by M. J. Broekman, N. P. Westmoreland, P. Cohen and K. L. Kaplan.

Platelet Aggregation

Thrombin has a dual action in hemostasis. In addition to converting fibrinogen into fibrin it makes platelets sticky. The exposure of platelets to collagen and thrombin causes the platelets to aggregate and plug the hole in the blood vessel. The process of platelet aggregation can be investigated with a simple device called an aggregometer. Platelet-rich plasma is prepared by centrifuging blood gently (with an anticoagulant added) to remove the red and white cells, leaving the lighter platelets suspended in the plasma. A tube of the platelet-rich plasma is placed in the path of a beam of light and is stirred, so that the diffuse cloud of tiny platelets scatters the light and prevents much of it from reaching a photocell on the other side of the transparent tube. When an aggregating agent is added, the platelets clump together, allowing more light to pass through the suspension. A tracing of the amount of light reaching the photocell provides a continuous record of the course of platelet aggregation.

If a suspension of finely ground collagen is added to stirred platelet-rich plasma, there is no effect for a minute or so and then aggregation begins. The initial event is an interaction between some specific sites on the collagen molecule and specific glycoproteins (sugar-protein molecules) on the platelet surface, resulting in the adhesion of the platelets to collagen. This sets in motion poorly understood events in the membrane that culminate in the secretion of the contents of the dense granules and the alpha granules; the granules' contents can be found in the plasma, and examination of the platelets shows they have lost their granules.

One of the components of granules, ADP, is a potent aggregating agent: purified ADP added to a suspension in a concentration as low as one micromolar initiates aggregation within seconds, and the concentration of released ADP in a suspension to which collagen has been added can reach from five to 10 micromolar. Apparently, then, the secretion of ADP is largely (perhaps entirely) responsible for the aggregation caused by collagen; the time required for secretion explains the lag between the addition of collagen and the onset of aggregation.

The initial response of platelets stimulated by ADP is a change in shape. Long processes protrude from the rim of the platelet and then the disk becomes fatter, until it looks like an irregular, spiny sphere. At the same time specific receptors for fibrinogen appear on the platelet surface; their presence can be demonstrated by the ability of ADP-stimulated platelets to bind radioactively labeled fibrinogen. ADP leads to aggregation only in the presence of fibrinogen, which is, of course, in normal plasma; manipulating the medium in certain ways prevents not only ADP-dependent aggregation but also the binding of fibrinogen. This suggests that fibrinogen serves as a kind of glue binding platelets to one another. It is well suited for such a purpose because it is a dimer (a double molecule), and perhaps each half of it can bind to a different platelet. ADP does not permanently alter the platelet surface; if it is removed, the platelets release their bound fibrinogen and disaggregate, and then they can be stimulated all over again.

Secretion

Thrombin stimulates aggregation directly, as ADP does, and it also stimulates secretion. If a low concentration of thrombin is added to platelet-rich plasma, aggregation takes place in two phases: moderately in about 10 seconds and then more vigorously in about a minute. The first wave is caused by thrombin itself, the second wave by secreted ADP. Thrombin stimulates platelets by interacting with a particular surface glycoprotein and cleaving it. Again fibrinogen is probably the final glue, but in the case of thrombin stimulation it can be fibrinogen secreted from the platelet granules; fibrinogen need not be present initially in the medium.

There are apparently two pathways

leading to secretion, only one of which has so far been worked out. Stimulation by adhesion to collagen or by thrombin liberates arachidonic acid, a fatty acid present in the platelet membrane, which is quickly converted into compounds called endoperoxides; these in turn are converted into thromboxane A_2, which is the actual stimulus for secretion. Aspirin and some other anti-inflammatory drugs can block the conversion of arachidonic acid into thromboxane A_2. The stimulation of platelets from the blood of a person who has taken aspirin therefore results in an abnormal aggregation response: collagen induces far less aggregation, and low concentrations of thrombin induce only the first (direct) phase. The existence of a second secretory mechanism is indicated by the fact that stronger stimulation of aspirin-treated platelets, by either collagen or thrombin, leads to some secretion even though no thromboxane A_2 is formed.

Platelet secretion and platelet aggregation work together in hemostasis. The adhesion of platelets to collagen in the cut blood-vessel wall causes the platelets to secrete ADP, which stimulates aggregation. Passing platelets adhere to those already bound to the collagen. Serotonin, secreted from the dense granules, is a weak aggregating agent and also a vasoconstrictor that narrows the blood vessels locally, whether they are cut or intact, and thereby helps to restrict bleeding. Fibrinogen, a necessary cofactor for aggregation, is present in the plasma and is also secreted from the alpha granules; some fibrinogen is converted into fibrin by thrombin. Factor V, which helps to convert prothrombin into thrombin, is present in plasma, but it is probably secreted from the alpha granules in a more active form; it adheres to the platelet surface to promote the local generation of more thrombin. Substances in the blood-vessel wall, in the plasma and both on and in the platelets themselves thus act together to form the solid plug that arrests bleeding.

Abnormal Platelet Function

What is the role of these various processes in the prevention of hemorrhage? One way to find out is to test the "bleeding time" either of normal individuals to whom drugs altering platelet function have been administered or of individuals who have particular platelet defects as a result of a congenital disorder. The test is done by elevating the blood pressure in the small vessels (by partially inflating a cuff on the upper arm) and then making several tiny cuts on the forearm. The drops of blood are removed every 30 seconds without touching the cut. Normally bleeding stops within six minutes, but if platelet function is abnormal, the bleeding may continue until it is stopped by the application of direct pressure.

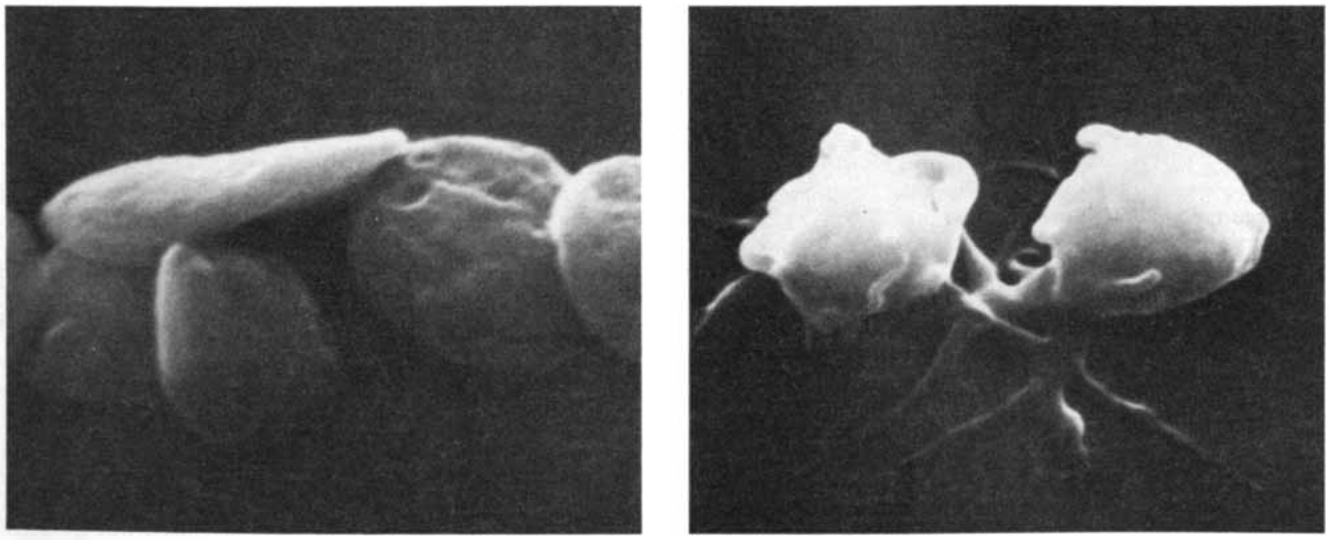
The fundamental need for platelets is clear: patients with a low platelet count, or thrombocytopenia (thrombocyte is an older term for platelets), have a long bleeding time. They also bleed excessively after minor injuries or spontaneously, particularly from the mucous membranes. Thrombocytopenia can be caused by defective platelet production in the bone marrow, either congenital or resulting from leukemia, aplastic anemia or chemotherapy for cancer. Occasionally, however, an individual makes antibodies to his own platelets, so that they are destroyed almost as fast as they are made. Because the disease is idiopathic (of unknown cause) and because its major symptom is purpura, or little punctate hemorrhages (petechiae) and bruises in the skin, the disorder is known as idiopathic thrombocytopenic purpura, or ITP.

Certain albinos have a congenital absence of dense granules in their platelets; this condition, known as storage-pool disease, also results in a long bleeding time. The ingestion of aspirin, which interrupts the secretion pathway, prolongs the bleeding time slightly (although it does not cause other excessive bleeding in normal individuals). These two observations indicate that secretion by platelets is important for hemostasis. Patients with the rare hemorrhagic disorder known as thrombasthenia have an excessive bleeding time; their platelets cannot be aggregated at all by collagen, thrombin or ADP and also fail to bind fibrinogen. People with a congenital lack of fibrinogen, a very rare disorder, also have a long bleeding time, and so the essential role of fibrinogen in aggregation is clear.

Surprisingly, patients with certain clotting disorders such as hemophilia do not have a long bleeding time even though they have frequent severe hemorrhages spontaneously or after such minor traumas as a tooth extraction or a bump. Hemophilia results from the lack of antihemophilic factor, a plasma protein that is essential, along with other factors, for the main pathway that converts prothrombin into thrombin. Because the mechanism for thrombin generation that is initiated by tissue factor does not require antihemophilic factor it apparently provides enough thrombin to stop bleeding from the small injury administered to test the bleeding time.

Von Willebrand's Disease

Other patients with a long bleeding time suffer from the hereditary condi-



PLATELETS CHANGE SHAPE when they are exposed to ADP, a nucleotide liberated from the dense granules. Fresh platelets are rather smooth, flat disks, as is seen in a scanning electron micrograph (*left*) made by White. After treatment with ADP long processes protrude from the platelet, which swells to become an irregular "spiny sphere"; the processes adhere to a surface (*right*) or to other platelets.

Win the JAMESON Father's Day Sweepstakes

15 Grand Prizes to Ireland on Aer Lingus

You can be one of the big Jameson Irish Whiskey prize winners. Send your Father on a once-in-a-lifetime trip (for two) to Ireland. One of 15 truly grand prizes with the kind of special treatment every father deserves.

Your Dad will fly Aer Lingus—Ireland's quality international airline. He'll get $1,000 in "green" to spread around the Emerald Isle. He'll have the time of his life.

PLUS 500 OTHER PRIZES

500 lucky runners-up will win an elegant set of six imported cut glass crystal "On the Rocks" glasses. (The perfect complement for those drinkers of fine Scotch who prefer the lighter, more delicate taste of Imported Jameson Irish Whiskey.)

To enter, just fill in your Father's name and address below and answer the questions which appear on the coupon. (NOTE: You'll find all the answers appearing on the Jameson label in your liquor cabinet, at your liquor store, favorite bar or restaurant.) It couldn't be easier. Enter today and make your Dad a bigger winner than he already is.

Jameson—World's largest selling Irish Whiskey.

OFFICIAL RULES

1. On entry form, or a 3" x 5" piece of paper, print your name, address and zip code. Then, answer the 3 questions with information found on the front label of any bottle of Jameson Irish Whiskey. If you don't own a bottle, visit your favorite restaurant or tavern, or go to any participating liquor store and look at a bottle of Jameson.

2. Enter as often as you wish, but each entry must be properly completed, addressed and mailed in a separate envelope and received by September 30, 1980 to be eligible. Prize winners will be determined in a witnessed random drawing of correct entries by Siebel/Mohr Incorporated, an independent judging organization whose decisions are final. No purchase required.

3. Each grand prize winner will receive 2 round trip economy tickets to Ireland on Aer Lingus plus $1,000 cash. It's incumbent upon winners to make their own arrangements for the trip. Winners shall depart from the normal Aer Lingus departure points within the Continental U.S.A. Any additional expenses incurred on the trip will be borne by the winners. Trips must be taken by December 31, 1981. Any necessary taxes must be paid by winners. The 500 second prize winners will receive an elegant set of six imported cut glass crystal "On the rocks" glasses. Prizes are non-transferrable and non-redeemable.

4. Only one prize per family or household. The odds of winning will be determined by the number of correct entries received. All prizes will be awarded.

5. Sweepstakes open to residents of the Continental U.S.A., Alaska and Hawaii. Employees and their families of Calvert Distillers Company and Aer Lingus, their affiliated and subsidiary companies, liquor wholesalers and retailers, their advertising agencies and judging organization, are not eligible. Sweepstakes void where prohibited or restricted by law. All federal, state and local laws apply.

6. Entrants must be of legal drinking age under the laws of their home state.

7. A list of all major winners can be acquired at the conclusion of the sweepstakes by sending a stamped, self-addressed envelope to Jameson Irish Sweepstakes, P.O. Box 8247, St. Paul, Minnesota 55182. NO PURCHASE REQUIRED

JAMESON IRISH SWEEPSTAKES

I have read the contest rules listed on this page, and would like to enter the Jameson Irish Sweepstakes. My answers are written below (correct answers appear on the front label of each Jameson bottle).

1. What year appears on the Jameson label?_____

2. What Dublin street name appears on the Jameson label?_____

3. What is the motto under the Jameson coat of arms?_____

My Dad's Name (please print)*_____

My Dad's Address_____

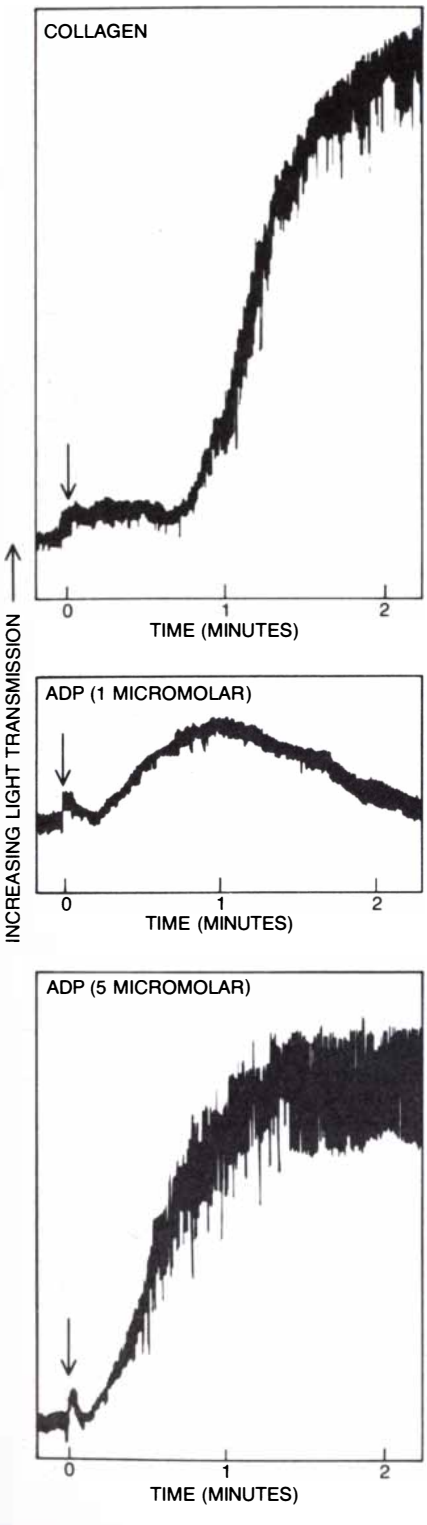
City_____ State_____ Zip_____

Mail Entries to: **JAMESON FATHER'S DAY IRISH SWEEPSTAKES P.O. BOX 8238, ST. PAUL, MINNESOTA 55182**

* NOTE: Remember, Father's Day is also for Grandfathers.

For additional information on travel to Ireland, call Aer Lingus—toll free (see your local directory).

Jameson. World's Largest Selling Irish Whiskey. 80 PROOF · CALVERT DISTILLERS CO. N.Y.C.



AGGREGOMETER TRACINGS record the aggregation of platelets in platelet-rich plasma in response to an aggregating agent, in these cases collagen and two concentrations of ADP. The initial increase in light transmission is due to dilution by the agent, the small downward deflection to a change in platelet shape and the subsequent increase to aggregation. With collagen there is a lag before ADP is secreted by the platelets to cause aggregation; when ADP is supplied directly, effect is faster. The effect of a low concentration of ADP is reversed as enzymes destroy ADP.

tion called von Willebrand's disease. In these patients the activity of two plasma proteins, antihemophilic factor and von Willebrand factor (which may normally be linked), is low; it is the latter factor that is necessary for a normal bleeding time. Its role was difficult to understand because the platelets of von Willebrand patients aggregate normally in the test tube in the presence of ADP, collagen and thrombin.

A test developed by Hans R. Baumgartner, Harvey J. Weiss and Thomas Tschopp, who have worked together at the Hoffmann–La Roche laboratory in Basel and at Roosevelt Hospital in New York, has helped to elucidate the interaction of platelets with the blood-vessel wall in von Willebrand patients and others. Blood is circulated past rings cut from rabbit arteries whose endothelial cells have been removed to expose the thin subendothelium, which includes what appears to be a special form of collagen. When the rings are perfused with normal blood, the subendothelium is carpeted with platelets in a few minutes. Many of the platelets spread out and are degranulated: they have secreted the contents of their granules. Small aggregates of platelets accumulate at intervals along the wall.

What the platelets adhere to is the collagen, and under various conditions the response is much as it is in aggregometer studies. For example, the aggregates fail to form when the artery samples are perfused with aspirin-treated or thrombasthenic blood. The Baumgartner perfusion system reveals, however, a requirement for von Willebrand factor that is not evident in aggregometer studies: the factor must be present in the plasma for platelets to adhere normally to the special collagen just below the endothelial cells. It is still not clear why von Willebrand factor seems to be needed only when blood is moving past the blood-vessel wall at a rather high rate and whether it is necessary for adhesion to subendothelium because of some peculiarity in the collagen there. The factor is present in endothelial cells and platelets and also in the blood plasma, which seems to be the important source in hemostasis.

Further evidence of the importance of von Willebrand factor comes from the study of another congenital disorder, the Bernard-Soulier giant-platelet syndrome. In these patients the very large platelets fail to adhere to the subendothelium of perfused artery rings or to clump in the presence of von Willebrand factor; the receptor for the factor is missing.

Platelet Pathology

The mistakes of nature manifested in storage-pool disease, thrombasthenia and Bernard-Soulier syndrome provide information on the mechanisms of normal platelet function. For example, the absence of dense granules in the platelets in storage-pool disease can be correlated with the low levels in those platelets of adenine nucleotides and serotonin. The impaired aggregation of storage-pool-deficient platelets in the presence of collagen and the prolonged bleeding time in storage-pool patients demonstrate, in turn, that the contents of the dense granules are important for normal hemostasis. (Rare patients with the "gray-platelet syndrome" lack alpha granules. Studies of the physiology of their platelets are under way and should clarify the role of these granules' contents.)

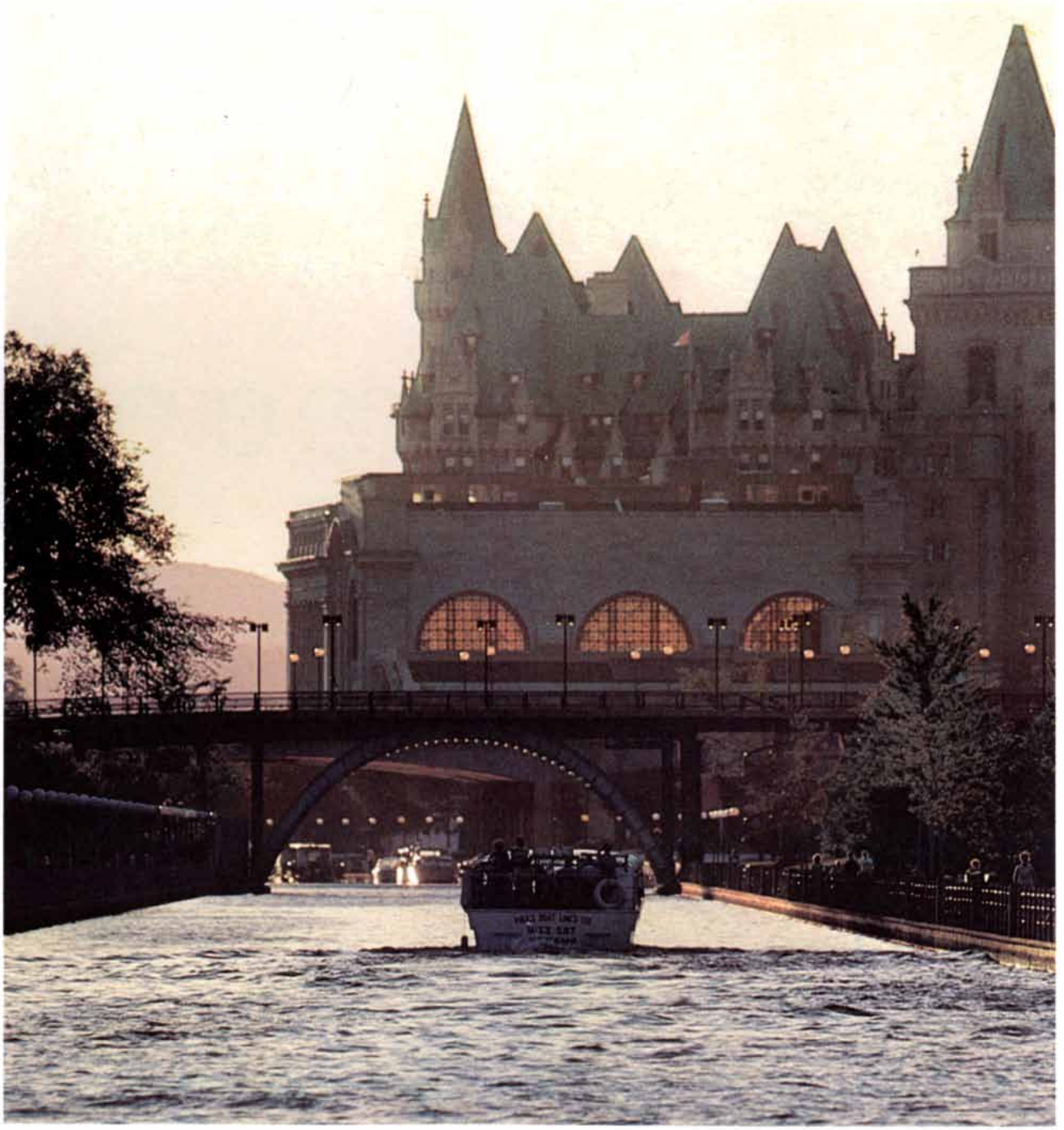
In thrombasthenia and the Bernard-Soulier syndrome the defects are in glycoproteins exposed on the platelet's surface. The membrane proteins can be separated into different bands on a gel by electrophoresis, and special stains for carbohydrates identify the glycoproteins. Proteins exposed on the surface can be distinguished by reacting intact platelets with a radioactive isotope in a compound that cannot penetrate the membrane but that becomes attached to it. When the platelets are broken and subjected to electrophoresis, radioactivity identifies the surface proteins. Normal platelets yield three major bands of surface glycoproteins designated in order of decreasing size GP I, GP II and GP III. (Each band is probably composed of several glycoproteins; investigators in a number of laboratories are now attempting to isolate and characterize the various molecules.)

Gels prepared with thrombasthenic platelets show abnormally small bands for GP II and GP III. Congenital disorders usually involve only one gene and hence one protein, so that it was surprising to find apparent deficiencies in two proteins, but some recent studies suggest that the separation is an artifact and that only one protein may be deficient. Perhaps it will prove to be the fibrinogen receptor, since thrombasthenic platelets neither aggregate nor bind fibrinogen. In the Bernard-Soulier syndrome a portion of the GP I band is absent. It seems likely that the missing part is the receptor for von Willebrand factor, with which these platelets do not react.

Therapy

Transfusion plays a major role in therapy for platelet disorders. Blood from donors is now commonly separated into a large number of fractions, each of which has its particular value: plasma for increasing the blood volume, red cells for treating anemia, particular plasma proteins for treating specific deficiency diseases (such as hemophilia or von Willebrand's disease) and so on. A difficulty in the case of platelets is that

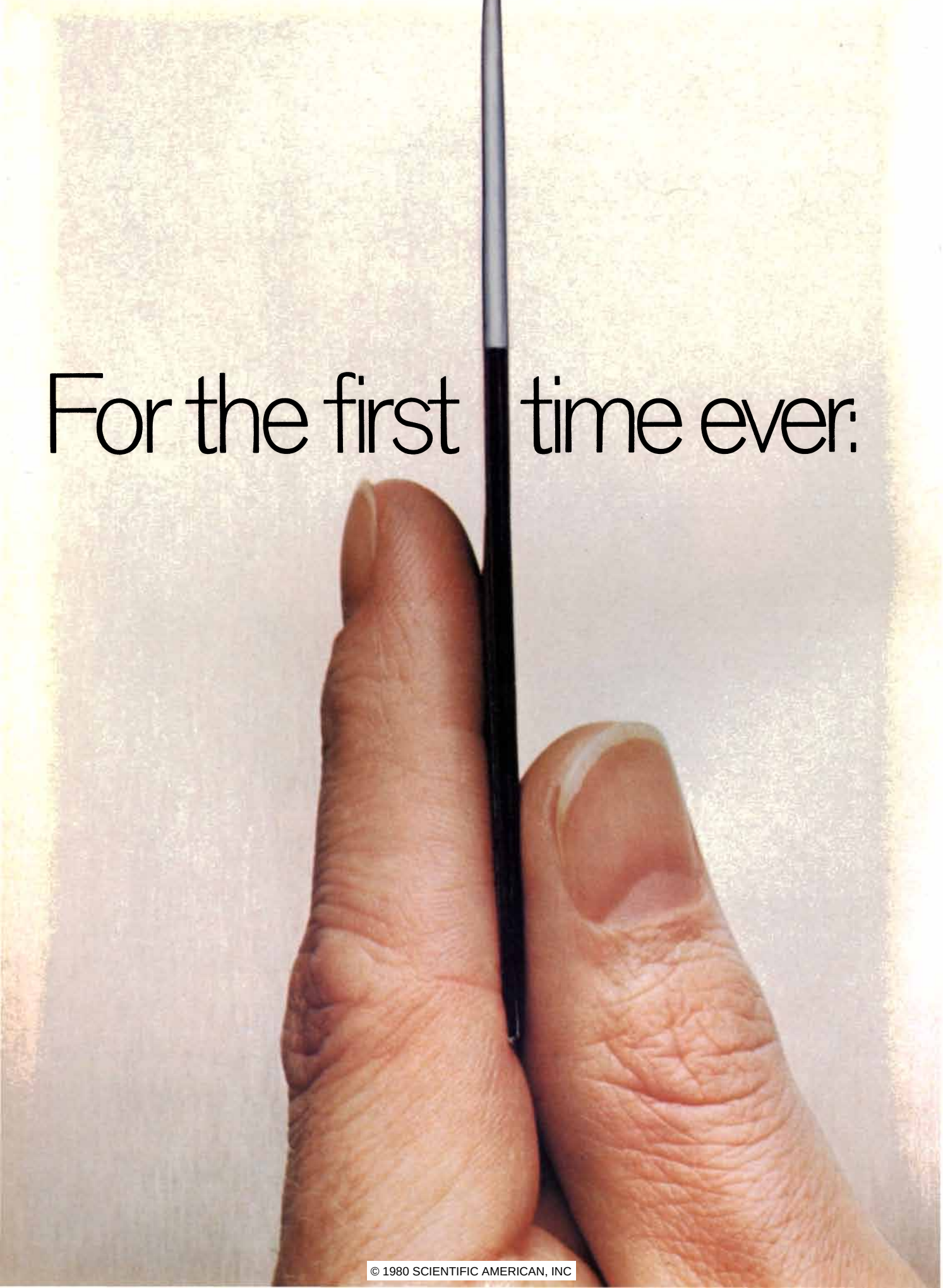
"capital sights"

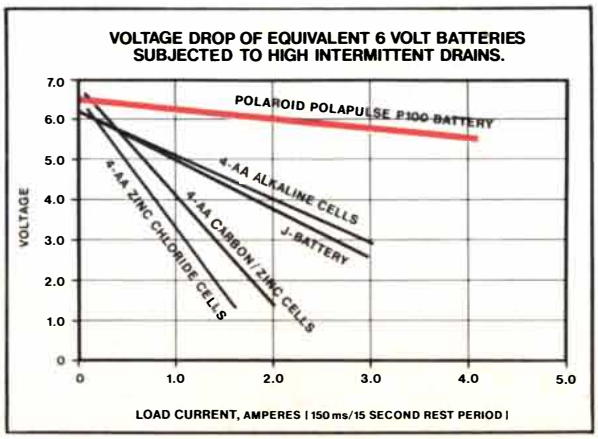


Savour the old world ambience of Ottawa, Canada's capital city, the splendours of our heritage in art, architecture, pomp, pageantry and spectacular Changing the Guard ceremonials on Parliament Hill. The pleasures of riverside parks and promenades, canals and winding waterways, bicycle paths and garden walks – yours to discover this summer in Ottawa, Ontario/Canada.

Call us COLLECT (416) 965-4008 or write: Ontario Travel, Dept. C.S., Queen's Park, Toronto M7A 2E5.

ONTARIO
yours to discover!





a wafer-thin battery with high surge capacity.

The battery technology that was a major factor in making the Polaroid SX-70 Land camera the world's finest instant camera is now available—in an even more advanced version—as a power source where thinness is an important design consideration.

The new Polapulse P100 is a six-volt battery that can accurately be described as a revolutionary development in commercial batteries. For while the P100 contains four unitized 1½-volt cells in one 3.73 x 3.06 inch package, it is only .18 inch thick and weighs less than an ounce.

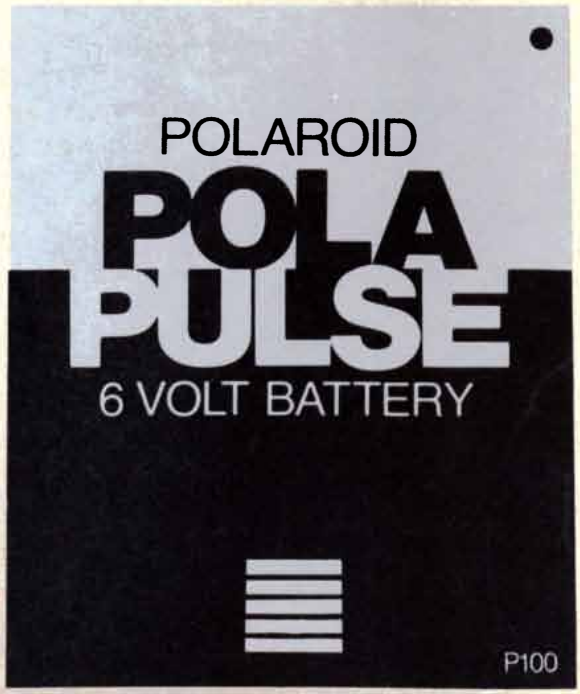
The Polaroid Polapulse battery behaves like an alkaline battery in its efficient use of chemical energy at low-drain rates—but is significantly superior at the high end. As you can see in the graph, the Polaroid Polapulse battery has remarkable high-drain performance. Due largely to the broad surface area of its electrodes, it has the capability to recover quickly after delivering large bursts of current. And in use, it is virtually impossible to accidentally reverse the polarity of this battery.

As a result of a unique seal combined with the Polapulse battery chemistry, no known leak damage has resulted from more than 300 million thin batteries in SX-70 film packs.

Obviously, the combination of power and compactness offered by the Polapulse battery goes a long way toward solving the problem of battery thickness as it affects product design. Calculators, electronic games, toys, remote controls and security devices are important applications, to mention but a few.

To help you determine the potential of this product as a power source for your designs, we will be happy to send you our Designer's Kit consisting of 5 Polapulse P100 batteries and molded battery holder with external connections. The price is $15.00* plus applicable state and local taxes. Technical characteristics and performance data are included.

Send requests for our brochure, and checks or money orders for the Designer's Kit, to: Polaroid Corporation, Commercial Battery Division, 784 Memorial Drive, Cambridge, Massachusetts 02139.



Battery shown actual size

Polaroid

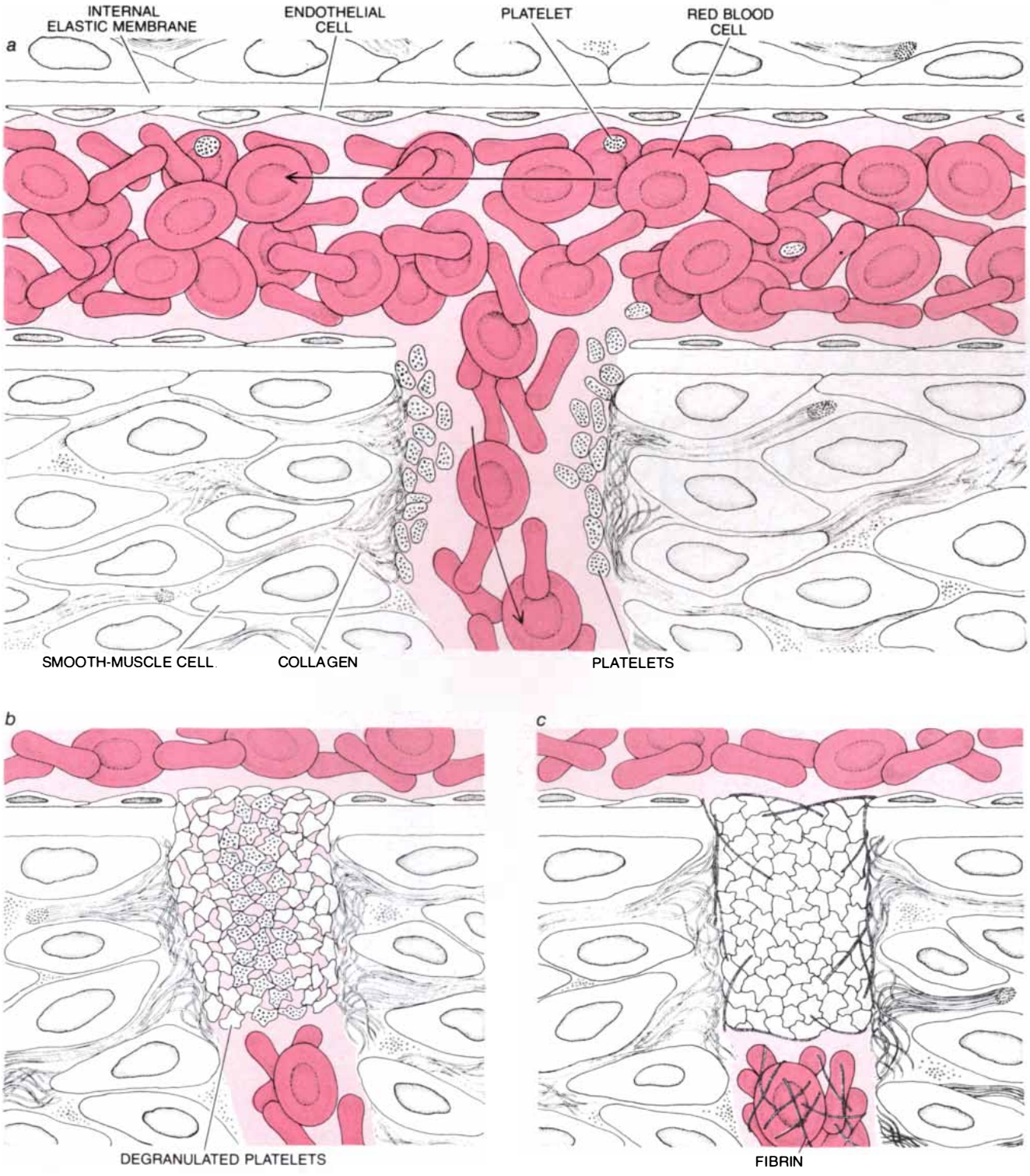
Our inventions can be your components.

Original battery design developed jointly by Polaroid Corporation and Ray-O-Vac Company.

*Price subject to change.

unlike red cells and plasma they cannot be stored for weeks; they must be transfused within a few days after donation. Moreover, a patient who needs many transfusions will develop antibodies against the foreign platelets if they are not of the same type as his own. Unfortunately platelets (like grafted tissues) are harder to match than red blood cells, which for most purposes can be typed simply as *Rh* positive or *Rh* negative and in the four groups *A, B, O* or *AB*. Platelets differ markedly from person to person, and platelets from a close relative of the patient are usually the most compatible.

Platelet transfusions are helpful when the platelet count is low, as it is in thrombocytopenia caused by defective platelet production, and also when the platelets are defective, as they are in the



ROLE OF PLATELETS IN HEMOSTASIS, or the stoppage of bleeding, is diagrammed. As blood begins to flow out through a cut in the vessel wall, platelets adhere to collagen in the wall (*a*). The platelets are thereby stimulated to secrete the contents of their granules, including ADP, and other passing platelets adhere to the first layer, building up a loose plug in the wound channel (*b*). Changes in the platelets and contact of blood with damaged cells convert the plasma protein prothrombin into the enzyme thrombin. The thrombin in turn converts fibrinogen into fibrin strands, which reinforce the platelet plug, and it also causes platelets to pack together more closely (*c*).

The 1980 Mazda RX-7 GS

Just one look is all it takes to appreciate the exceptional value of the Mazda RX-7 versus Datsun 280ZX or Porsche 924.

As remarkable as the Mazda RX-7 is on its own merits, it looks all the better when compared with the competition. Because the sleek, aerodynamic RX-7 is virtually everything you could want in a refined sports car—at an almost unbelievable price.

It can reach 0-50 in 6.3 seconds. Its inherently compact rotary engine is placed behind the front axle, for ideal weight distribution and superb handling.

In auto racing, a specially-prepared RX-7 won its class at the Daytona 24-hour race. Another RX-7 set a world speed record at Bonneville.

The smoothness of the rotary engine makes the RX-7 a quiet sports car. All this performance from a car that can attain excellent gas mileage on the open road.

17 EST. mpg 28 EST. hwy mpg**

But the front mid-engine RX-7 offers infinitely more than performance. It also provides extraordinary comfort.

So if you know what you want in a sports car, and you don't want to pay a king's ransom to get it, take a look at the RX-7 GS or S Model. The beautifully-styled, high-mileage, high-performance sports cars from Mazda.

You're also going to like the looks of RX-7 GS standard features.

• AM/FM stereo radio with power antenna • Side-window demisters • Cut-pile carpeting • Tinted glass • 5-speed • Tachometer • Styled steel wheels • Steel-belted radial tires • Front and rear stabilizer bars • Ventilated front disc and finned rear drum brakes with power assist • Electric remote hatch release. 3-speed automatic transmission, air conditioning, aluminum wheels and sun roof available as options.

$8395*

*Manufacturer's suggested retail price for GS Model shown. S Model $7645. Slightly higher in California. Actual prices established by dealers. Taxes, license, freight, optional equipment and any other dealer charges are extra. (Wide alloy wheels shown $275-$295.) All prices subject to change without notice.

**EPA estimates for comparison purposes for GS Model with 5-spd. trans. The mileage you get may vary depending on how fast you drive, the weather, and trip length. The actual highway mileage will probably be less. California, 16 estimated mpg, 27 estimated highway mpg.

Mazda's rotary engine licensed by NSU-WANKEL.

mazda

The more you look, the more you like.

The J&B Serving Bar

It will serve Dad long past Father's Day.

Think of it as an appreciation of Dad. The J&B Serving Bar is made of hand-rubbed walnut, satin finished and protected with an alcohol resistant coating. The clear lucite holder with brass cradle will house your 1.75 liter J&B bottle. Antique brass handles make serving simple and, you can put handy bar implements in the utility drawer. Each Bar also comes with four fine Belgium crystal double old-fashioned glasses.

To order your Bar, enclose $39.95, plus state and local taxes (price does not include bottle of J&B Rare Scotch). Please add $3.00 for handling and mailing. Indicate the initials (maximum of 3 letters) to be engraved on the brass plate. Send to: J&B Serving Bar, P.O. Box 1379, Minneapolis, Minnesota 55440.

J&B RARE SCOTCH

Allow 6-8 weeks for delivery. Offer subject to discontinuation without notice. Offer good in the U.S.A. Void where prohibited by law.

86 Proof Blended Scotch Whisky. © 1980 The Paddington Corp. N.Y.

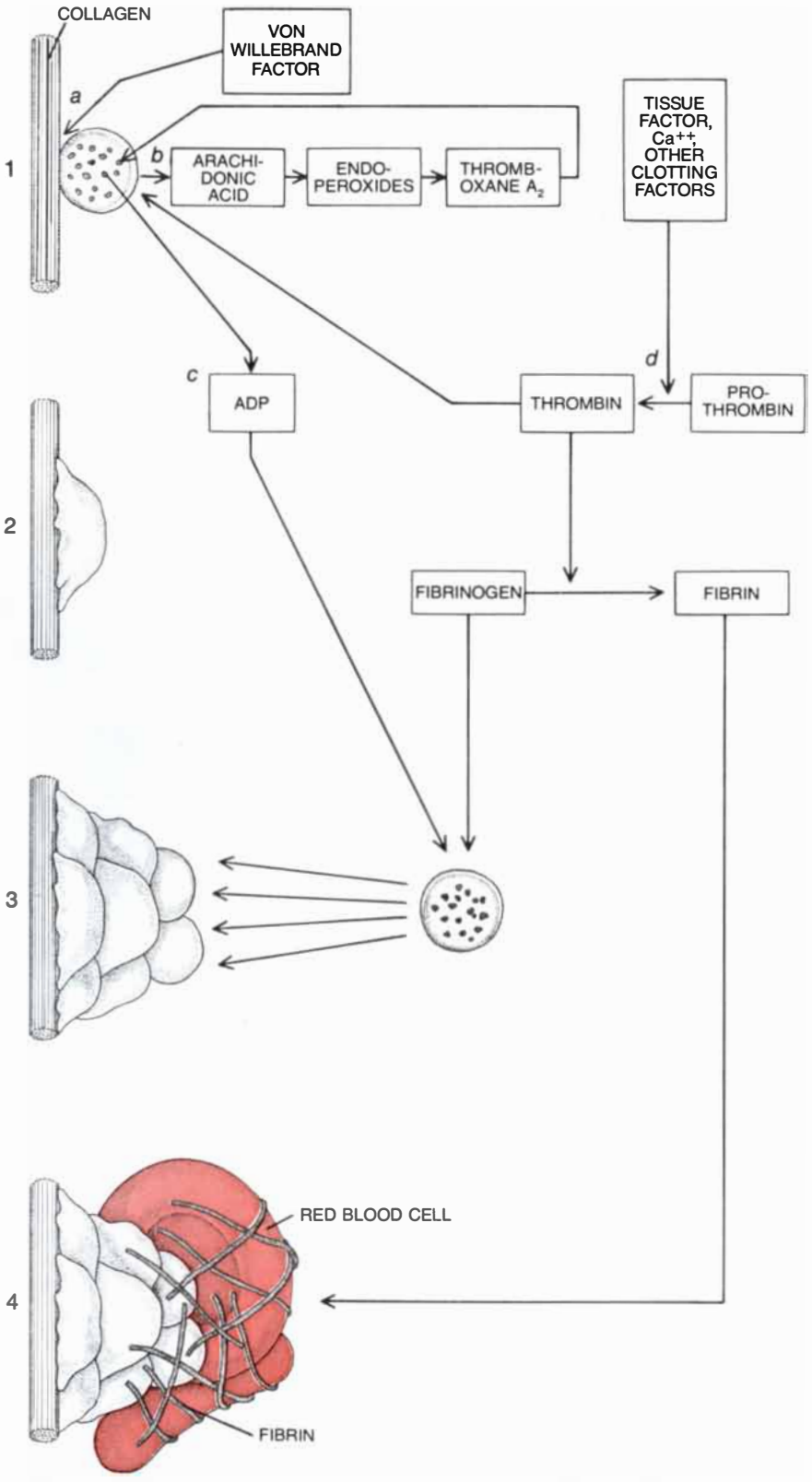
Bernard-Soulier syndrome. They are of little help in idiopathic thrombocytopenic purpura because the patients' antibodies destroy the foreign platelets as well as their own. Fortunately several immunosuppressive procedures are effective, including removal of the spleen and treatment with steroid drugs, and ITP patients usually recover.

Thrombosis

Because platelets can stick to one another and to the wall of a blood vessel and because they promote clotting they have a central role in the formation of thrombi, or intravascular clots, that impede the flow of blood. Thrombi often form in veins, particularly in elderly bedridden people who have undergone surgery. These venous thrombi can occlude a vein, but they are dangerous primarily for their tendency to break loose, becoming emboli that can be swept by the bloodstream through the heart and the pulmonary artery to lodge in and obstruct a small artery in the lung. Venous thrombi are composed of alternating layers of platelet masses and of strands of fibrin with entrapped red cells. Thrombi also form in arteries; they have a higher proportion of platelets and therefore look grayish rather than red. The occlusion of an artery by a thrombus is less well tolerated by the body than the occlusion of a vein, particularly when the artery is one that carries blood to a vital region such as the brain or the heart muscle.

The commonest cause of arterial thrombi is the disease known as arteriosclerosis or atherosclerosis, which is characterized by a marked thickening of the innermost layer of the artery: the intima. This is normally only a monolayer of endothelial cells and the thin subendothelium, bounded on the outside by the internal elastic membrane. In atherosclerosis the intima is invaded by smooth-muscle cells from beyond the membrane and becomes much thicker. As the disease progresses large fatty deposits form on the inside of the vessel wall, further narrowing the lumen (the bore of the artery). Atherosclerosis is the condition underlying most heart attacks. Large thrombi may form on the wall of a narrowed coronary artery, impeding or cutting off the blood flow; small thrombi may break off as emboli that lodge in a smaller artery downstream. Either kind of thrombus can block the blood supply and lead to myocardial infarction: the death of part of the heart muscle. Strokes, on the other hand, are often associated with atherosclerosis of the carotid arteries in the neck. Either a fixed thrombus or an embolus reduces the blood supply to part of the brain, often abruptly.

Within the past 15 years several groups of investigators, including J. F.



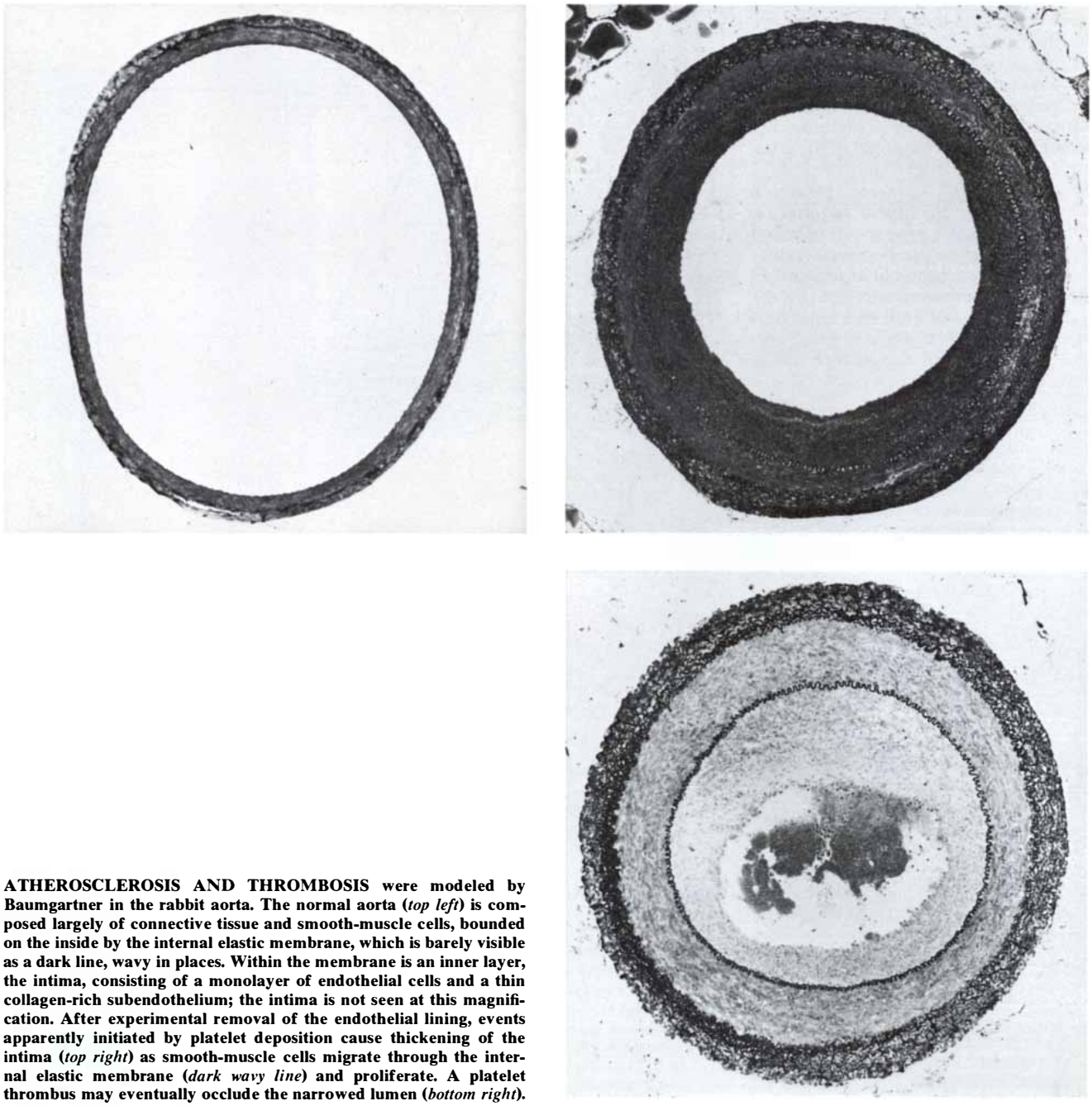
COMPLEX INTERACTIONS of platelets, platelet constituents and other substances involved in the formation of the hemostatic plug and of thrombi are still far from being understood; some of them are diagrammed here schematically. Contact of a platelet with collagen (*1*) in the presence of von Willebrand factor (*a*) initiates a pathway (*b*) that stimulates the secretion of ADP from the dense granules (*c*). The adhering platelet changes shape, spreads out along the collagen and degranulates (*2*). Meanwhile a number of steps involving tissue factor, calcium ions and other clotting factors convert prothrombin in the plasma into thrombin (*d*), which is also formed on the platelet surface. Thrombin too stimulates secretion, and it also converts fibrinogen (from the plasma and from platelets) into fibrin. Under the influence of collagen, ADP and thrombin, platelets aggregate (*3*). Strands of fibrin reinforce the plug. The process may stop at this stage or may go on to form a larger thrombus with trapped red blood cells (*4*).

Mustard's group at the McMaster University Medical Center and Russell Ross's group at the University of Washington School of Medicine, have provided considerable evidence that platelets are implicated in the development of the underlying atherosclerosis as well as in the formation of thrombi. The first pathological event is thought to be some injury to the endothelial cells. The injury may be mechanical, perhaps from the impact and turbulence of flowing blood, in particular at places where arteries branch. Or it may be biochemical. Carbon monoxide and other substances in city smog and cigarette smoke, dietary fats and hormones (such as adrenalin) produced by the body under stress all seem to contribute to the development of atherosclerosis, and they may do so by injuring endothelial cells so that they slough off and expose the underlying subendothelium.

Baumgartner has developed a rabbit-aorta system for studying both hemostasis and the genesis of atherosclerosis. The endothelial cells are removed from the vessel by introducing a balloon at the end of a catheter into the aorta of an anesthetized rabbit, inflating it and passing it through the vessel; the rabbit recovers quickly. Within a few minutes the aorta is lined with platelets. In a few days the intima begins to thicken as smooth-muscle cells migrate through gaps in the internal elastic membrane and undergo cell division, narrowing the lumen. The smooth-muscle cells, like normal endothelium, resist the adhesion of platelets and the development of thrombi. Theodore H. Spaet and Michael B. Stemerman of Montefiore Hospital in New York have shown, however, that repeated ballooning leads to more thickening. Perhaps repeated injury to the vessel lining does the same thing in human beings.

Platelets and Atherosclerosis

One critical stimulus for the migration and division of smooth-muscle cells may be the platelet-derived growth factor, one of the substances secreted from the alpha granules. Two observations in animals, as yet unconfirmed, provide evidence for some platelet role. Drastic re-



ATHEROSCLEROSIS AND THROMBOSIS were modeled by Baumgartner in the rabbit aorta. The normal aorta (*top left*) is composed largely of connective tissue and smooth-muscle cells, bounded on the inside by the internal elastic membrane, which is barely visible as a dark line, wavy in places. Within the membrane is an inner layer, the intima, consisting of a monolayer of endothelial cells and a thin collagen-rich subendothelium; the intima is not seen at this magnification. After experimental removal of the endothelial lining, events apparently initiated by platelet deposition cause thickening of the intima (*top right*) as smooth-muscle cells migrate through the internal elastic membrane (*dark wavy line*) and proliferate. A platelet thrombus may eventually occlude the narrowed lumen (*bottom right*).

The Sky is No Limit For a Creative Mind and a TRS-80™ Microcomputer!

Russ Genet of Fairborn, Ohio uses a TRS-80 Personal Computer for analysis of variable star photometric measurements. Several professional observatories regularly request the data he obtains from his home-built equipment.

Why did he choose a TRS-80? He writes: "My selection of the TRS-80 was not at all accidental. Every manufacturer of microcomputers was contacted . . . strongly considered was the availability of peripherals, service and software (and price of course). Computational power and ease of interfacing were important considerations. Color screens and fancy joysticks didn't carry much weight."

The TRS-80 gives Russ the mental leverage he needs for sophisticated data analysis. A TRS-80 at your fingertips will help turn your ideas into productive realities. You were wise to wait until the small-computer market sorted itself out. Now it's time to buy the winner—TRS-80!

Priced From $499

FOR MORE REASONS, SEND FOR OUR FREE COMPUTER CATALOG

Radio Shack, Dept. CMA-476
1300 One Tandy Center
Fort Worth, Texas 76102

Name _____

Title _____ Firm _____

Street _____

City _____ State _____

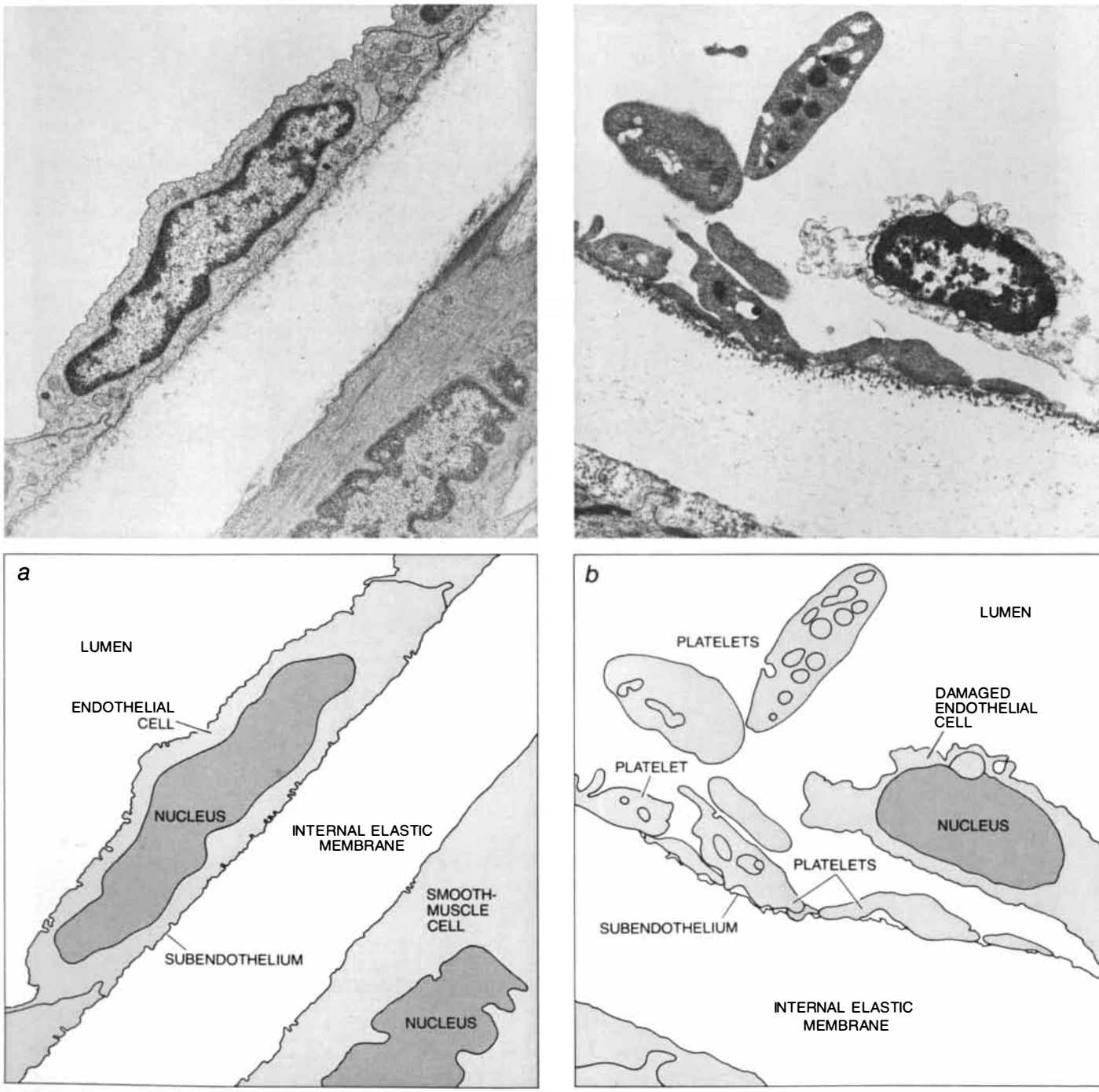
Zip _____ Phone _____

Radio Shack®
The biggest name in little computers

duction of a rabbit's platelet count before ballooning prevented subsequent thickening of the aortic wall. And a strain of pigs with severe von Willebrand's disease failed, unlike normal pigs, to develop experimental atherosclerosis when they were put on a diet high in cholesterol. The implication is that in the absence of von Willebrand factor their platelets did not adhere to the cholesterol-damaged arterial wall.

There is considerable evidence that platelets behave abnormally in individuals with severe atherosclerosis. One finding is that the platelets of some of these individuals have a shortened survival time. To measure the life span of platelets the platelets in a blood sample are incubated with radioactively labeled chromate, which labels them without affecting their function. The labeled platelets are reinjected. In normal subjects about a tenth of the labeled platelets (and therefore presumably of the unlabeled ones as well) disappear from the circulation daily, indicating that the normal survival time is about 10 days. In many people with severe atherosclerosis the platelet survival time averages only six or seven days. Presumably the platelets either adhere to the abnormally roughened arterial walls or are injured by contact with them and are removed from the circulation elsewhere.

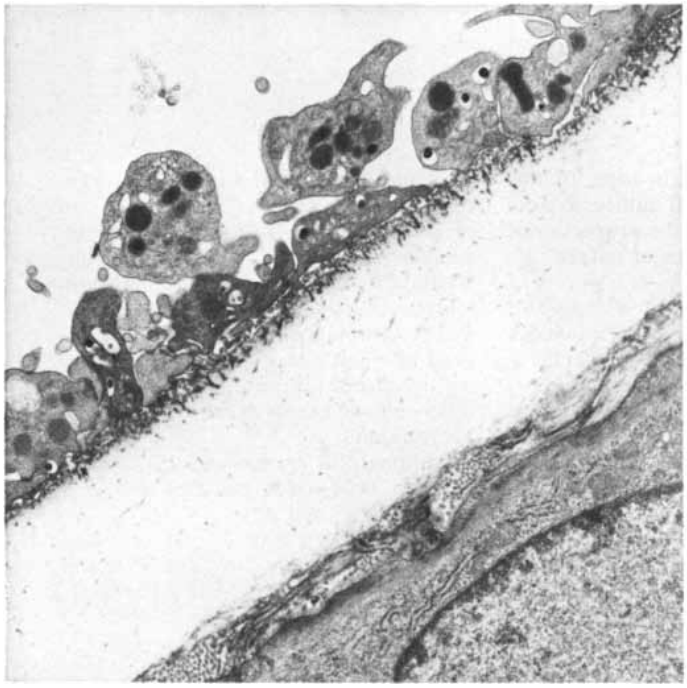
Another kind of evidence that platelets are affected in severe arterial disease comes from the measurement of platelet products in the plasma. In addition to the growth factor at least two substances in platelet granules, platelet factor 4 and beta-thromboglobulin, are peculiar to those granules; only minute amounts of

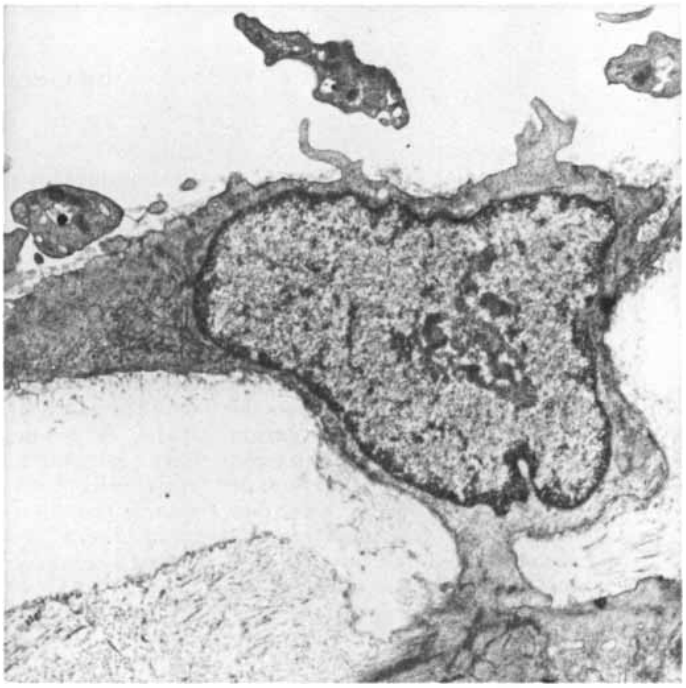


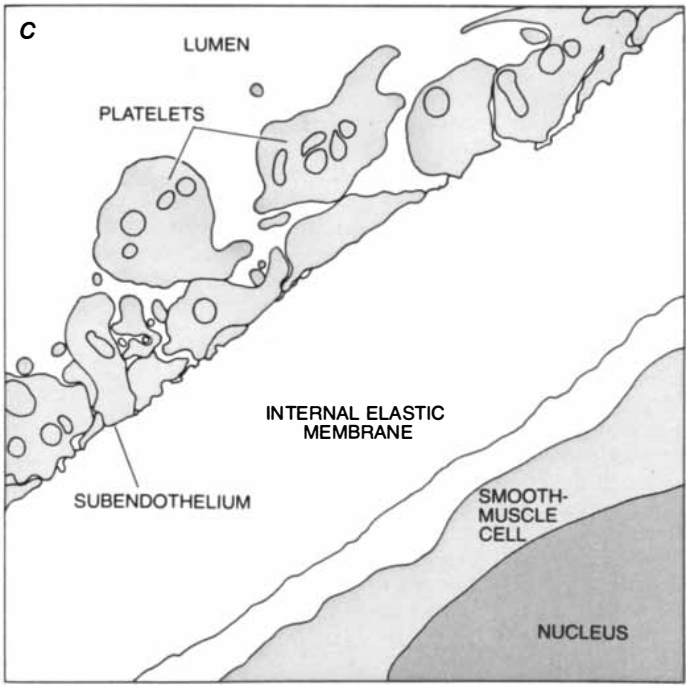
CHANGES IN INTIMA of the rabbit aorta following damage to endothelial cells are shown in electron micrographs made by Baumgartner, with the various structures identified in a drawing under each micrograph; the enlargement in each case is about 10,000 diameters. In the intact arterial wall (*a*) one sees the endothelial-cell lining of the lumen, the internal elastic membrane and part of a smooth-muscle cell

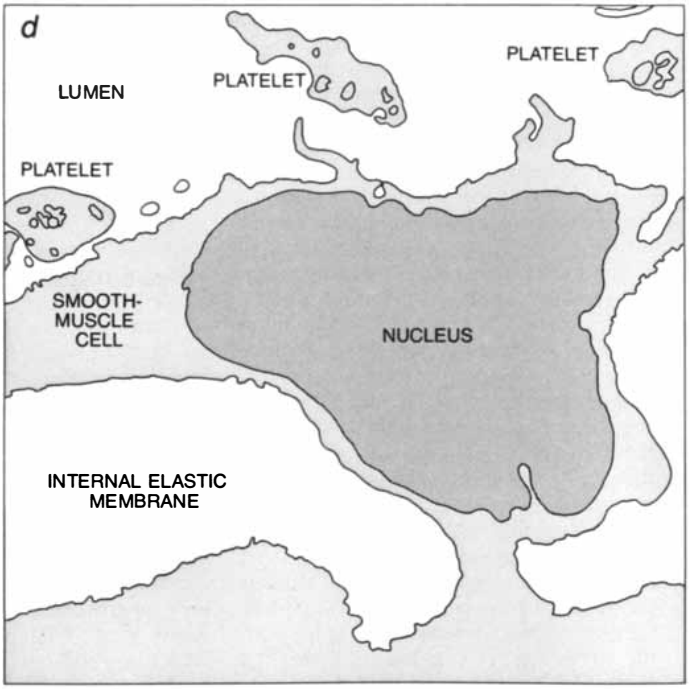
them can be found in plasma carefully separated from normal blood that has been treated to inhibit platelet secretion. Plasma from individuals with thrombosis or severe atherosclerosis often contains much larger amounts of the two substances, indicating that their platelets are continually either rupturing or secreting the contents of their granules into the circulation.

Research is under way in many laboratories to determine the extent of involvement and the precise role of platelets in atherosclerosis and thrombosis and in diseases such as diabetes, in which these are common complications. The studies involve not only the measurement of platelet survival time and the plasma content of platelet products but also the effects of particular drugs on these variables and on the incidence of heart attacks and other sequels of atherosclerosis. Some drugs, such as dipyridamole and sulfinpyrazone, seem to prolong the life span of platelets that would otherwise have a short survival time, but the discovery of this effect was largely fortuitous and the mechanism of the action of the two drugs in this respect is obscure. There are other drugs, such as aspirin, whose mode of action with respect to platelets is well understood, but unfortunately these drugs do not seem to be as effective in prolonging platelet survival. Both basic physiological and biochemical research and applied clinical studies can contribute to a better understanding of the role platelets play in atherosclerosis—the leading cause of death in advanced societies—and in other diseases and congenital disorders.









below it. When damaged endothelial cells slough off (*b*), platelets adhere to the subendothelium and to one another until the platelets form a layer covering the subendothelium (*c*). Then a smooth-muscle cell migrates through a gap in the internal elastic membrane (*d*); in time such smooth-muscle cells proliferate, thereby forming a thickened pseudointima that may predispose to formation of a thrombus.

Gauge Theories of the Forces between Elementary Particles

All the basic forces of nature are now described by theories of this kind. The properties of the forces are deduced from symmetries or regularities apparent in the laws of physics

by Gerard 't Hooft

An understanding of how the world is put together requires a theory of how the elementary particles of matter interact with one another. Equivalently, it requires a theory of the basic forces of nature. Four such forces have been identified, and until recently a different kind of theory was needed for each of them. Two of the forces, gravitation and electromagnetism, have an unlimited range; largely for this reason they are familiar to everyone. They can be felt directly as agencies that push or pull. The remaining forces, which are called simply the weak force and the strong force, cannot be perceived directly because their influence extends only over a short range, no larger than the radius of an atomic nucleus. The strong force binds together the protons and the neutrons in the nucleus, and in another context it binds together the particles called quarks that are thought to be the constituents of protons and neutrons. The weak force is mainly responsible for the decay of certain particles.

A long-standing ambition of physicists is to construct a single master theory that would incorporate all the known forces. One imagines that such a theory would reveal some deep connection between the various forces while accounting for their apparent diversity. Such a unification has not yet been attained, but in recent years some progress may have been made. The weak force and electromagnetism can now be understood in the context of a single theory. Although the two forces remain distinct, in the theory they become mathematically intertwined. What may ultimately prove more important, all four forces are now described by means of theories that have the same general form. Thus if physicists have yet to find a single key that fits all the known locks, at least all the needed keys can be cut from the same blank. The theories in this single favored class are formally designated non-Abelian gauge theories with local symmetry. What is meant by this forbidding label is the main topic of this article. For now, it will suffice to note that the theories relate the properties of the forces to symmetries of nature.

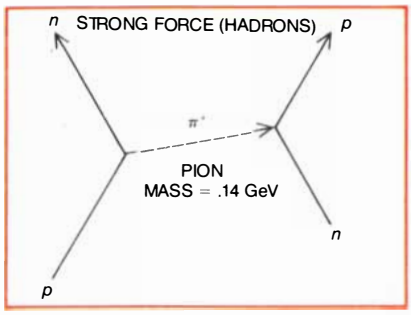
Symmetries and apparent symmetries in the laws of nature have played a part in the construction of physical theories since the time of Galileo and Newton. The most familiar symmetries are spatial or geometric ones. In a snowflake, for example, the presence of a symmetrical pattern can be detected at a glance. The symmetry can be defined as an invariance in the pattern that is observed when some transformation is applied to it. In the case of the snowflake the transformation is a rotation by 60 degrees, or one-sixth of a circle. If the initial position is noted and the snowflake is then turned by 60 degrees (or by any integer multiple of 60 degrees), no change will be perceived. The snowflake is invariant with respect to 60-degree rotations. According to the same principle, a square is invariant with respect to 90-degree rotations and a circle is said to have continuous symmetry because rotation by any angle leaves it unchanged.

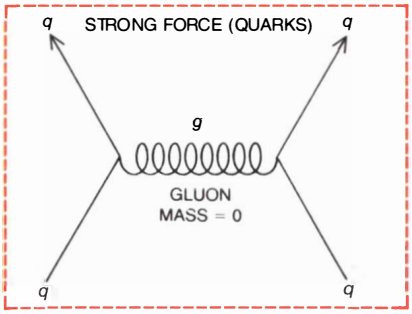
Although the concept of symmetry had its origin in geometry, it is general enough to embrace invariance with respect to transformations of other kinds. An example of a nongeometric symmetry is the charge symmetry of electromagnetism. Suppose a number of electrically charged particles have been set out in some definite configuration and all the forces acting between pairs of particles have been measured. If the polarity of all the charges is then reversed, the forces remain unchanged.

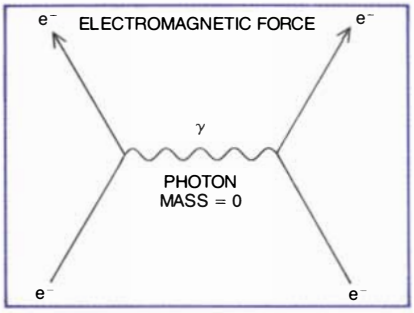
Another symmetry of the nongeometric kind concerns isotopic spin, a property of protons and neutrons and of the many related particles called hadrons, which are the only particles responsive to the strong force. The basis of the symmetry lies in the observation that the proton and the neutron are remarkably similar particles. They differ in mass by only about a tenth of a percent, and except for their electric charge they are identical in all other properties. It therefore seems that all protons and neutrons could be interchanged and the strong interactions would hardly be altered. If the electromagnetic forces (which depend on electric charge) could somehow be turned off, the isotopic-spin symmetry would be exact; in reality it is only approximate.

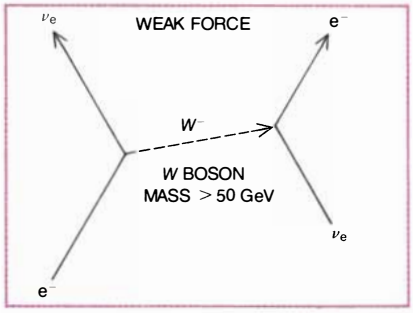
Although the proton and the neutron seem to be distinct particles and it is hard to imagine a state of matter intermediate between them, it turns out that symmetry with respect to isotopic spin is a continuous symmetry, like the symmetry of a sphere rather than like that of a snowflake. I shall give a simplified explanation of why that is so. Imagine that inside each particle are a pair of crossed arrows, one representing the proton component of the particle and the other representing the neutron component. If the proton arrow is pointing up (it makes no difference what direction is defined as up), the particle is a proton; if the neutron arrow is up, the particle is a neutron. Intermediate positions correspond to quantum-mechanical superpositions of the two states, and the particle then looks sometimes like a proton and sometimes like a neutron. The symmetry transformation associated with isotopic spin rotates the internal indicators of all protons and neutrons everywhere in the universe by the same amount and at the same time. If the rotation is by exactly 90 degrees, every proton becomes a neutron and every neutron becomes a proton. Symmetry with respect to isotopic spin, to the extent it is exact, states that no effects of this transformation can be detected.

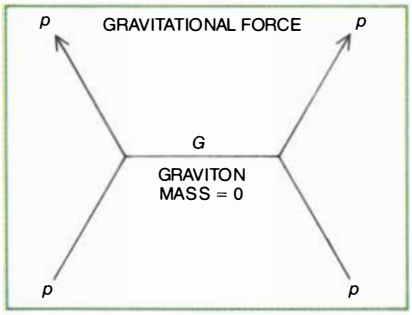
All the symmetries I have discussed so far can be characterized as global symmetries; in this context the word global means "happening everywhere at once." In the description of isotopic-spin symmetry this constraint was made explicit: the internal rotation that transforms

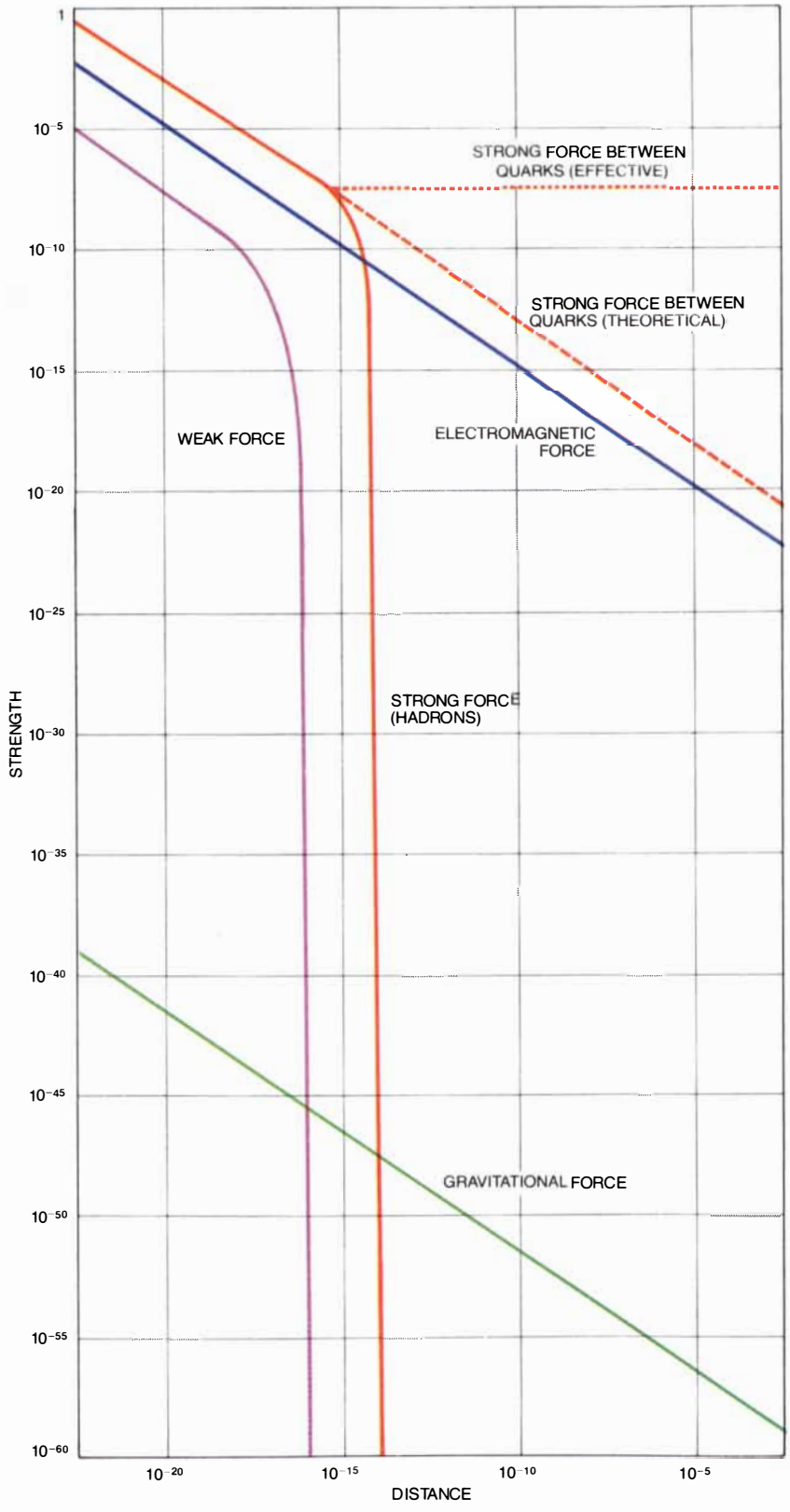






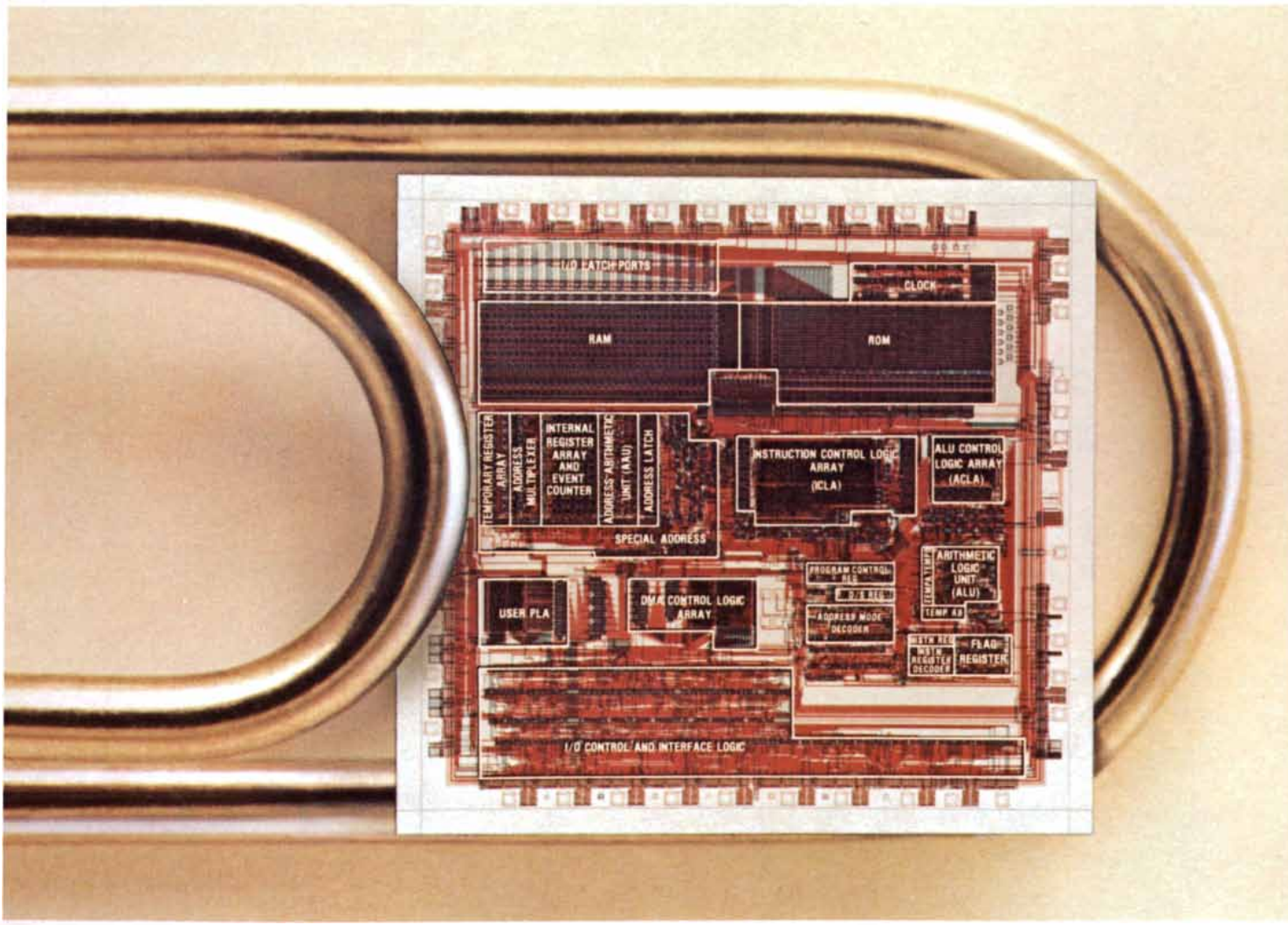






FOUR BASIC FORCES mediate all known interactions among the particles of matter. The forces differ greatly in strength and effective range, but they are all described by theories of the same mathematical form, namely local gauge theories. Electromagnetism and gravitation are said to be of infinite range, although their influence declines as the square of the distance between two interacting particles. The weak force is confined to an exceedingly small range of about 10^{-15} centimeter. The properties of the strong force are somewhat more complicated. As the strong force is observed acting between hadrons, such as the proton and the neutron (*solid colored line*), it has a finite range of some 10^{-13} centimeter. The strong force also binds together the particles called quarks that make up hadrons, and in that context it could be expected to follow an inverse-square law (*broken colored line*). The actual behavior is apparently stranger: the force remains constant regardless of distance (*dotted colored line*). In quantum field theories (*diagrams at left*) the force between two particles is made manifest through the exchange of a third particle, which is called a virtual particle. The range of the force is determined by the mass of the exchanged virtual particle. Massless virtual particles, such as the photon and the graviton, give rise to forces that have infinite range.

The one-chip computer: offspring of the transistor



The MAC-4 one-chip computer, developed for a variety of telecommunications applications, is compared to a standard-sized paper clip. The chip's numerous functional areas are labeled.

One of the transistor's latest descendants is the Bell System's 30,000-element MAC-4 "computer-on-a-chip." It's another in a long line of microelectronic developments that have come from Bell Laboratories.

The MAC-4 is so efficient that a program written on it takes 25 percent less storage space than that required by most other microcomputers. Its assembler language, C, also developed at Bell Labs, has features that make MAC-4 easier to program, debug and maintain. And the MAC-4 can handle anything from nibbles to bytes to words with its 4-, 8-, 12-, and 16-bit operations capacity.

Like other one-chip computers, the MAC-4 has sufficient memory to support its varied tasks—3000 nibbles of read-only memory and 200 nibbles of random access memory coupled to 34 input/output ports.

Fabricated with the latest CMOS technology, the MAC-4 needs little power. Thus it is well matched to a variety of telecommunications applications.

It started with the transistor

MAC-4 is just one current example of the many microelectronic devices to come from Bell Labs since we started the solid-state revolution with the invention of the transistor in 1947.

Over the past three decades, our advances in materials, processing, and devices have been vital to solid-state technology. These include:

- The Junction Transistor
- Crystal Pulling
- Zone Refining
- Field-Effect Transistor
- Diffusion
- Solar Cell
- Oxide Masking
- Thermocompression Bonding
- Photolithography
- Epitaxial Film Process
- Magnetic Bubble Memory
- Charge-Coupled Device
- Semiconductor Heterostructure Laser Used in Lightwave Communications
- Electron-Beam Exposure System

Today and tomorrow

Today, we continue to make important contributions to solid-state technology. For example, we've developed a rugged 65,536-bit RAM that can tolerate processing faults. Corrections can be made on the chip itself, so we can get more usable chips out of each manufacturing batch—and thus lower unit costs.

In materials processing, we've developed a technique for precisely controlling the growth of successive atomic layers of single crystal materials. This "molecular beam epitaxy" process is finding increasing use within Bell Labs and elsewhere in the electronics industry. We've used it to fabricate a device that permits us to double the speed of electrons by channeling them into crystal layers where they meet less resistance.

Other advances, in X-ray lithography and new resist materials, for example, promise to help place more elements on microelectronic devices and thus enhance their ability to perform important tasks.

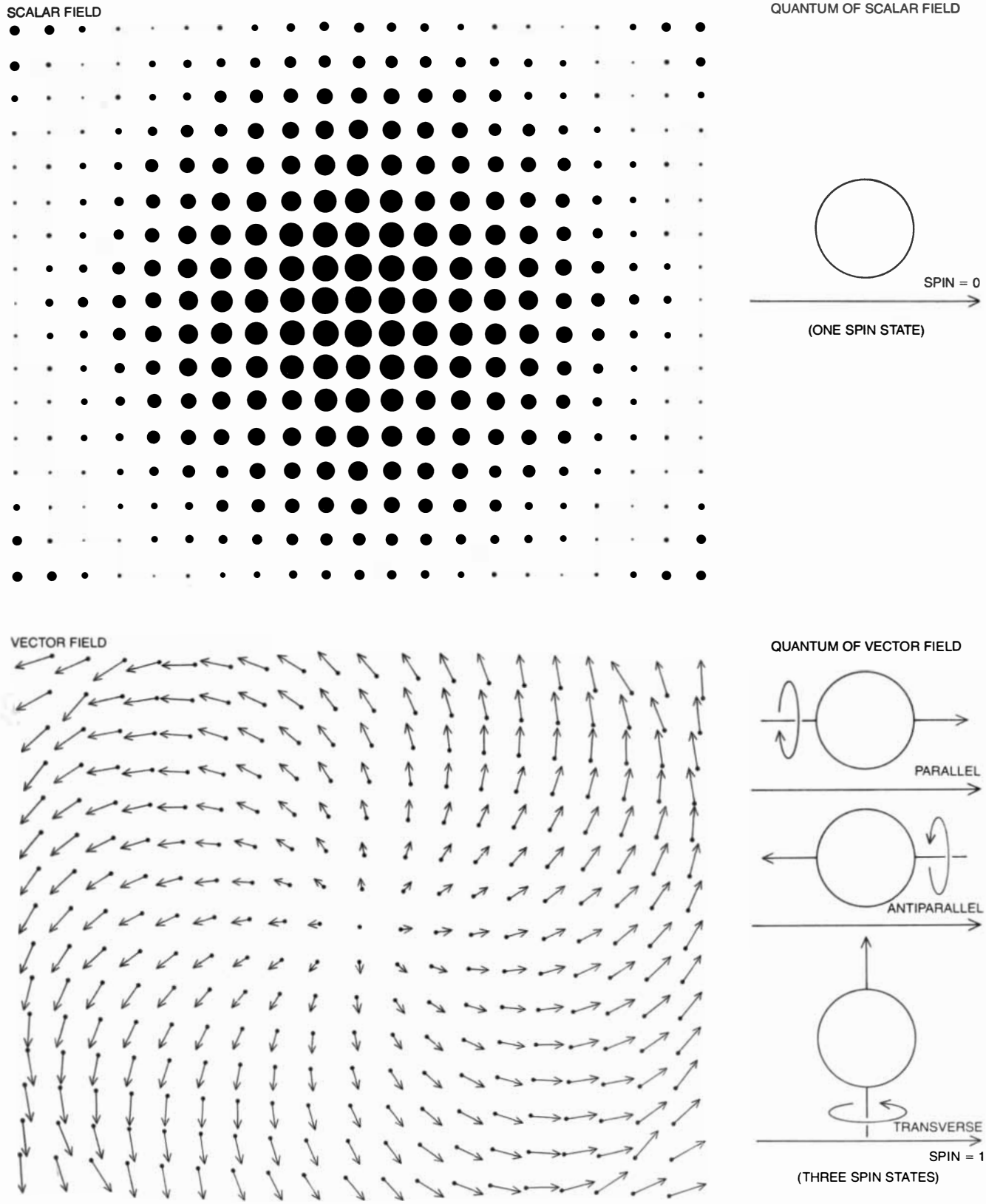
As the solid-state revolution continues, these and other developments from Bell Labs will play an important part in it. What's important to us is the promise these advances offer for new telecommunications products and services. Like the transistor, MAC-4 and its solid-state relatives will find more and more applications in the nationwide telecommunications network.

For information about employment, write:

Bell Laboratories, Room 3C-303,
600 Mountain Avenue,
Murray Hill, N.J. 07974.
Please include a résumé.
An equal opportunity employer.

Bell Laboratories

From Science: Service



CONCEPT OF A FIELD, a quantity defined at each point throughout some region of space and time, is important in the construction of gauge theories. A scalar field has only a magnitude at each point; in this example the magnitude is given by the area of the dots. A vector field has both a magnitude and a direction and can be illustrated by drawing an arrow at each point. A scalar field might represent a quantity such as the temperature or the density of a fluid, whereas a vector field could represent its velocity. In quantum field theories the influence of a field can be embodied in a virtual particle. The number of components in the field is reflected in the number of distinct orientations of the particle, which in turn depends on its spin angular momentum. A scalar field has just one component (its value can be given by a single number) and is represented by a spin-zero particle with one spin state, or orientation. A vector field in three-dimensional space has three components (a magnitude and two angles), and it corresponds to a spin-one particle with three spin states.

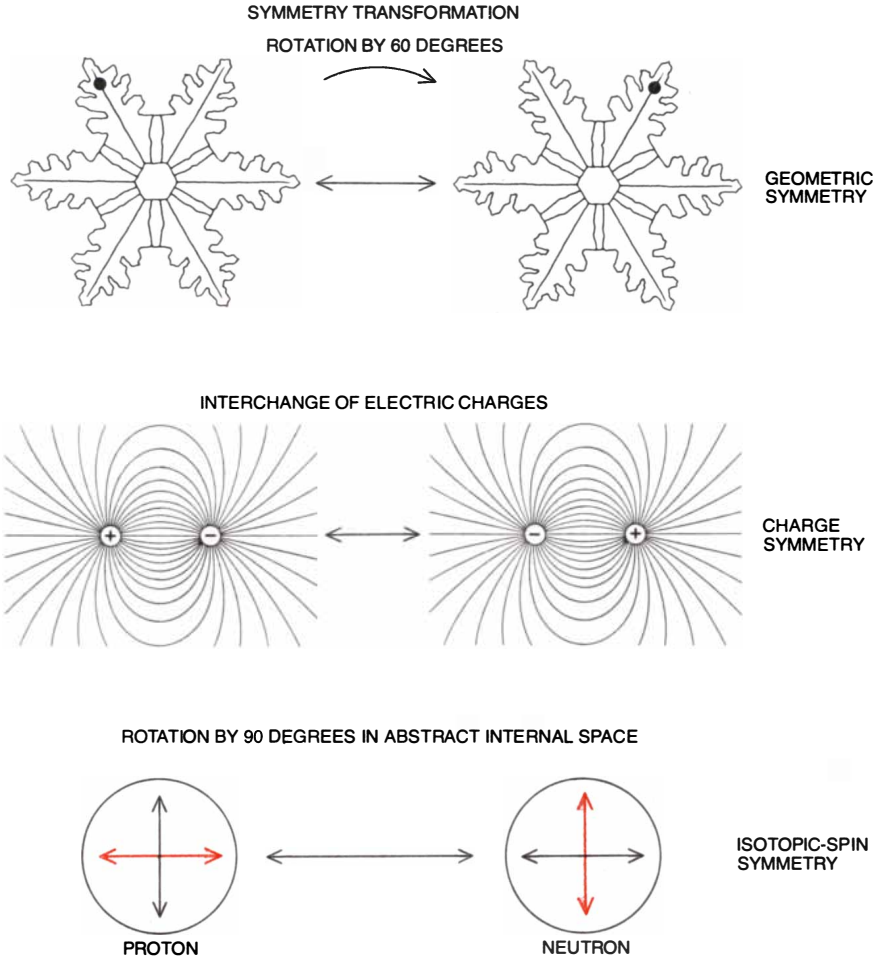
protons into neutrons and neutrons into protons is to be carried out everywhere in the universe at the same time. In addition to global symmetries, which are almost always present in a physical theory, it is possible to have a "local" symmetry, in which the convention can be decided independently at every point in space and at every moment in time. Although "local" may suggest something of more modest scope than a global symmetry, in fact the requirement of local symmetry places a far more stringent constraint on the construction of a theory. A global symmetry states that some law of physics remains invariant when the same transformation is applied everywhere at once. For a local symmetry to be observed the law of physics must retain its validity even when a different transformation takes place at each point in space and time.

Gauge theories can be constructed with either a global or a local symmetry (or both), but it is the theories with local symmetry that hold the greatest interest today. In order to make a theory invariant with respect to a local transformation something new must be added: a force. Before showing how this comes about, however, it will be necessary to discuss in somewhat greater detail how forces are described in modern theories of elementary-particle interactions.

The basic ingredients of particle theory today include not only particles and forces but also fields. A field is simply a quantity defined at every point throughout some region of space and time. For example, the quantity might be temperature and the region might be the surface of a frying pan. The field then consists of temperature values for every point on the surface.

Temperature is called a scalar quantity, because it can be represented by position along a line, or scale. The corresponding temperature field is a scalar field, in which each point has associated with it a single number, or magnitude. There are other kinds of field as well, the most important for present purposes being the vector field, where at each point a vector, or arrow, is drawn. A vector has both a magnitude, which is represented by the length of the arrow, and a direction, which in three-dimensional space can be specified by two angles; hence three numbers are needed in order to specify the value of the vector. An example of a vector field is the velocity field of a fluid; at each point throughout the volume of the fluid an arrow can be drawn to show the speed and direction of flow.

In the physics of electrically charged objects a field is a convenient device for expressing how the force of electromagnetism is conveyed from one place to another. All charged particles are supposed to emanate an electromagnetic field; each particle then interacts with the sum of all the fields rather than directly with the other particles.

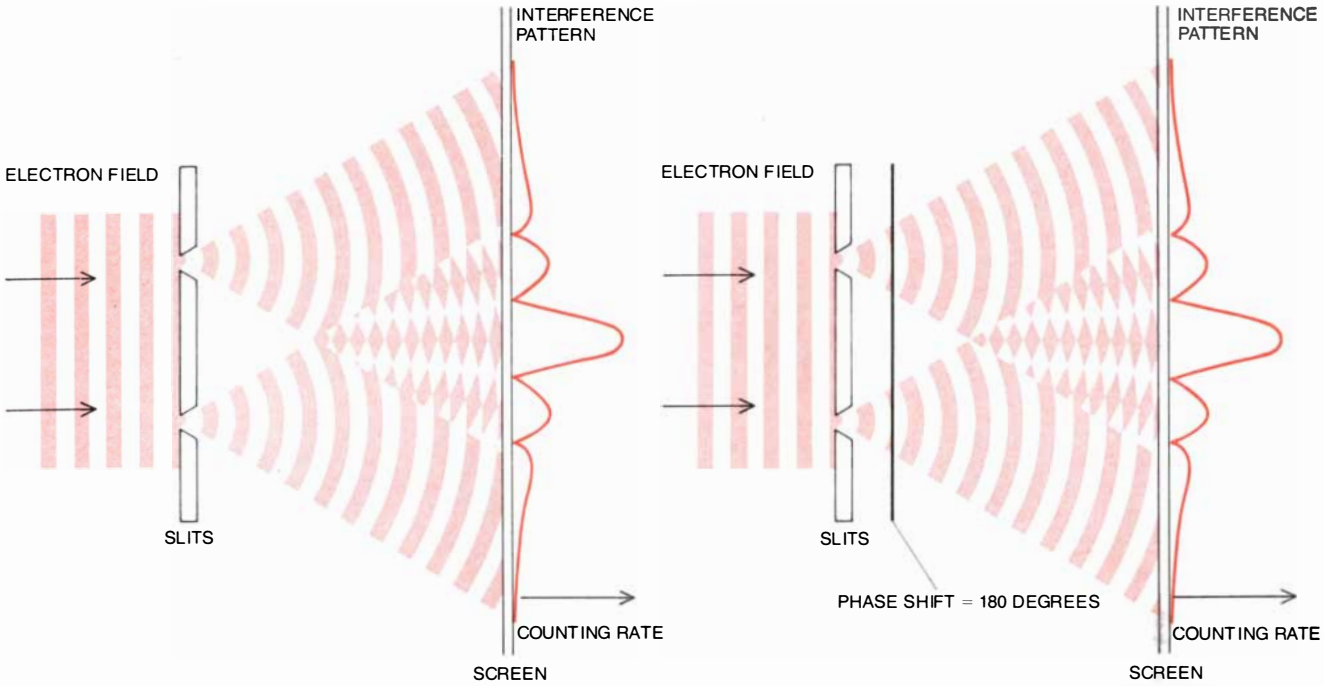


SYMMETRIES OF NATURE determine the properties of forces in gauge theories. The familiar symmetry of a snowflake can be characterized by noting that the pattern is unchanged when it is rotated 60 degrees; the snowflake is said to be invariant with respect to such rotations. In physics nongeometric symmetries are introduced. Charge symmetry, for example, is the invariance of the forces acting among a set of charged particles when the polarities of all the charges are reversed. Isotopic-spin symmetry is based on the observation that little would be changed in the strong interactions of matter if the identities of all protons and neutrons were interchanged. Hence proton and neutron become merely the alternative states of a single particle, the nucleon, and transitions between the states can be made (or imagined) by adjusting the orientation of an indicator in an internal space. It is symmetries of this kind, where the transformation is an internal rotation or a phase shift, that are referred to as gauge symmetries.

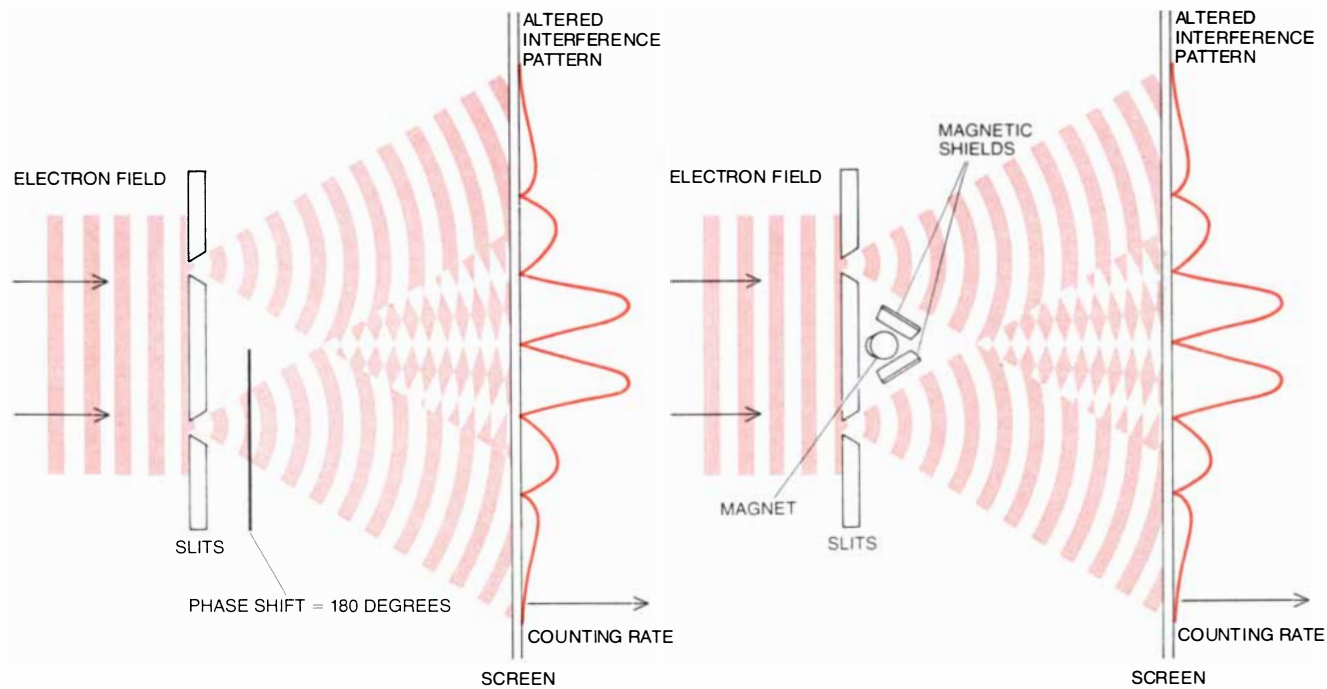
In quantum mechanics the particles themselves can be represented as fields. An electron, for example, can be considered a packet of waves with some finite extension in space. Conversely, it is often convenient to represent a quantum-mechanical field as if it were a particle. The interaction of two particles through their interpenetrating fields can then be summed up by saying the two particles exchange a third particle, which is called the quantum of the field. For example, when two electrons, each surrounded by an electromagnetic field, approach each other and bounce apart, they are said to exchange a photon, the quantum of the electromagnetic field.

The exchanged quantum has only an ephemeral existence. Once it has been emitted it must be reabsorbed, either by the same particle or by another one, within a finite period. It cannot keep going indefinitely, and it cannot be detected in an experiment. Entities of this kind are called virtual particles. The larger their energy, the briefer their existence. In effect a virtual particle borrows or embezzles a quantity of energy, but it must repay the debt before the shortage can be noticed.

The range of an interaction is related to the mass of the exchanged quantum. If the field quantum has a large mass, more energy must be borrowed in order to support its existence, and the debt must be repaid sooner lest the discrepancy be discovered. The distance the particle can travel before it must be re-



GAUGE SYMMETRY OF ELECTROMAGNETISM is an invariance with respect to shifts in the phase of the matter field that represents an electron. The phase itself cannot be measured, but it has an influence on such observable quantities as the interference pattern formed when the waves of an electron field pass through a pair of slits. The peaks in this pattern are found wherever the waves are in phase, and the nodes are found where the waves are out of phase. A shift in phase greatly alters the configuration of the field, but it leaves the observable interference pattern unchanged. The symmetry is an exact one, so that the phase shift cannot be detected. It is therefore only a matter of convention what phase is chosen in any theoretical description of the field. In the absence of forces acting between the electrons, however, the symmetry is a global one: the observed pattern is invariant only if the same phase shift is applied everywhere.



LOCAL GAUGE SYMMETRY of the electron matter field is restored when magnetic fields are taken into account. Shifting the phase of one diffracted electron beam but not the other clearly alters the observed interference pattern (*diagram at left*). The same effect can be obtained, however, by introducing a small magnetic field perpendicular to the electron beam and between the slits (*diagram at right*). Remarkably, the magnetic field induces the phase shift even when shields are arranged so that the field cannot penetrate the region where the electron waves propagate and interfere. An experimenter examining the interference patterns could not distinguish between the effects of a phase shift imposed arbitrarily on one electron beam and the effects of a magnetic field introduced between the slits. Any local shift in the phase of the electron matter field could therefore be reproduced by electric and magnetic fields, and so the phase of the electron field is arbitrary. The theory that combines electron matter fields with electric and magnetic fields is quantum electrodynamics.

absorbed is thereby reduced and so the corresponding force has a short range. In the special case where the exchanged quantum is massless the range is infinite.

The number of components in a field corresponds to the number of quantum-mechanical states of the field quantum. The number of possible states is in turn related to the intrinsic spin angular momentum of the particle. The spin angular momentum can take on only discrete values; when the magnitude of the spin is measured in fundamental units, it is always an integer or a half integer. Moreover, it is not only the magnitude of the spin that is quantized but also its direction or orientation. (To be more precise, the spin can be defined by a vector parallel to the spin axis, and the projections, or components, of this vector along any direction in space must have values that are integers or half integers.) The number of possible orientations, or spin states, is equal to twice the magnitude of the spin, plus one. Thus a particle with a spin of one-half, such as the electron, has two spin states: the spin can point parallel to the particle's direction of motion or antiparallel to it. A spin-one particle has three orientations, namely parallel, antiparallel and transverse. A spin-zero particle has no spin axis; since all orientations are equivalent, it is said to have just one spin state.

A scalar field, which has just one component (a magnitude), must be represented by a field quantum that also has one component, or in other words by a spin-zero particle. Such particles are therefore called scalar particles. Similarly, a three-component vector field requires a spin-one field quantum with three spin states: a vector particle. The electromagnetic field is a vector field, and the photon, in conformity with these specifications, has a spin of one unit. The gravitational field is a more complicated structure called a tensor and has 10 components; not all of them are independent, however, and the quantum of the field, the graviton, has a spin of two units, which ordinarily corresponds to five spin states.

In the cases of electromagnetism and gravitation one further complication must be taken into account. Since the photon and the graviton are massless, they must always move with the speed of light. Because of their velocity they have a property not shared by particles with a finite mass: the transverse spin states do not exist. Although in some formal sense the photon has three spin states and the graviton has five, in practice only two of the spin states can be detected.

The first gauge theory with local symmetry was the theory of electric and magnetic fields introduced in 1868 by James Clerk Maxwell. The foundation of Maxwell's theory is the proposition

that an electric charge is surrounded by an electric field stretching to infinity, and that the movement of an electric charge gives rise to a magnetic field also of infinite extent. Both fields are vector quantities, being defined at each point in space by a magnitude and a direction.

In Maxwell's theory the value of the electric field at any point is determined ultimately by the distribution of charges around the point. It is often convenient, however, to define a potential, or voltage, that is also determined by the charge distribution: the greater the density of charges in a region, the higher its potential. The electric field between two points is then given by the voltage difference between them.

The character of the symmetry that makes Maxwell's theory a gauge theory can be illustrated by considering an imaginary experiment. Suppose a system of electric charges is set up in a laboratory and the electromagnetic field generated by the charges is measured and its properties are recorded. If the charges are stationary, there can be no magnetic field (since the magnetic field arises from movement of an electric charge); hence the field is purely an electric one. In this experimental situation a global symmetry is readily perceived. The symmetry transformation consists in raising the entire laboratory to a high voltage, or in other words to a high electric potential. If the measurements are then repeated, no change in the electric field will be observed. The reason is that the field, as Maxwell defined it, is determined only by differences in electric potential, not by the absolute value of the potential. It is for the same reason that a squirrel can walk without injury on an uninsulated power line.

This property of Maxwell's theory amounts to a symmetry: the electric field is invariant with respect to the addition or subtraction of an arbitrary overall potential. As noted above, however, the symmetry is a global one, because the result of the experiment remains constant only if the potential is changed everywhere at once. If the potential were raised in one region and not in another, any experiment that crossed the boundary would be affected by the potential difference, just as a squirrel is affected if it touches both a power line and a grounded conductor.

A complete theory of electromagnetic fields must embrace not only static arrays of charges but also moving charges. In order to do that the global symmetry of the theory must be converted into a local symmetry. If the electric field were the only one acting between charged particles, it would not have a local symmetry. Actually when the charges are in motion (but only then), the electric field is not the only one present: the movement itself gives rise to a second field, namely the magnetic field. It is the effects of the magnetic field that restore the local symmetry.

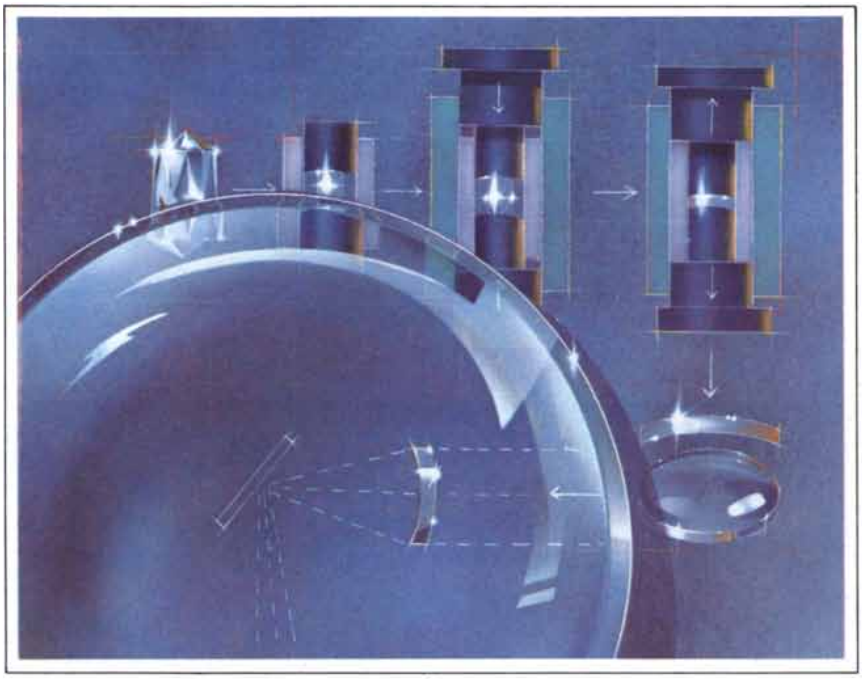
Just as the electric field depends ultimately on the distribution of charges but can conveniently be derived from an electric potential, so the magnetic field is generated by the motion of the charges but is more easily described as resulting from a magnetic potential. It is in this system of potential fields that local transformations can be carried out leaving all the original electric and magnetic fields unaltered. The system of dual, interconnected fields has an exact local symmetry even though the electric field alone does not. Any local change in the electric potential can be combined with a compensating change in the magnetic potential in such a way that the electric and magnetic fields are invariant.

Maxwell's theory of electromagnetism is a classical or non-quantum-mechanical one, but a related symmetry can be demonstrated in the quantum theory of electromagnetic interactions. It is necessary in that theory to describe the electron as a wave or a field, a convention that in quantum mechanics can be adopted for any material particle. It turns out that in the quantum theory of electrons a change in the electric potential entails a change in the phase of the electron wave.

The electron has a spin of one-half unit and so has two spin states (parallel and antiparallel). It follows that the associated field must have two components. Each of the components must be represented by a complex number, that is, a number that has both a real, or ordinary, part and an imaginary part, which includes as a factor the square root of -1. The electron field is a moving packet of waves, which are oscillations in the amplitudes of the real and the imaginary components of the field. It is important to emphasize that this field is not the electric field of the electron but instead is a matter field. It would exist even if the electron had no electric charge. What the field defines is the probability of finding an electron in a specified spin state at a given point and at a given moment. The probability is given by the sum of the squares of the real and the imaginary parts of the field.

In the absence of electromagnetic fields the frequency of the oscillations in the electron field is proportional to the energy of the electron, and the wavelength of the oscillations is proportional to the momentum. In order to define the oscillations completely one additional quantity must be known: the phase. The phase measures the displacement of the wave from some arbitrary reference point and is usually expressed as an angle. If at some point the real part of the oscillation, say, has its maximum positive amplitude, the phase at that point might be assigned the value zero de-

FROM A SINGLE CRYSTAL OF POTASSIUM BROMIDE, WE FORGED A NEW TECHNOLOGY CAPABLE OF MAKING SOPHISTICATED OPTICAL ELEMENTS OUT OF COMMON SALTS.



OUR NEW TECHNIQUE FOR HOT PRESS FORGING ALKALI HALIDES AND ALKALINE EARTH FLUORIDES WILL HELP REDUCE THE COST OF PRODUCING OPTICAL LENSES AND WINDOWS FOR EVERYTHING FROM THERMOGRAPHIC BODY SCANNERS TO OPTICAL INTERFEROMETERS.

Optical grade halide materials like potassium bromide and lithium fluoride have broad transmission capabilities which make them ideally suited for use in applications such as medical thermography, satellite weather monitoring, infrared night vision systems, and laser-assisted nuclear fusion for the conversion of energy. Grown as single crystals, these common salts are transparent in ultraviolet, visible and infrared light.

But they also have limited structural strength. And are too soft to produce scratch-free optical surfaces by grinding and polishing.

Attracted by the potential of the materials' useful properties, a Honeywell research team—partially funded by the Department of Energy and the Department of Defense—began an investigation. Combining skills in such diverse fields as ceramics, optics and process development, we developed a new isostatic forging technique which compensates for the materials' inherent shortcomings.

In our patented forging process, a single crystal is deformed by pressing it at controlled temperatures and strain rates. This produces a considerably strengthened polycrystalline material, with optical characteristics similar to the original single crystal.

The dies used to produce the desired lens surfaces are made of optically polished pyrex or metal. Because the surface of the forged material closely replicates the surface of the dies, there is no need for grinding or polishing. (An additional advantage of this particular process is the ease with which aspheric lenses may be produced from a single set of aspheric dies.)

Work is underway to develop coatings that will provide protection against moisture and other environmental factors.

In order to test the results of their work, Honeywell scientists, working with university and commercial instrumentation scientists, had to develop a novel holographic and shearing interferometer system. Combined with our previously developed video digitization/fringe analysis system, this new interferometer provides us with a unique facility for non-contact optical evaluation.

If you are interested in learning more about Honeywell's research work in forged optical elements, you are invited to correspond with Mr. David Wertman, Honeywell Corporate Technology Center, 10701 Lyndale Avenue So., Minneapolis, MN 55420. If you have an advanced degree and are interested in a career in solid state electronics, sensors, or material sciences, please write to Dr. T. F. Hueter, Vice President Corporate Technology, Honeywell, Honeywell Plaza, Minneapolis, MN 55408.

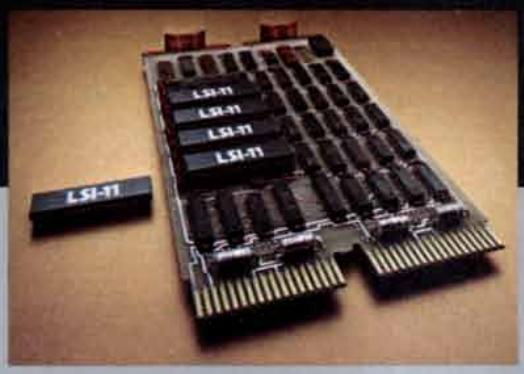
Honeywell

Although Honeywell engineering is world-wide, the bulk of basic research and applied research is done in Minneapolis. The most recent *Quality of Life* Study conducted by Midwest Research Institute shows Minnesota to be one of the best places in the country to live and work considering cultural, social, economic, educational and political factors.

The Twin Cities is the home of many of America's advanced technology companies employing a great many scientists and engineers. This ideal research environment is further enhanced by Honeywell's ongoing program of affiliation with universities across the country: The University of California at Berkeley, MIT, Stanford, Carnegie Mellon, Illinois, Cornell, Waterloo of Ontario and Minnesota.

We've sold more high performance microcomputers than anyone.

Anyone.



By the end of 1979, Digital Equipment Corporation had sold more 16-bit micros than any other company in the business.

Over 100,000 of them.

And the reason is simple. We give you more to work with. More hardware. More software. And more true systems capability.

That means you can develop your products faster, and offer your customers the right balance of cost and performance every time.

What's more, Digital's micros are software compatible. Not just with each other, but with our whole PDP-11 minicomputer family as well. So you'll never run out of ways to expand your business.

Behind all Digital's micro products is a support commitment that's unmatched in the industry. 13,000 people worldwide. Technical consultation and training. And a wide range of support agreements—from do-it-yourself service using our special kits, to full support including coverage for your customers.

It's the total approach to micros. And it's the reason Digital has sold more high performance micros than anyone.

Anyone.

Digital Equipment Corporation,
Dept. NR2/2, 146 Main Street,
Maynard, MA 01754.

It took the minicomputer company to make micros this easy.

digital

grees. Where the real part next falls to zero the phase is 90 degrees and where it reaches its negative maximum the phase is 180 degrees. In general the imaginary part of the amplitude is 90 degrees out of phase with the real part, so that whenever one part has a maximal value the other part is zero.

It is apparent that the only way to determine the phase of an electron field is to disentangle the contributions of the real and the imaginary parts of the amplitude. That turns out to be impossible, even in principle. The sum of the squares of the real and the imaginary parts can be known, but there is no way of telling at any given point or at any moment how much of the total derives from the real part and how much from the imaginary part. Indeed, an exact symmetry of the theory implies that the two contributions are indistinguishable. Differences in the phase of the field at two points or at two moments can be measured, but not the absolute phase.

The finding that the phase of an electron wave is inaccessible to measurement has a corollary: the phase cannot have an influence on the outcome of any possible experiment. If it did, that experiment could be used to determine the phase. Hence the electron field exhibits a symmetry with respect to arbitrary changes of phase. Any phase angle can be added to or subtracted from the electron field and the results of all experiments will remain invariant.

This principle can be made clearer by considering an example: the two-slit diffraction experiment with electrons, which is the best-known demonstration of the wavelike nature of matter. In the experiment a beam of electrons passes through two narrow slits in a screen and the number of electrons reaching a second screen is counted. The distribution of electrons across the surface of the second screen forms a diffraction pattern of alternating peaks and valleys.

The quantum-mechanical interpretation of this experiment is that the electron wave splits into two segments on striking the first screen and the two diffracted waves then interfere with each other. Where the waves are in phase the interference is constructive and many electrons are counted at the second screen; where the waves are out of phase destructive interference reduces the count. Clearly it is only the difference in phase that determines the pattern formed. If the phases of both waves were shifted by the same amount, the phase difference at each point would be unaffected and the same pattern of constructive and destructive interference would be observed.

It is symmetries of this kind, where the phase of a quantum field can be adjusted at will, that are called gauge symmetries. Although the absolute value of the phase is irrelevant to the outcome of experiments, in constructing a theory of electrons it is still necessary to specify the phase. The choice of a particular value is called a gauge convention.

Gauge symmetry is not a very descriptive term for such an invariance, but the term has a long history and cannot now be dislodged. It was introduced in about 1920 by Hermann Weyl, who was then attempting to formulate a theory that would combine electromagnetism and the general theory of relativity. Weyl was led to propose a theory that remained invariant with respect to arbitrary dilatations or contractions of space. In the theory a separate standard of length and time had to be adopted at every point in space-time. He compared the choice of a scale convention to a choice of gage blocks, the polished steel blocks employed by machinists as a standard of length. The theory was nearly correct, the necessary emendation being to replace "length scales" by "phase angles." Writing in German, Weyl had referred to "Eich Invarianz," which was initially translated as "calibration invariance," but the alternative translation "gauge" has since become standard.

The symmetry of the electron matter field described above is a global symmetry: the phase of the field must be shifted in the same way everywhere at once. It can easily be demonstrated that a theory of electron fields alone, with no other forms of matter or radiation, is not invariant with respect to a corresponding local gauge transformation. Consider again the two-slit diffraction experiment with electrons. An initial experiment is carried out as before and the electron-diffraction pattern is recorded. Then the experiment is repeated, but one slit is fitted with the electron-optical equivalent of a half-wave plate, a device that shifts the phase of a wave by 180 degrees. When the waves emanating from the two slits now interfere, the phase difference between them will be altered by 180 degrees. As a result wherever the interference was constructive in the first experiment it will now be destructive, and vice versa. The observed diffraction pattern will not be unchanged; on the contrary, the positions of all the peaks and depressions will be interchanged.

Suppose one wanted to make the theory consistent with a local gauge symmetry. Perhaps it could be fixed in some way; in particular, perhaps another field could be added that would compensate for the changes in electron phase. The new field would of course have to do more than mend the defects in this one experiment. It would have to preserve the invariance of all observable quantities when the phase of the electron field was altered in any way from place to place and from moment to moment. Mathematically the phase shift must be

allowed to vary as an arbitrary function of position and time.

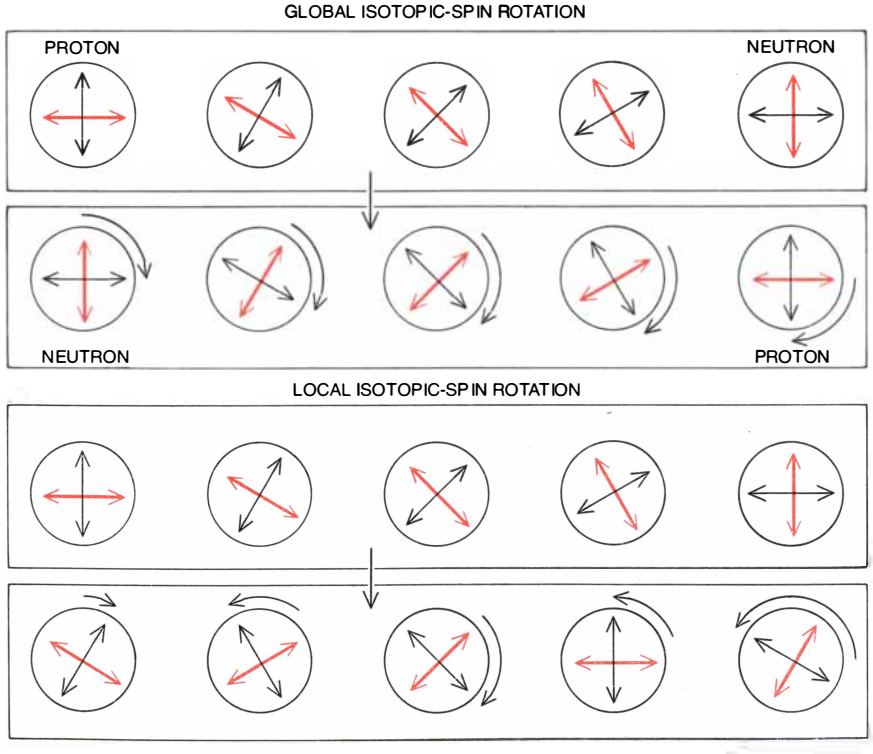
Although it may seem improbable, a field can be constructed that meets these specifications. It turns out that the required field is a vector one, corresponding to a field quantum with a spin of one unit. Moreover, the field must have infinite range, since there is no limit to the distance over which the phases of the electron fields might have to be reconciled. The need for infinite range implies that the field quantum must be massless. These are the properties of a field that is already familiar: the electromagnetic field, whose quantum is the photon.

How does the electromagnetic field ensure the gauge invariance of the electron field? It should be remembered that the effect of the electromagnetic field is to transmit forces between charged particles. These forces can alter the state of motion of the particles; what is most important in this context, they can alter the phase. When an electron absorbs or emits a photon, the phase of the electron field is shifted. It was shown above that the electromagnetic field itself exhibits an exact local symmetry; by describing the two fields together the local symmetry can be extended to both of them.

The connection between the two fields lies in the interaction of the electron's charge with the electromagnetic field. Because of this interaction the propagation of an electron matter wave in an electric field can be described properly only if the electric potential is specified. Similarly, to describe an electron in a magnetic field the magnetic vector potential must be specified. Once these two potentials are assigned definite values the phase of the electron wave is fixed everywhere. The local symmetry of electromagnetism, however, allows the electric potential to be given any arbitrary value, which can be chosen independently at every point and at every moment. For this reason the phase of the electron matter field can also take on any value at any point, but the phase will always be consistent with the convention adopted for the electric and the magnetic potentials.

What this means in the two-slit diffraction experiment is that the effects of an arbitrary shift in the phase of the electron wave can be mimicked by applying an electromagnetic field. For example, the change in the observed interference pattern caused by interposing a half-wave plate in front of one slit could be caused instead by placing the slits between the poles of a magnet. From the resulting pattern it would be impossible to tell which procedure had been followed. Since the gauge conventions for the electric and the magnetic potentials can be chosen locally, so can the phase of the electron field.

The theory that results from combining electron matter fields with electromagnetic fields is called quantum electrodynamics. Formulating the theory and proving its consistency was a labor of some 20 years, begun in the 1920's by P. A. M. Dirac and essentially completed in about 1948 by Richard P. Feynman, Julian Schwinger, Sin-itiro Tomonaga and others.



ISOTOPIC-SPIN SYMMETRY serves as the basis of another gauge theory, first discussed in 1954 by C. N. Yang and Robert L. Mills. If isotopic-spin symmetry is valid, the choice of which position of the internal arrow indicates a proton and which a neutron is entirely a matter of convention. Global symmetry (*upper diagram*) requires the same convention to be adopted everywhere, and any rotation of the arrow must be made in the same way at every point. In the Yang-Mills theory isotopic spin is made a local symmetry (*lower diagram*), so that the orientation of the arrow is allowed to vary from place to place. In order to preserve the invariance of all observable quantities with respect to such local isotopic-spin transformations it is necessary to introduce at least six fields, corresponding to three massless vector particles, or vector bosons. One of these particles can be identified as the photon; the other two carry electric charge. The theory has been influential, but in its original form it was unrealistic. It makes protons and neutrons indistinguishable and predicts massless charged particles that do not exist.

The symmetry properties of quantum electrodynamics are unquestionably appealing, but the theory can be invested with physical significance only if it agrees with the results of experiments. Indeed, before sensible experimental predictions can even be made the theory must pass certain tests of internal consistency. For example, quantum-mechanical theories predict the probabilities of events: the probabilities must not be negative, and all the probabilities taken together must add up to 1. In addition energies must be assigned positive values but should not be infinite.

It was not immediately apparent that quantum electrodynamics could qualify as a physically acceptable theory. One problem arose repeatedly in any attempt to calculate the result of even the simplest electromagnetic interactions, such as the interaction between two electrons. The likeliest sequence of events in such an encounter is that one electron emits a single virtual photon and the other electron absorbs it. Many more complicated exchanges are also possible, however; indeed, their number is infinite. For example, the electrons could interact by exchanging two photons, or three, and so on. The total probability of the interaction is determined by the sum of the contributions of all the possible events.

Feynman introduced a systematic procedure for tabulating these contributions by drawing diagrams of the events in one spatial dimension and one time dimension. A notably troublesome class of diagrams are those that include "loops," such as the loop in space-time that is formed when a virtual photon is emitted and later reabsorbed by the same electron. As was shown above, the maximum energy of a virtual particle is limited only by the time needed for it to reach its destination. When a virtual photon is emitted and reabsorbed by the same particle, the distance covered and the time required can be reduced to

Yes, the times call for enormous sacrifices. But who should make them? Car makers? Or car buyers?

As well prepared as you may be in these times to accept less in a car, Saab has made it quite unnecessary.

Saabs, you see, are designed and built in such a way that, as the experts at *Car and Driver* magazine so aptly put it, Saabs stand as "... perpetual monuments to the more fundamental virtues of traveling by car."

Nothing of consequence, in other words, has been forgotten.

Room.

The exterior dimensions of the Saab 900 are virtually identical to those of the Audi 4000 and 5000, the Volvo DL and GLE, the BMW 320i and 528i and the Mercedes 280E.

Inside, however, the Saab is bigger than all of them.

By EPA standards, in fact, the Saab is a mid-sized car. While the others are all compacts.

Performance.

Against the clock in two years of separate road tests—all of '78 and '79—the four-cylinder, front-wheel drive Saab 900 Turbo was faster than a number of cars on the *Road & Track* slalom course, among them three Mercedes, four BMWs, two Ferraris, two Jaguars and a couple of Porsches, including the 928.

(Given that kind of agility, there should be little wonder why a couple of Saabs won national titles at the '79 SCCA Championships.)

Braking.

A car that goes as quickly as the Saab is obligated to brake equally as spectacularly. And the Saab does.

From 60 to 0 in the *Road & Track* tests, the Saab 900 Turbo stopped faster than two Audis, two Jaguars, five BMWs, a Ferrari, a Maserati, a Mercedes and a Volvo, among others.

Utility.

The Saab 900 has a trunk equal in size to those in the largest sedans being made today.

Yet when even those huge proportions aren't large enough and you begin wishing you had a station wagon, the Saab accommodates you.

Fold the rear seat down, lift the rear hatchback and the Saab presents a station wagon-like cargo space over six feet long and 53 cubic feet big.

Comfort.

The seats in the Saab 900 include such things as special thigh supports, lumbar supports, even small recesses in the seat back to cradle your shoulder blades.

On some models, a heating element inside the front seats automatically warms you from the bottom up when it's cold outside.

Such meticulous attention to anatomical imperatives has yielded one of the most comfortable cars ever built. One rated more comfortable in a recent independent study, in fact, than the Mercedes 280E, a car that costs more than twice as much.

Economy.

The Saab 900 is not a tiny compact or sub-compact that gets good gas mileage.

It's a comfortable *mid-sized* car that does.

The Saab 900 EMS, for example, gets (21) EPA estimated mpg and 30 estimated highway mpg.

Better than the Audi 5000, the Volvo GT, the Volvo DL, the Volvo GLE, the Peugeot 604, the BMW 528i, the Mercedes 280E, the Mercedes 280CE and the Mercedes 280SE.

And nearly as good as some of the miniatures.

(Remember, use estimated mpg for comparison only. Mileage varies with speed, trip length and weather. Actual highway mileage will probably be less.)

Prestige.

What could be more prestigious in our times than buying a new car and not making a single, solitary compromise?

Test drive a Saab and you'll see how it's possible.

SAAB

The most intelligent car ever built.

zero, and so the maximum energy can be infinite. For this reason some diagrams with loops make an infinite contribution to the strength of the interaction.

The infinities encountered in quantum electrodynamics led initially to predictions that have no reasonable interpretation as physical quantities. Every interaction of electrons and photons was assigned an infinite probability. The infinities spoiled even the description of an isolated electron: because the electron can emit and reabsorb virtual particles it has infinite mass and infinite charge.

The cure for this plague of infinities is the procedure called renormalization. Roughly speaking, it works by finding one negative infinity for each positive infinity, so that in the sum of all the possible contributions the infinities cancel. The achievement of Schwinger and of the other physicists who worked on the problem was to show that a finite residue could be obtained by this method. The finite residue is the theory's prediction. It is uniquely determined by the requirement that all interaction probabilities come out finite and positive.

The rationale of this procedure can be explained as follows. When a measurement is made on an electron, what is actually measured is not the mass or the charge of the pointlike particle with which the theory begins but the properties of the electron together with its enveloping cloud of virtual particles. Only the net mass and charge, the measurable quantities, are required to be finite at all stages of the calculation. The properties of the pointlike object, which are called the "bare" mass and the "bare" charge, are not well defined.

Initially it appeared that the bare mass would have to be assigned a value of negative infinity, an absurdity that made many physicists suspicious of the renormalized theory. A more careful analysis, however, has shown that if the bare mass is to have any definite value, it tends to zero. In any case all quantities with implausible values are unobservable, even in principle. Another objection to the theory is more profound: mathematically quantum electrodynamics is not perfect. Because of the methods that must be used for making predictions in the theory the predictions are limited to a finite accuracy of some hundreds of decimal places.

Clearly the logic and the internal consistency of the renormalization method leave something to be desired. Perhaps the best defense of the theory is simply that it works very well. It has yielded results that are in agreement with experiments to an accuracy of about one part in a billion, which makes quantum electrodynamics the most accurate physical theory ever devised. It is the model for theories of the other fundamental forces and the standard by which such theories are judged.

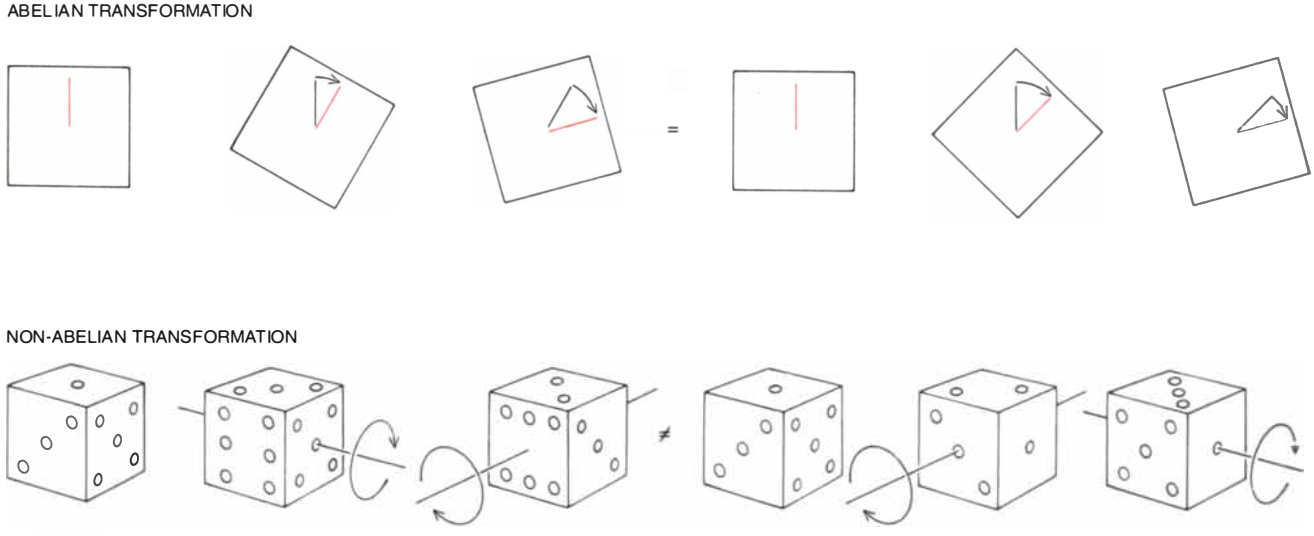
At the time quantum electrodynamics was completed another theory based on a local gauge symmetry had already been known for some 30 years. It is Einstein's general theory of relativity. The symmetry in question pertains not to a field distributed through space and time but to the structure of space-time itself.

Every point in space-time can be labeled by four numbers, which give its position in the three spatial dimensions and its sequence in the one time dimension. These numbers are the coordinates of the event, and the procedure for assigning such numbers to each point in space-time is a coordinate system. On the earth, for example, the three spatial coordinates are commonly given as longitude, latitude and altitude; the time coordinate can be given in hours past noon. The origin in this coordinate system, the point where all four coordinates have values of zero, lies at noon at sea level where the prime meridian crosses the Equator.

The choice of such a coordinate system is clearly a matter of convention. Ships at sea could navigate just as successfully if the origin of the coordinate system were shifted to Utrecht in the Netherlands. Every point on the earth and every event in its history would have to be assigned new coordinates, but calculations made with those coordinates would invariably give the same results as calculations made in the old system. In particular any calculation of the distance between two points would give the same answer.

The freedom to move the origin of a coordinate system constitutes a symmetry of nature. Actually there are three related symmetries: all the laws of nature remain invariant when the coordinate system is transformed by translation, by rotation or by mirror reflection. It is vital to note, however, that the symmetries are only global ones. Each symmetry transformation can be defined as a formula for finding the new coordinates of a point from the old coordinates. Those formulas must be applied simultaneously in the same way to all the points.

The general theory of relativity stems



EFFECTS OF REPEATED TRANSFORMATIONS distinguish quantum electrodynamics, which is an Abelian theory, from the Yang-Mills theory, which is non-Abelian. An Abelian transformation is commutative: if two transformations are applied in succession, the outcome is the same no matter which sequence is chosen. An example is rotation in two dimensions. Non-Abelian transformations are not commutative, so that two transformations will generally yield different results if their sequence is reversed. Rotations in three dimensions exhibit this dependence on sequence. Quantum electrodynamics is Abelian in that successive phase shifts can be applied to an electron field without regard to the sequence. The Yang-Mills theory is non-Abelian because the net effect of two isotopic-spin rotations is generally different if the sequence of rotations is reversed. One sequence might yield a proton and the opposite sequence a neutron.

HOW TO BUILD A BOEING.

Boeing is now building an airplane that'll save millions of gallons of fuel: the new generation 757.

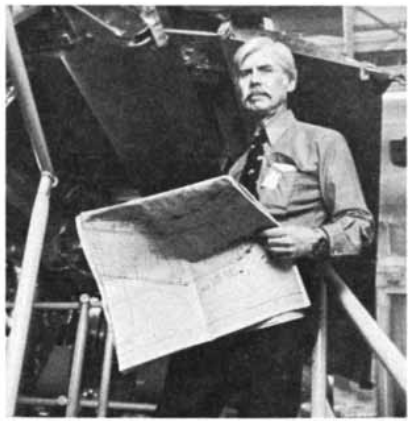
How much will it save?

A 757 flying 1.3 million miles a year will save 1.8 million gallons of fuel annually over the airplane it will replace.

Fuel economy has always been a concern to an airplane designer. Now it's more critical than ever.

Heading up one engineering group is Doug Miller. His specialty is preliminary design and development.

Doug and the design team were involved in the development of an airplane wing that has exceptionally efficient aerodynamics. It



would never have been possible if Boeing had not been testing and perfecting components of lightweight carbon-fiber and high-strength pure aluminum alloys.

Result: The 757 wing will get the airplane off the ground and flying with less fuel consumption than any airplane its size.

New aerodynamics, new materials, and engineering inventiveness along with a long-term commitment to constantly reach out and explore the unknown have made the 757 a reality.

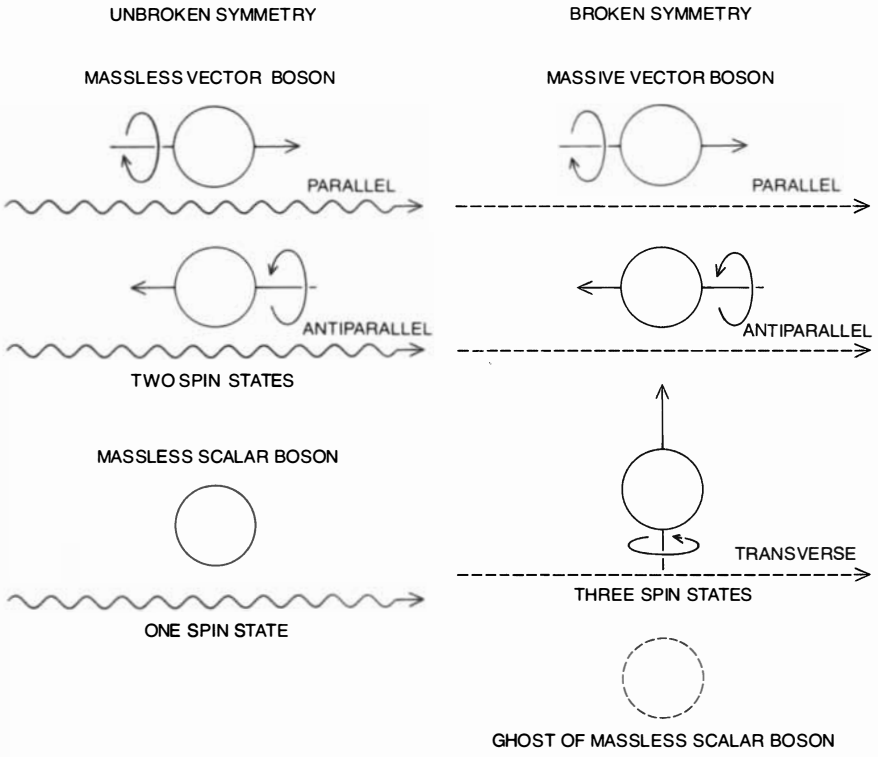
Boeing believes almost anything is possible. Doug and the team are but one part of the immensely complex process that has helped create a future world of efficient commercial aviation — a step that can keep air travel one of the best values in the world of rising inflation.

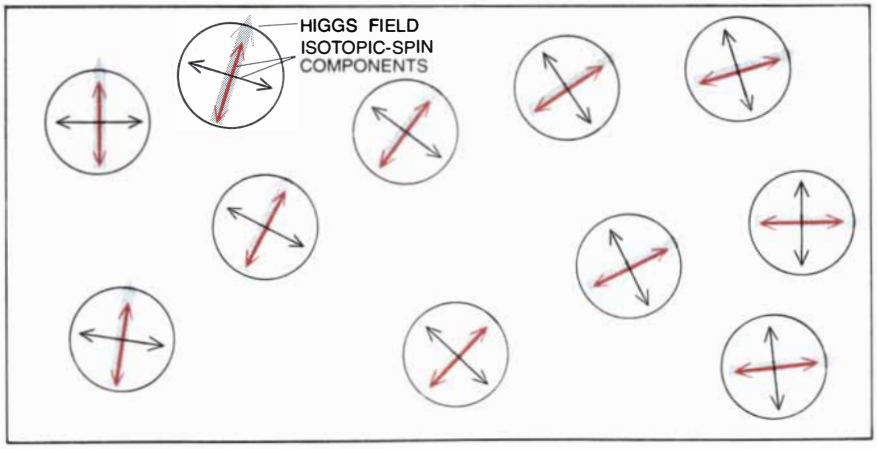
THE BOEING FAMILY

Getting people together.

from the fundamental observation that the structure of space-time is not necessarily consistent with a coordinate system made up entirely of straight lines meeting at right angles; instead a curvilinear coordinate system may be needed. The lines of longitude and latitude employed on the earth constitute such a system, since they follow the curvature of the earth.

In such a system a local coordinate transformation can readily be imagined. Suppose height is defined as vertical distance from the ground rather than from mean sea level. The digging of a pit would then alter the coordinate system, but only at those points directly over the pit. The digging itself represents the local coordinate transformation. It would appear that the laws of physics





HIGGS MECHANISM can lend mass to the photonlike vector bosons of the Yang-Mills theory, thereby making the theory more realistic. The massless bosons have three possible spin orientations (parallel, antiparallel and transverse to the direction of motion), but only two of these are observable; the transverse state does not exist, a peculiarity of all massless particles, which move with the speed of light. If the Yang-Mills particles were to acquire a mass, the transverse state would become observable, and this added mode of motion must have some source. In the Higgs mechanism the source is an extra scalar field, corresponding to a massless spin-zero boson. The Yang-Mills particle is said to "eat" the Higgs boson, which thereupon becomes an unobservable "ghost." The Higgs field also provides a frame of reference (*gray arrows*) in which protons can be distinguished from neutrons. The arrow of the Higgs field rotates along with the other arrows in a gauge transformation, and so there is no absolute orientation, but the relative orientation of the isotopic-spin arrows can be measured with respect to the Higgs arrow. The symmetry of the theory, which without the Higgs mechanism would have abolished all differences between the proton and the neutron, has not been lost but only hidden.

(or the rules of navigation) do not remain invariant after such a transformation, and in a universe without gravitational forces that would be the case. An airplane set to fly at a constant height would dip suddenly when it flew over the excavation, and the accelerations needed to follow the new profile of the terrain could readily be detected.

As in electrodynamics, local symmetry can be restored only by adding a new field to the theory; in general relativity the field is of course that of gravitation. The presence of this field offers an alternative explanation of the accelerations detected in the airplane: they could result not from a local change in the coordinate grid but from an anomaly in the gravitational field. The source of the anomaly is of no concern: it could be a concentration of mass in the earth or a distant object in space. The point is that any local transformation of the coordinate system could be reproduced by an appropriate set of gravitational fields. The pilot of the airplane could not distinguish one effect from the other.

Both Maxwell's theory of electromagnetism and Einstein's theory of gravitation owe much of their beauty to a local gauge symmetry; their success has long been an inspiration to theoretical physicists. Until recently theoretical accounts of the other two forces in nature have been less satisfactory. A theory of the weak force formulated in the 1930's by Enrico Fermi accounted for some basic features of the weak interaction, but the theory lacked local symmetry. The strong interactions seemed to be a jungle of mysterious fields and resonating particles. It is now clear why it took so long to make sense of these forces: the necessary local gauge theories were not understood.

The first step was taken in 1954 in a theory devised by C. N. Yang and Robert L. Mills, who were then at the Brookhaven National Laboratory. A similar idea was proposed independently at about the same time by R. Shaw of the University of Cambridge. Inspired by the success of the other gauge theories, these theories begin with an established global symmetry and ask what the consequences would be if it were made a local symmetry.

The symmetry at issue in the Yang-Mills theory is isotopic-spin symmetry, the rule stating that the strong interactions of matter remain invariant (or nearly so) when the identities of protons and neutrons are interchanged. In the global symmetry any rotation of the internal arrows that indicate the isotopic-spin state must be made simultaneously everywhere. Postulating a local symmetry allows the orientation of the arrows to vary independently from place to place and from moment to moment. Rotations of the arrows can depend on any

arbitrary function of position and time. This freedom to choose different conventions for the identity of a nuclear particle in different places constitutes a local gauge symmetry.

As in other instances where a global symmetry is converted into a local one, the invariance can be maintained only if something more is added to the theory. Because the Yang-Mills theory is more complicated than earlier gauge theories it turns out that quite a lot more must be added. When isotopic-spin rotations are made arbitrarily from place to place, the laws of physics remain invariant only if six new fields are introduced. They are all vector fields, and they all have infinite range.

The Yang-Mills fields are constructed on the model of electromagnetism, and indeed two of them can be identified with the ordinary electric and magnetic fields. In other words, they describe the field of the photon. The remaining Yang-Mills fields can also be taken in pairs and interpreted as electric and magnetic fields, but the photons they describe differ in a crucial respect from the known properties of the photon: they are still massless spin-one particles, but they carry an electric charge. One photon is negative and one is positive.

The imposition of an electric charge on a photon has remarkable consequences. The photon is defined as the field quantum that conveys electromagnetic forces from one charged particle to another. If the photon itself has a charge, there can be direct electromagnetic interactions among the photons. To cite just one example, two photons with opposite charges might bind together to form an "atom" of light. The familiar neutral photon never interacts with itself in this way.

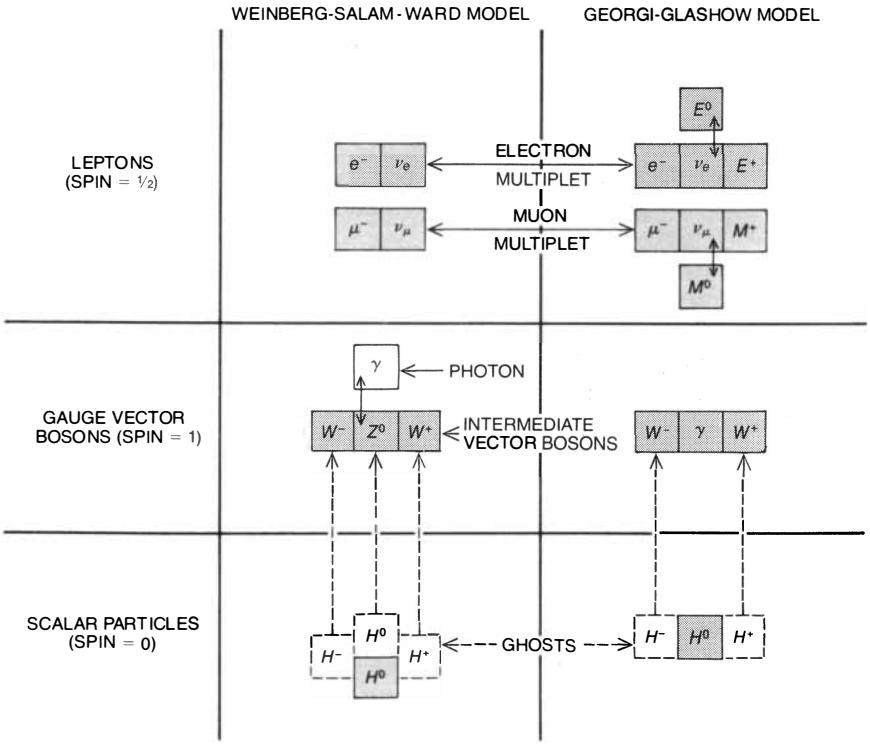
The surprising effects of charged photons become most apparent when a local symmetry transformation is applied more than once to the same particle. In quantum electrodynamics, as was pointed out above, the symmetry operation is a local change in the phase of the electron field, each such phase shift being accompanied by an interaction with the electromagnetic field. It is easy to imagine an electron undergoing two phase shifts in succession, say by emitting a photon and later absorbing one. Intuition suggests that if the sequence of the phase shifts were reversed, so that first a photon was absorbed and later one was emitted, the end result would be the same. This is indeed the case. An unlimited series of phase shifts can be made, and the final result will be simply the algebraic sum of all the shifts no matter what their sequence.

In the Yang-Mills theory, where the symmetry operation is a local rotation of the isotopic-spin arrow, the result of multiple transformations can be quite different. Suppose a hadron is subjected to a gauge transformation, A, followed soon after by a second transformation, B; at the end of this sequence the isotopic-spin arrow is found in the orientation that corresponds to a proton. Now suppose the same transformations were applied to the same hadron but in the reverse sequence: B followed by A. In general the final state will not be the same; the particle may be a neutron instead of a proton. The net effect of the two transformations depends explicitly on the sequence in which they are applied.

Because of this distinction quantum electrodynamics is called an Abelian theory and the Yang-Mills theory is called a non-Abelian one. The terms are borrowed from the mathematical theory of groups and honor Niels Henrik Abel, a Norwegian mathematician who lived in the early years of the 19th century. Abelian groups are made up of transformations that, when they are applied one after another, have the commutative property; non-Abelian groups are not commutative.

Commutation is familiar in arithmetic as a property of addition and multiplication, where for any numbers A and B it can be stated that $A + B = B + A$ and $A \times B = B \times A$. How the principle can be applied to a group of transformations can be illustrated with a familiar example: the group of rotations. All possible rotations of a two-dimensional object are commutative, and so the group of such rotations is Abelian. For instance, rotations of $+60$ degrees and -90 degrees yield a net rotation of -30 degrees no matter which is applied first. For a three-dimensional object free to rotate about three axes the commutative law does not hold, and the group of three-dimensional rotations is non-Abelian. As an example, consider an airplane heading due north in level flight. A 90-degree yaw to the left followed by a 90-degree roll to the left leaves the airplane heading west with its left wing tip pointing straight down. Reversing the sequence of transformations, so that a 90-degree roll to the left is followed by a 90-degree left yaw, puts the airplane in a nose dive with the wings aligned on the north-south axis.

Like the Yang-Mills theory, the general theory of relativity is non-Abelian:



WEINBERG-SALAM-WARD MODEL incorporates electromagnetism and the weak force in a local gauge theory. The model applies to the interactions of the particles called leptons, which include the electron (e^-), the muon (μ^-) and two kinds of neutrino (ν_e and ν_μ). A requirement that the interactions of these particles remain invariant with respect to local transformations of a leptonic equivalent of isotopic spin gives rise to four massless fields. Three of these fields are then given a mass through the Higgs mechanism; they become the intermediate vector bosons W^+, W^- and Z^0. The fourth vector boson is the photon. Three of the Higgs particles are eaten by the vector bosons and become ghosts, but a fourth is left over and should be observable. The theory does not truly unify the electromagnetic forces and the weak forces because the photon is still in a family of its own. A theory proposed by Howard Georgi and Sheldon Lee Glashow suggested a more profound unification, where the photon and the massive vector bosons were in the same family, but that theory is now contradicted by experiment.

DREAMERS, HERETICS, GADFLIES, MAVERICKS, AND GENIUSES.

The story goes that Henry Ford once hired an efficiency expert to evaluate his company.

After a few weeks, the expert made his report. It was highly favorable except for one thing.

"It's that man down the hall," said the expert. "Every time I go by his office he's just sitting there with his feet on his desk. He's wasting your money."

"That man," replied Mr. Ford, "once had an idea that saved us millions of dollars. At the time, I believe his feet were planted right where they are now."

At IBM, we have 46 people like that, and we don't worry about where they put their feet either. They are the IBM Fellows.

They earned the title by having ideas that made a difference. Their job is to have more ideas like that, but under a very special condition.

It's called freedom.

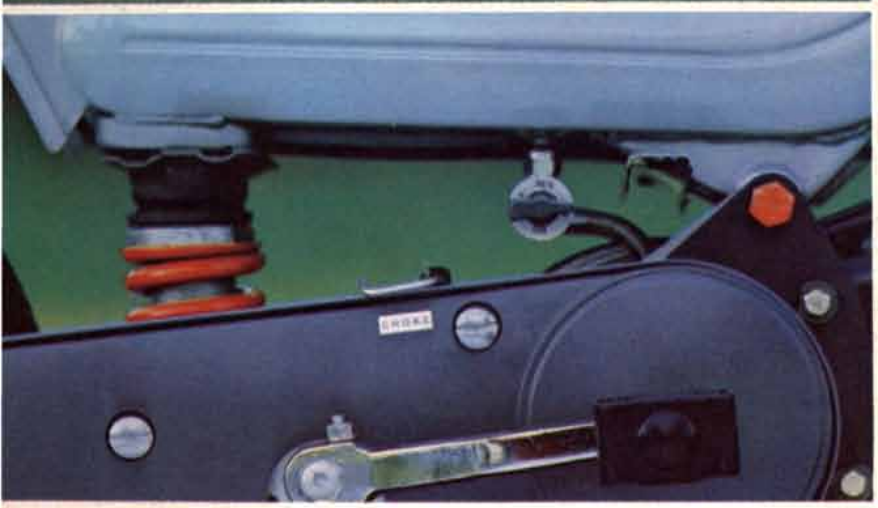
Freedom from deadlines. Freedom from committees. Freedom from the usual limits of corporate approval.

For a term of at least 5 years, an IBM Fellow is free to pursue any advanced project of value to IBM, even if chances for success may seem remote.

As a result, some of the great innovations of our time have come from IBM Fellows.

We may not always understand what they're doing, much less how they do it. But we do know this:

The best way to inspire an IBM Fellow is to get out of the way. IBM®



INTRODUCING SI. VESPA'S YES MACHINE.

No more "no's," it's time to say "yes" to an entirely new and innovative moped, the Vespa Si (say "see," Italian for "yes").

Yes, to the unmistakably sophisticated and sleek design that says, "It's a Vespa."

Test ride a Si moped and say "yes" to the remarkably smooth ride. That's because the Si uses a unique and advanced internal cantilever suspension. The shock absorbing action is hidden, but you'll know it's functioning. The front suspension is a telescopic fork in oil bath with springs and rebound buffers.

Say "yes" to the unique, sporty mag wheels which are standard equipment on all Si's.

"Yes" to the great mileage the Si gives—up to 140 mpg. Now that's economy.

"Yes" to the variable ratio drive that delivers extra power when it's needed.

Say "yes" to the efficient two stroke engine. It's practically maintenance-free!

The new Vespa Si moped. Proudly brought to you by Vespa of America and the Piaggio Group, along with other Vespa mopeds, the Ciao (say "chow"), Bravo, and two-passenger Grande. With over 6 million Vespa scooters and over 2 million Vespa mopeds sold throughout the world, Vespa and Piaggio have built up in over thirty years a world wide reputation for two wheel excellence. So we back all our Vespa mopeds and scooters with a 12-month, unlimited mileage warranty.

Now, how can you say no to a Si?

For the Vespa dealer nearest you, check your local Yellow Pages, or write us.

Mileage is based on CUNA Standards. Yours may vary. The Vespa Grande is built for two persons. Two-passenger operation is not permitted in some states. Check local laws for operation and ownership. Ask your Vespa dealer about Vespa Limited Warranty. Vespa of America, Consumer Relations, 355 Valley Drive, Brisbane, CA 94005.

PIAGGIO GROUP

vespa®

THE UNCOMMON CARRIER

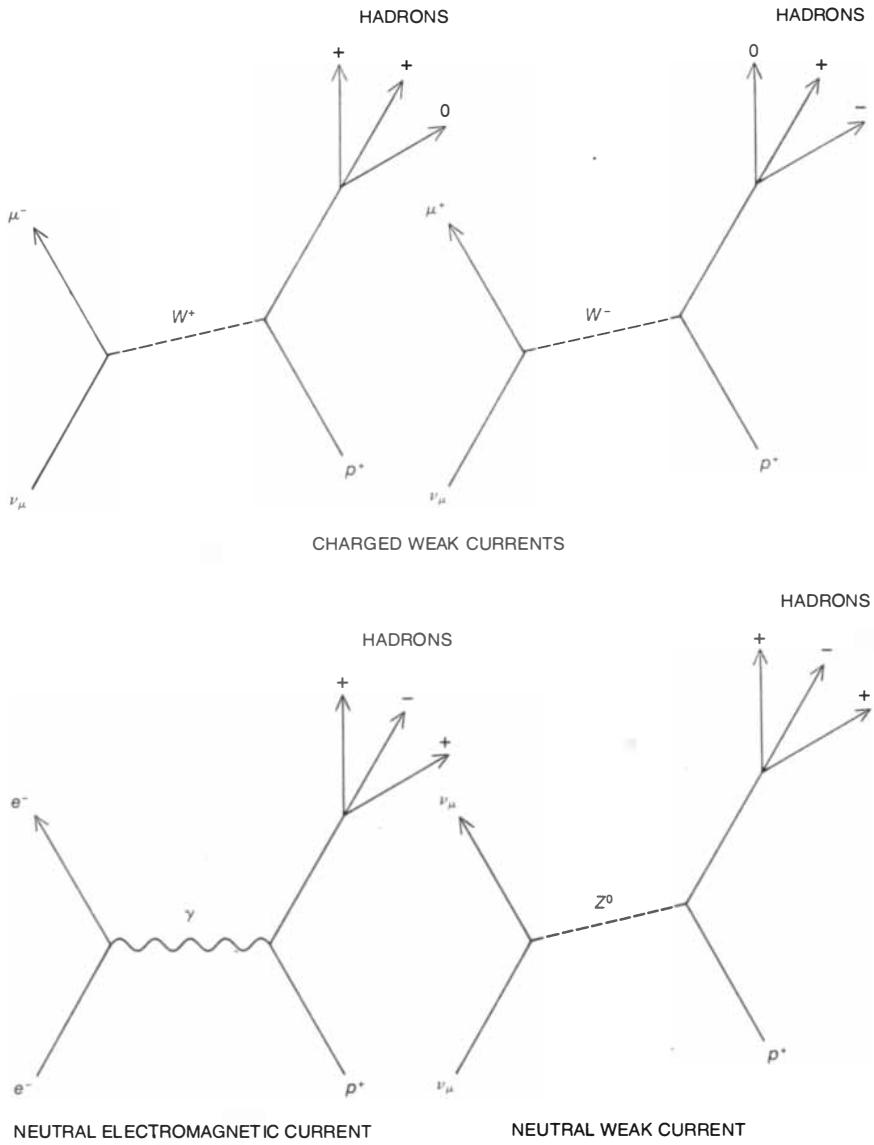
in making two successive coordinate transformations, the order in which they are made usually has an effect on the outcome. In the past 10 years or so several more non-Abelian theories have been devised, and even the electromagnetic interactions have been incorporated into a larger theory that is non-Abelian. For now, at least, it seems all the forces of nature are governed by non-Abelian gauge theories.

The Yang-Mills theory has proved to be of monumental importance, but as it was originally formulated it was totally unfit to describe the real world. A first objection to it is that isotopic-spin symmetry becomes exact, with the result that protons and neutrons are indistinguishable; this situation is obviously contrary to fact. Even more troubling is the prediction of electrically charged photons. The photon is necessarily massless because it must have an infinite range. The existence of any electrically charged particle lighter than the electron would alter the world beyond recognition. Of course, no such particle has been observed. In spite of these difficulties the theory has great beauty and philosophical appeal. One strategy adopted in an attempt to fix its defects was to artificially endow the charged field quanta with a mass greater than zero.

Imposing a mass on the quanta of the charged fields does not make the fields disappear, but it does confine them to a finite range. If the mass is large enough, the range can be made as small as is wished. As the long-range effects are removed the existence of the fields can be reconciled with experimental observations. Moreover, the selection of the neutral Yang-Mills field as the only real long-range one automatically distinguishes protons from neutrons. Since this field is simply the electromagnetic field, the proton and the neutron can be distinguished by their differing interactions with it, or in other words by their differing electric charges.

With this modification the local symmetry of the Yang-Mills theory would no longer be exact but approximate, since rotation of the isotopic-spin arrow would now have observable consequences. That is not a fundamental objection: approximate symmetries are quite commonplace in nature. (The bilateral symmetry of the human body is only approximate.) Moreover, at distance scales much smaller than the range of the massive components of the Yang-Mills field, the local symmetry becomes better and better. Thus in a sense the microscopic structure of the theory could remain locally symmetric, but not its predictions of macroscopic, observable events.

The modified Yang-Mills theory was easier to understand, but the theory still had to be given a quantum-mechanical interpretation. The problem of infinities turned out to be severer than it had been in quantum electrodynamics, and the standard recipe for renormalization would not solve it. New techniques had to be devised.



NEUTRAL WEAK CURRENTS provide the decisive test of the Weinberg-Salam-Ward model. It once appeared that all weak interactions involved a transfer of electric charge between the interacting particles; these events could be explained by just two intermediate vector bosons, the W^+ and the W^-. Events in which no charge was transferred were characteristic of electromagnetic interactions, where the exchanged virtual particle is a photon. The Weinberg-Salam-Ward model predicts that weak interactions can also proceed without charge transfer; these neutral weak currents are mediated by the neutral boson Z^0, which is identical with the photon except that it has a very large mass. Neutral weak currents were first observed in 1973.

An important idea was introduced in 1963 by Feynman: it is the notion of a "ghost" particle, a particle added to a theory in the course of a calculation that vanishes when the calculation is finished. It is known from the outset that the ghost particle is fictitious, but its use can be justified if it never appears in the final state. This can be ensured by making certain the total probability of producing a ghost particle is always zero.

Among theoretical groups that continued work on the Yang-Mills theory the ghost-particle method was taken seriously only at the University of Utrecht, where I was then a student. Martin J. G. Veltman, my thesis adviser, together with John S. Bell of the European Organization for Nuclear Research (CERN) in Geneva, was led to the conclusion that the weak interactions might be described by some form of the Yang-Mills theory. He undertook a systematic analysis of the renormalization problem in the modified Yang-Mills model (with massive charged fields), examining each class of Feynman diagrams in turn. The diagrams having no closed loops were readily shown to make only finite contributions

to the total interaction probability. The diagrams with one loop do include infinite terms, but by exploiting the properties of the ghost particles it was possible to make the positive infinities and the negative ones cancel exactly.

As the number of loops increases, the number of diagrams rises steeply; moreover, the calculations required for each diagram become more intricate. To assist in the enormous task of checking all the two-loop diagrams a computer program was written to handle the algebraic manipulation of the probabilities. The output of the program is a list of the coefficients of the infinite quantities remaining after the contributions of all the diagrams have been summed. If the infinities are to be expunged from the theory, the coefficients must without exception be zero. By 1970 the results were known and the possibility of error had been excluded; some infinities remained.

The failure of the modified Yang-Mills theory was to be blamed not on any defect in the Yang-Mills formulation itself but rather on the modifications. The masses of the charged fields had to be put in "by hand" and as a result the invariance with respect to local isotopic-spin rotations was not quite perfect. It was suggested at the time by the Russian investigators L. D. Faddeev, V. N. Popov, E. S. Fradkin and I. V. Tyutin that the pure Yang-Mills theory, with only massless fields, could indeed be renormalized. The trouble with this theory is that it not only is unrealistic but also has long-range fields that are difficult to work with.

In the meantime another new ingredient for the formulation of gauge theories had been introduced by F. Englert and Robert H. Brout of the University of Brussels and by Peter Higgs of the University of Edinburgh. They found a way to endow some of the Yang-Mills fields with mass while retaining exact gauge symmetry. The technique is now called the Higgs mechanism.

The fundamental idea of the Higgs mechanism is to include in the theory an extra field, one having the peculiar property that it does not vanish in the vacuum. One usually thinks of a vacuum as a space with nothing in it, but in physics the vacuum is defined more precisely as the state in which all fields have their lowest possible energy. For most fields the energy is minimized when the value of the field is zero everywhere, or in other words when the field is "turned off." An electron field, for example, has its minimum energy when there are no electrons. The Higgs field is unusual in this respect. Reducing it to zero costs energy; the energy of the field is smallest when the field has some uniform value greater than zero.

The effect of the Higgs field is to provide a frame of reference in which the orientation of the isotopic-spin arrow can be determined. The Higgs field can be represented as an arrow superposed on the other isotopic-spin indicators in the imaginary internal space of a hadron. What distinguishes the arrow of the Higgs field is that it has a fixed length, established by the vacuum value of the field. The orientation of the other isotopic-spin arrows can then be measured with respect to the axis defined by the Higgs field. In this way a proton can be distinguished from a neutron.

It might seem that the introduction of the Higgs field would spoil the gauge symmetry of the theory and thereby lead again to insoluble infinities. In actuality, however, the gauge symmetry is not destroyed but merely concealed. The symmetry specifies that all the laws of physics must remain invariant when the isotopic-spin arrow is rotated in an arbitrary way from place to place. This implies that the absolute orientation of the arrow cannot be determined, since any experiment for measuring the orientation would have to detect some variation in a physical quantity when the arrow was rotated. With the inclusion of the Higgs field the absolute orientation of the arrow still cannot be determined because the arrow representing the Higgs field also rotates during a gauge transformation. All that can be measured is the angle between the arrow of the Higgs field and the other isotopic-spin arrows, or in other words their relative orientations.

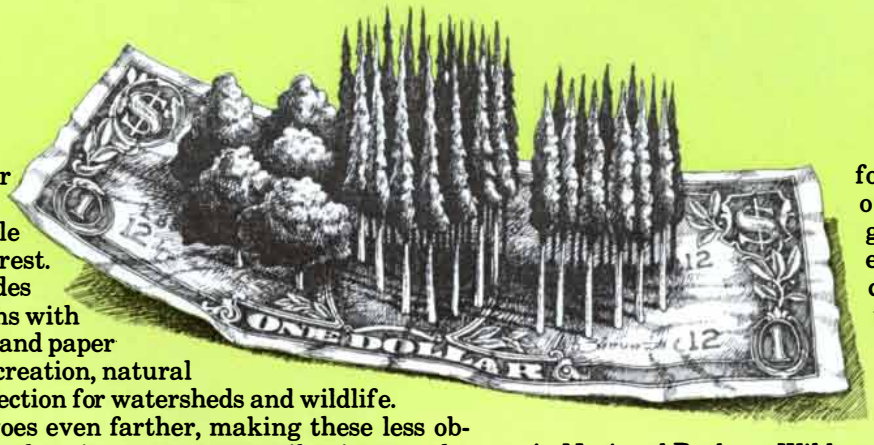
The Higgs mechanism is an example of the process called spontaneous symmetry breaking, which was already well established in other areas of physics. The concept was first put forward by Werner Heisenberg in his description of ferromagnetic materials. Heisenberg pointed out that the theory describing a ferromagnet has perfect geometric symmetry in that it gives no special distinction to any one direction in space. When the material becomes magnetized, however, there is one axis—the direction of magnetization—that can be distinguished from all other axes. The theory is symmetrical but the object it describes is not. Similarly, the Yang-Mills theory retains its gauge symmetry with respect to rotations of the isotopic-spin arrow, but the objects described—protons and neutrons—do not express the symmetry.

How does the Higgs mechanism lend mass to the quanta of the Yang-Mills field? The process can be explained as follows. The Higgs field is a scalar quantity, having only a magnitude, and so the quantum of the field must have a spin of zero. The Yang-Mills fields are vectors, like the electromagnetic field, and are represented by spin-one quanta. Ordinarily a particle with a spin of one unit has three spin states (oriented parallel, antiparallel and transverse to its direction of motion), but because the Yang-

A report on the great American forest.

Money does grow on trees.

(And vice versa.)



Consider the wonderfully versatile American forest.

It provides all Americans with useful wood and paper products, recreation, natural beauty, protection for watersheds and wildlife.

But it goes even farther, making these less obvious, but no less important, contributions to the country's economic well-being:

Jobs — millions of workers in the woods, in the factories that turn wood and fiber into thousands of essential products, and on construction sites all over this growing land.

Taxes — billions of dollars a year, going to support schools, hospitals, public safety, countless other vital public services.

International trade — wood products we export help strengthen the American dollar and improve the nation's balance of payments.

Inflation deterrent — the more productive the forest, the more likely that the nation's supply of wood and paper products will be adequate to meet sharply increasing demands — and will be available at reasonable prices. Thus, a productive commercial forest, growing trees for today *and* tomorrow, becomes a significant inflation fighter.

Your stake in the commercial forest

So every American has a stake in increasing the productivity of the commercial forests. (*Commercial forest,* as defined by the U.S. Forest Service, is *all* forestland — whether owned by individuals, government or the forest industry — that is capable of, and potentially available for, growing repeated crops of trees for harvest. It includes land in National Forests but not in National Parks or Wilderness areas.)

So far, the commercial forest has been able to cope with all the demands made on it. But we can't expect it to continue to provide its benefits automatically.

Why trees need money too

If wood supply is to keep up with the predicted doubling of demand in this nation over the next 50 years, expenditures for replanting and regeneration will have to be substantially increased.

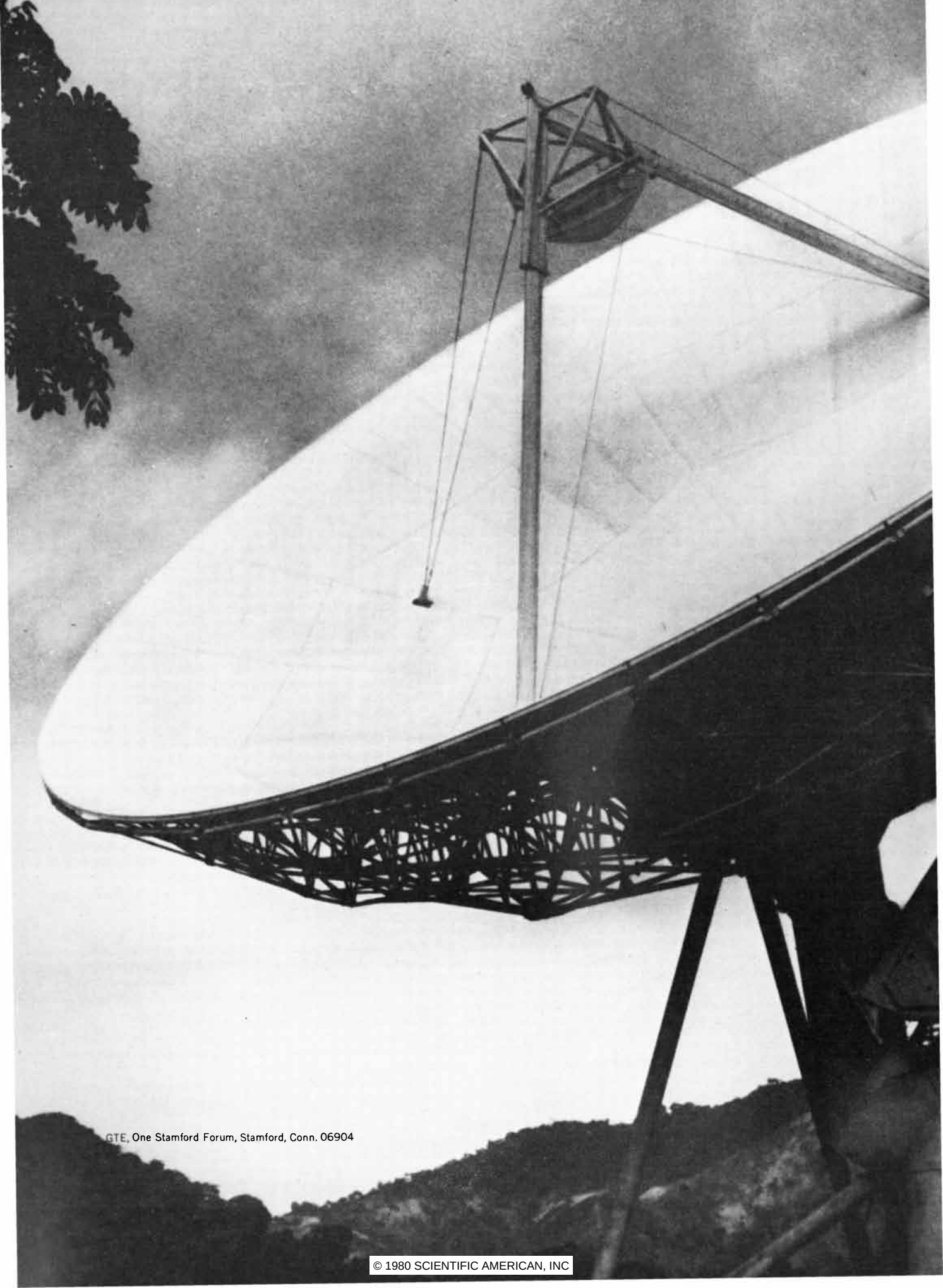
And the greatest potential for improvement is on publicly held land.

So that means the nation needs to establish policies and take actions to encourage productivity — not only in the National Forests but in other forests as well.

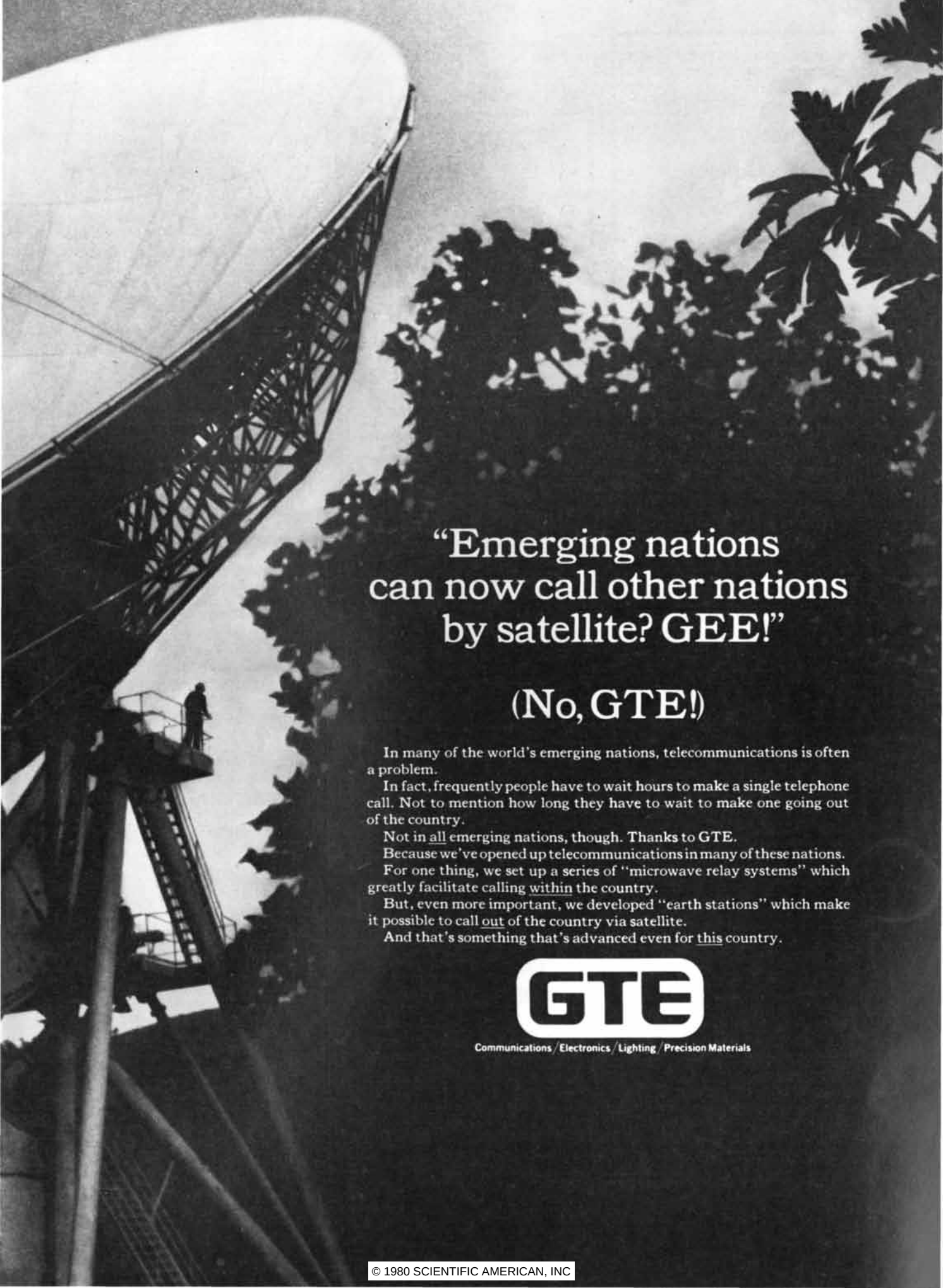
If you'd like to be better informed on how important it is to keep America's forests productive, write American Forest Institute, P.O. Box 873, Springfield, VA 22150 for a free booklet, "The Great American Forest."

The great American forest. Trees for tomorrow. And tomorrow. And all the tomorrows after that.

Trees. America's renewable resource.



GTE, One Stamford Forum, Stamford, Conn. 06904



"Emerging nations can now call other nations by satellite? GEE!"

(No, GTE!)

In many of the world's emerging nations, telecommunications is often a problem.

In fact, frequently people have to wait hours to make a single telephone call. Not to mention how long they have to wait to make one going out of the country.

Not in all emerging nations, though. Thanks to GTE.

Because we've opened up telecommunications in many of these nations.

For one thing, we set up a series of "microwave relay systems" which greatly facilitate calling within the country.

But, even more important, we developed "earth stations" which make it possible to call out of the country via satellite.

And that's something that's advanced even for this country.

GTE

Communications / Electronics / Lighting / Precision Materials

Mills particles are massless and move with the speed of light they are a special case; their transverse states are missing. If the particles were to acquire a mass, they would lose this special status and all three spin states would have to be observable. In quantum mechanics the accounting of spin states is strict and the extra state must come from somewhere; it comes from the Higgs field. Each Yang-Mills quantum coalesces with one Higgs particle; as a result the Yang-Mills particle gains mass and a spin state, whereas the Higgs particle disappears. A picturesque description of this process has been suggested by Abdus Salam of the International Center for Theoretical Physics in Trieste: the massless Yang-Mills particles "eat" the Higgs particles in order to gain weight, and the swallowed Higgs particles become ghosts.

In 1971, Veltman suggested that I investigate the renormalization of the pure Yang-Mills theory. The rules for constructing the needed Feynman diagrams had already been formulated by Faddeev, Popov, Fradkin and Tyutin, and independently by Bryce S. DeWitt of the University of Texas at Austin and Stanley Mandelstam of the University of California at Berkeley. I could adapt to the task the powerful methods for renormalization studies that had been developed by Veltman.

Formally the results were encouraging, but if the theory was to be a realistic one, some means had to be found to confine the Yang-Mills fields to a finite range. I had just learned at a summer school how Kurt Symanzik of the German Electron Synchrotron and Benjamin W. Lee of the Fermi National Accelerator Laboratory had successfully handled the renormalization of a theoretical model in which a global symmetry is spontaneously broken. It therefore seemed natural to try the Higgs mechanism in the Yang-Mills theory, where the broken symmetry is a local one.

A few simple models gave encouraging results: in these selected instances all infinities canceled no matter how many gauge particles were exchanged and no matter how many loops were included in the Feynman diagrams. The decisive test would come when the theory was checked by the computer program for infinities in all possible diagrams with two loops. The results of that test were available by July, 1971; the output of the program was an uninterrupted string of zeros. Every infinity canceled exactly. Subsequent checks showed that infinities were also absent even in extremely complicated Feynman diagrams. My results were soon confirmed by others, notably by Lee and by Jean Zinn-Justin of the Saclay Nuclear Research Center near Paris.

The Yang-Mills theory had begun as

a model of the strong interactions, but by the time it had been renormalized interest in it centered on applications to the weak interactions. In 1967 Steven Weinberg of Harvard University and independently (but later) Salam and John C. Ward of Johns Hopkins University had proposed a model of the weak interactions based on a version of the Yang-Mills theory in which the gauge quanta take on mass through the Higgs mechanism. They speculated that it might be possible to renormalize the theory, but they did not demonstrate it. Their ideas therefore joined many other untested conjectures until some four years later, when my own results showed it was just that subclass of Yang-Mills theories incorporating the Higgs mechanism that can be renormalized.

The most conspicuous trait of the weak force is its short range: it has a significant influence only to a distance of 10^{-15} centimeter, or roughly a hundredth the radius of a proton. The force is weak largely because its range is so short: particles are unlikely to approach each other closely enough to interact. The short range implies that the virtual particles exchanged in weak interactions must be very massive. Present estimates run to between 80 and 100 times the mass of the proton.

The Weinberg-Salam-Ward model actually embraces both the weak force and electromagnetism. The conjecture on which the model is ultimately founded is a postulate of local invariance with respect to isotopic spin; in order to preserve that invariance four photonlike fields are introduced, rather than the three of the original Yang-Mills theory. The fourth photon could be identified with some primordial form of electromagnetism. It corresponds to a separate force, which had to be added to the theory without explanation. For this reason the model should not be called a unified field theory. The forces remain distinct; it is their intertwining that makes the model so peculiar.

At the outset all four of the fields in the Weinberg-Salam-Ward model are of infinite range and therefore must be conveyed by massless quanta; one field carries a negative electric charge, one carries a positive charge and the other two fields are neutral. The spontaneous symmetry breaking introduces four Higgs fields, each field represented by a scalar particle. Three of the Higgs fields are swallowed by Yang-Mills particles, so that both of the charged Yang-Mills particles and one of the neutral ones take on a large mass. These particles are collectively named massive intermediate vector bosons, and they are designated W^+, W^- and Z^0. The fourth Yang-Mills particle, which is a neutral one, remains massless: it is the photon of electromagnetism. Of the Higgs parti-

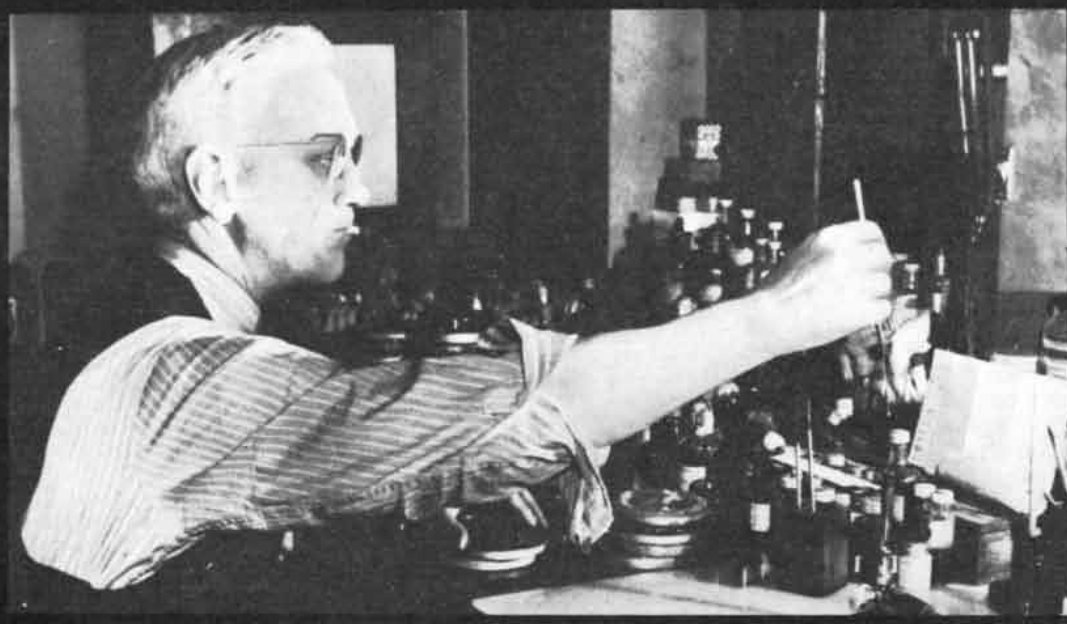


Photo: Bettman Archive

Coincidence often reaches a long arm into the world of science. It is the process of science–such as Alexander Fleming's chance discovery of penicillin–that makes the experience so compelling, so much like art.

Science is this century's art

The Search For Solutions. A book... a television series... a new way of seeing a world we once thought mysterious and remote. Horace Judson's probing of this special world reveals that the fun of science is in the pursuit of answers.

Judson's crisp and perceptive style captures scientists as they are: human and combative, propelled by a rage to know and governed by a sure sense that the right answer has its own elegance.

Illustrated with magnificent color photographs that enlarge our definition of what science is, Judson's book makes *us* the discoverers.

Here is a book about science that transcends age, sophistication and levels of knowledge to reach everyone. **"I do not know how Judson has succeeded in mastering the stores of information from so many disciplines... in a narrative so engrossing."** — LEWIS THOMAS, M.D.

Science is this century's art, and its ideas are among the most beautiful and fascinating treasures we can enjoy. *The Search For Solutions* is a rare gift.

Lavish 11" x 8" format.
More than 100 full-color photographs

THE SEARCH FOR SOLUTIONS

$16.95

By Horace Freeland Judson,
author of *The Eighth Day of Creation*
Introduction By Lewis Thomas, M.D.,
author of *The Lives of a Cell* and
The Medusa and the Snail

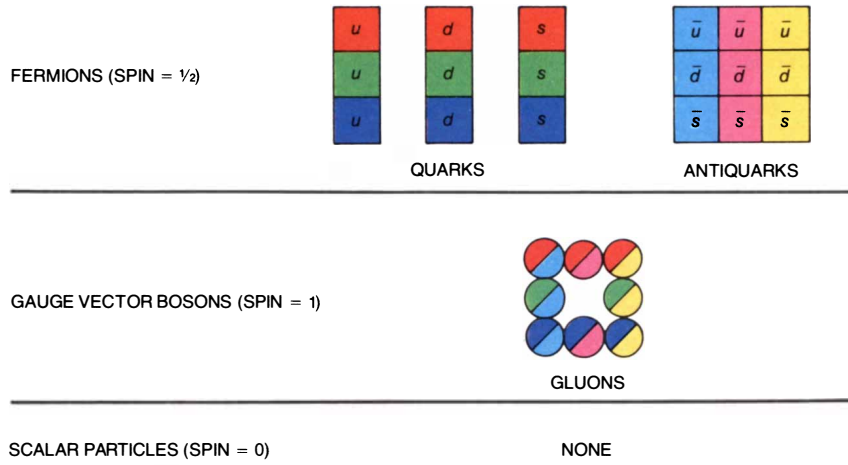
Holt, Rinehart & Winston

Explore the world of science in process
In a parallel television mini-series
Tune in
THE SEARCH FOR SOLUTIONS
Narrated by Stacy Keach
June 10, 17 & 24, 9:00 p.m. (ET)
on PBS

cles, the three that lend mass to the Yang-Mills particles become ghosts and are therefore unobservable, but the last Higgs particle is not absorbed, and it should be seen if enough energy is available to produce it.

The most intriguing prediction of the model was the existence of the Z^0, a particle identical with the photon in all respects except mass, which had not been included in any of the earlier, provisional accounts of the weak force. Without the Z^0 any weak interaction would necessarily entail an exchange of electric charge. Events of this kind are called charged-weak-current events. The Z^0 introduced a new kind of weak interaction, a neutral-weak-current event. By exchanging a Z^0, particles would interact without any transfer of charge and could retain their original identities. Neutral weak currents were first observed in 1973 at CERN.

The elaboration of a successful gauge theory of the strong interactions, which are unique to hadrons, could not be undertaken until a fundamental fact about the hadrons was understood: they are not elementary particles. A model of hadrons as composite objects was proposed in 1963 by Murray Gell-Mann of the California Institute of Technology; a similar idea was introduced independently and at about the same time by Yuval Ne'eman of Tel Aviv University and George Zweig of Cal Tech. In this model hadrons are made up of the smaller particles Gell-Mann named quarks. A hadron can be built out of quarks according to either of two blueprints. Combining three quarks gives rise to a baryon, a class of hadrons that includes the proton and the neutron. Binding together one quark and one antiquark makes a meson, a class typified by the pions. Every known hadron can be accounted for as one of these allowed combinations of quarks.



QUARK MODEL describes all hadrons, including the proton and the neutron, as being composite particles made up of the smaller entities called quarks. In the original form of the model the quarks were assumed to come in three "flavors," labeled *u*, *d* and *s*, each of which is now said to have three possible "colors," red, green and blue. There are also antiquarks with the corresponding anticolors cyan, magenta and yellow. The interactions of the quarks are now described by means of a gauge theory based on invariance with respect to local transformations of color. Sixteen fields are needed to hold this invariance. They are taken in pairs to make up eight massless vector bosons, called gluons, each bearing a combination of color and anticolor.

In the original model there were just three kinds of quark, designated "up," "down" and "strange." James D. Bjorken of the Stanford Linear Accelerator Center and Sheldon Lee Glashow of Harvard soon proposed adding a fourth quark bearing a property called charm. In 1971 a beautiful argument by Glashow, John Iliopoulos of Paris and Luciano Maiani of the University of Rome showed that a quark with charm is needed to cure a discrepancy in the gauge theory of weak interactions. Charmed quarks, it was concluded, must exist if both the gauge theory and the quark theory are correct. The discovery in 1974 of the *J* or psi particle, which consists of a charmed quark and a charmed antiquark, supported the Weinberg-Salam-Ward model and persuaded many physicists that the quark model as a whole should be taken seriously. It now appears that at least two more "flavors," or kinds, of quark are needed; they have been labeled "top" and "bottom."

The primary task of any theory of the strong interactions is to explain the peculiar rules for building hadrons out of quarks. The structure of a meson is not too difficult to account for: since the meson consists of a quark and an antiquark, it is merely necessary to assume that the quarks carry some property analogous to electric charge. The binding of a quark and an antiquark would then be explained on the principle that opposite charges attract, just as they do in the hydrogen atom. The structure of the baryons, however, is a deeper enigma. To explain how three quarks can form a bound state one must assume that three like charges attract.

The theory that has evolved to explain the strong force prescribes exactly these interactions. The analogue of electric charge is a property called color (although it can have nothing to do with the colors of the visible spectrum). The term color was chosen because the rules for forming hadrons can be expressed succinctly by requiring all allowed combinations of quarks to be "white," or colorless. The quarks are assigned the primary colors red, green and blue; the antiquarks have the complementary "anticolors" cyan, magenta and yellow. Each of the quark flavors comes in all three colors, so that the introduction of the color charge triples the number of distinct quarks.

From the available quark pigments there are two ways to create white: by mixing all three primary colors or by mixing one primary color with its complementary anticolor. The baryons are made according to the first scheme: the three quarks in a baryon are required to have different colors, so that the three primary hues are necessarily represented. In a meson a color is always accompanied by its complementary anticolor.

The theory devised to account for these baffling interactions is modeled directly on quantum electrodynamics and is called quantum chromodynamics. It is a non-Abelian gauge theory. The gauge symmetry is an invariance with respect to local transformations of quark color.

It is easy to imagine a global color symmetry. The quark colors, like the isotopic-spin states of hadrons, might be indicated by the orientation of an arrow in some imaginary internal space. Successive rotations of a third of a turn would change a quark from red to green to blue and back to red again. In a baryon, then, there would be three arrows, with one arrow set to each of the three colors. A global symmetry transformation, by definition, must affect all three arrows in the same way and at the same time. For example, all three arrows might rotate clockwise a third of a turn. As a result of such a transformation all three quarks would change color, but all observable properties of the hadron would remain as before. In particular there would still be one quark of each color, and so the baryon would remain colorless.

Quantum chromodynamics requires that this invariance be retained even when the symmetry transformation is a local one. In the absence of forces or interactions the invariance is obviously lost. Then a local transformation can change the color of one quark but leave the other quarks unaltered, which would give the hadron a net color. As in other gauge theories, the way to restore the

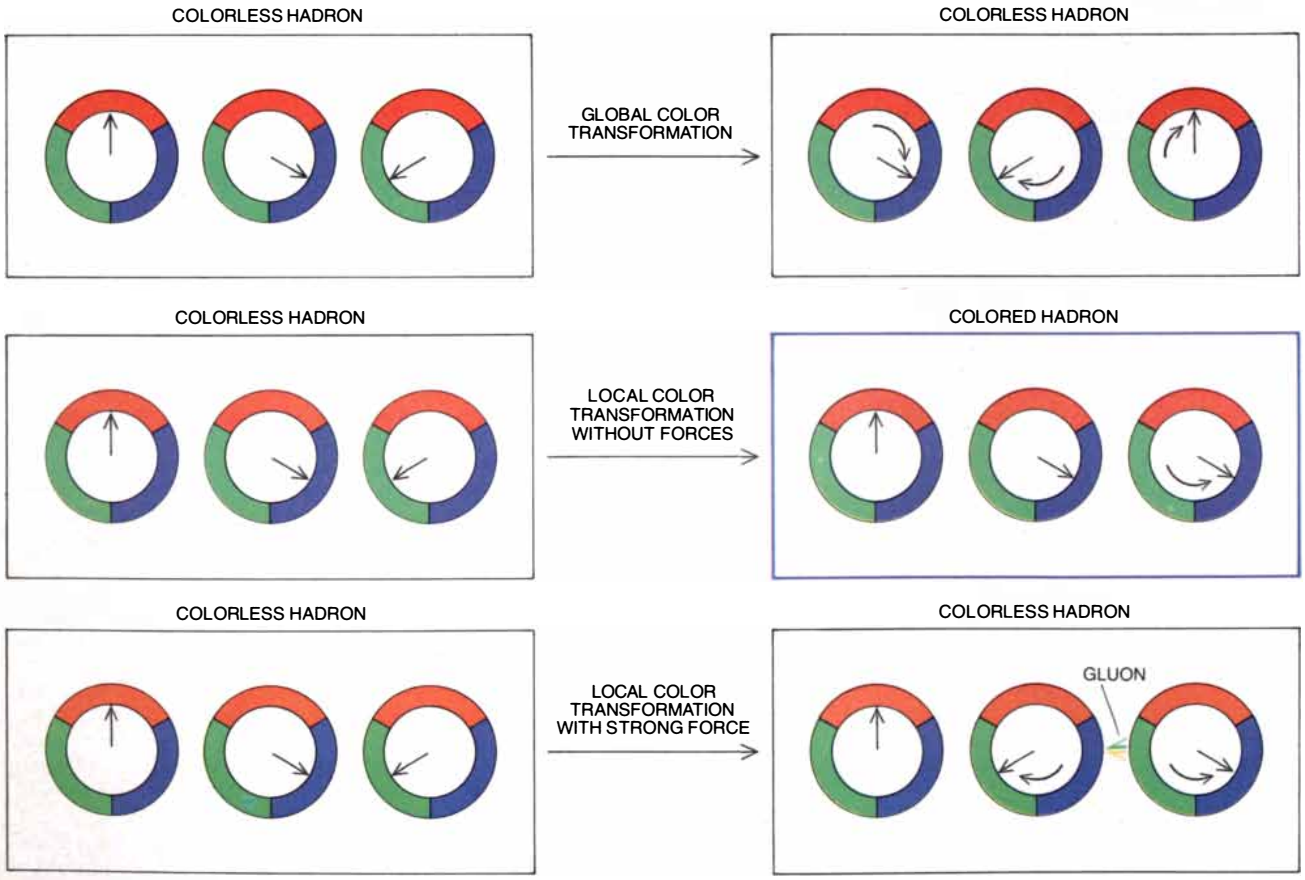
invariance with respect to local symmetry operations is to introduce new fields. In quantum chromodynamics the fields needed are analogous to the electromagnetic field but are much more complicated; they have eight times as many components as the electromagnetic field has. It is these fields that give rise to the strong force.

The quanta of the color fields are called gluons (because they glue the quarks together). There are eight of them, and they are all massless and have a spin angular momentum of one unit. In other words, they are massless vector bosons like the photon. Also like the photon the gluons are electrically neutral, but they are not color-neutral. Each gluon carries one color and one anticolor. There are nine possible combinations of a color and an anticolor, but one of them is equivalent to white and is excluded, leaving eight distinct gluon fields.

The gluons preserve local color symmetry in the following way. A quark is free to change its color, and it can do so independently of all other quarks, but every color transformation must be accompanied by the emission of a gluon, just as an electron can shift its phase only by emitting a photon. The gluon, propagating at the speed of light, is then absorbed by another quark, which will have its color shifted in exactly the way needed to compensate for the original change. Suppose, for example, a red quark changes its color to green and in the process emits a gluon that bears the colors red and antigreen. The gluon is then absorbed by a green quark, and in the ensuing reaction the green of the quark and the antigreen of the gluon annihilate each other, leaving the second quark with a net color of red. Hence in the final state as in the initial state there is one red quark and one green quark. Because of the continual arbitration of the gluons there can be no net change in the color of a hadron, even though the quark colors vary freely from point to point. All hadrons remain white, and the strong force is nothing more than the system of interactions needed to maintain that condition.

In spite of the complexity of the gluon fields, quantum electrodynamics and quantum chromodynamics are remarkably similar in form. Most notably the photon and the gluon are identical in their spin and in their lack of mass and electric charge. It is curious, then, that the interactions of quarks are very different from those of electrons.

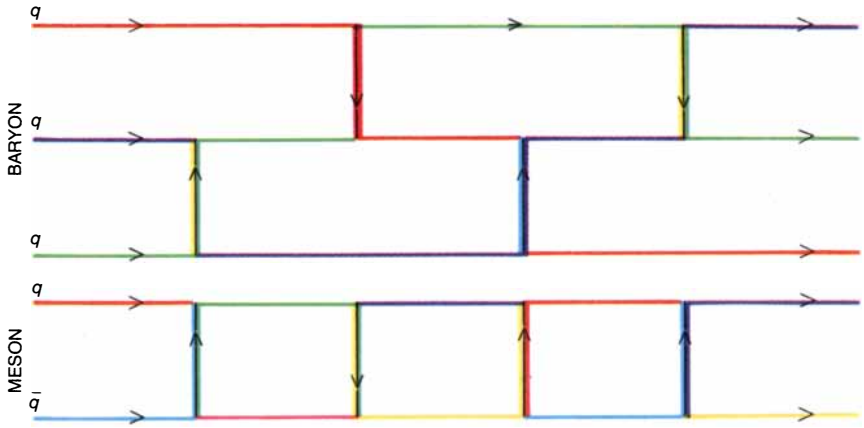
Both electrons and quarks form bound states, namely atoms for the electrons and hadrons for the quarks. Electrons, however, are also observed as independent particles; a small quantity of energy suffices to isolate an electron by ionizing an atom. An isolated quark has never been detected. It seems to be impossible to ionize a hadron, no matter how much energy is supplied. The quarks are evidently bound so tightly that they cannot be pried apart; paradoxically, however, probes of the in-



COLOR SYMMETRY requires that every hadron remain white, or colorless, even when the colors of its constituent quarks have been altered. The color of a quark can be indicated by the position of an arrow in an imaginary internal space. Global symmetry is easily achieved. If a hadron initially consists of three quarks, one in each of the three colors, then any synchronized rotation of all three of the arrows must leave the overall balance of the colors unchanged. In the absence of forces between the quarks, however, the global symmetry cannot be converted into a local symmetry. Changing the position of one color arrow while leaving the other two arrows fixed gives the hadron a net color. In order to preserve the local color symmetry, forces must be introduced. In particular when the color of one quark is changed, a virtual particle must be emitted that will readjust the colors of the other quarks so that the hadron as a whole will remain colorless. The fields that are required to ensure the colorlessness of all the hadrons are the eight gluon fields of quantum chromodynamics.

ternal structure of hadrons show the quarks moving freely, as if they were not bound at all.

Gluons too have not been seen directly in experiments. Their very presence in the theory provokes objections like those raised against the pure, massless Yang-Mills theory. If massless particles that so closely resemble the photon existed, they would be easy to detect and they would have been known long ago. Of course, it might be possible to give the gluons a mass through the Higgs mechanism. With eight gluons to be concealed in this way, however, the project becomes rather cumbersome. Moreover, the mass would have to be large or the gluons would have been produced by now in experiments with high-energy accelerators; if the mass is large, however, the range of the quark-binding force becomes too small.



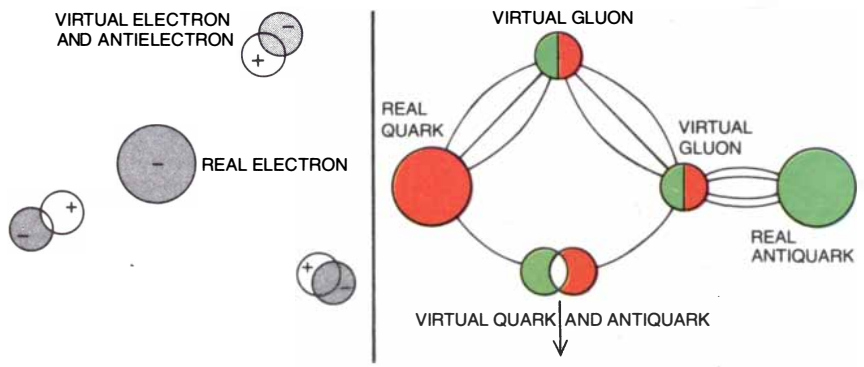
EXCHANGE OF GLUONS maintains a baryon (made up of three quarks) or a meson (made up of a quark and an antiquark) colorless. In this process the total color of the particles is conserved. For example, a red quark can be converted into a green quark only by emitting a gluon that bears the color red and the anticolor magenta; the magenta can be interpreted as antigreen. Hence the red of the quark is carried off by the red of the gluon, and green and antigreen are created in equal quantities. If the gluon is absorbed by a green quark, the green of the quark and the antigreen of the gluon annihilate each other, leaving the second quark with the color red.

A tentative resolution of this quandary has been discovered not by modifying the color fields but by examining their properties in greater detail. In discussing the renormalization of quantum electrodynamics I pointed out that even an isolated electron is surrounded by a cloud of virtual particles, which it constantly emits and reabsorbs. The virtual particles include not only neutral ones, such as the photon, but also pairs of oppositely charged particles, such as electrons and their antiparticles, the positrons. It is the charged virtual particles in this cloud that under ordinary circumstances conceal the "infinite" negative bare charge of the electron. In the vicinity of the bare charge the electron-positron pairs become slightly polarized: the virtual positrons, under the attractive influence of the bare charge, stay closer to it on the average than the virtual electrons, which are repelled. As a result the bare charge is partially neutralized; what is seen at long range is the difference between the bare charge and the screening charge of the virtual positrons. Only when a probe approaches to within less than about 10^{-10} centimeter do the unscreened effects of the bare charge become significant.

It is reasonable to suppose the same process would operate among color charges, and indeed it does. A red quark is enveloped by pairs of quarks and antiquarks, and the antired charges in this cloud are attracted to the central quark and tend to screen its charge. In quantum chromodynamics, however, there is a competing effect that is not present in quantum electrodynamics. Whereas the photon carries no electric charge and therefore has no direct influence on the screening of electrons, gluons do bear a color charge. (This distinction expresses the fact that quantum electrodynamics is an Abelian theory and quantum chromodynamics is a non-Abelian one.) Virtual gluon pairs also form a cloud around a colored quark, but it turns out that the gluons tend to enhance the color charge rather than attenuate it. It is as if the red component of a gluon were attracted to a red quark and therefore added its charge to the total effective charge. If there are no more than 16 flavors of quark (and at present only six are known), the "antiscreening" by gluons is the dominant influence.

This curious behavior of the gluons follows from rather involved calculations, and the interpretation of the results depends on how the calculation was done. When I calculate it, I find that the force responsible is the color analogue of the gluon's magnetic field. It is also significant, however, that virtual gluons can be emitted singly, whereas virtual quarks always appear as a quark and an antiquark. A single gluon, bearing a net color charge, enhances the force acting between two other color charges.

As a result of this "antiscreening" the effective color charge of a quark grows larger at long range than it is close by. A distant quark reacts to the combined fields of the central quark and the reinforcing gluon charges; at close range, once the gluon cloud has been penetrated, only the smaller bare charge is effective. The quarks in a hadron therefore act somewhat as if they were connected by rubber bands: at very close range, where the bands are slack, the quarks



POLARIZATION OF THE VACUUM explains to some extent the peculiar force law that seems to allow quarks complete freedom of movement within a hadron but forbids the isolation of quarks or gluons. In quantum electrodynamics (*left*) pairs of virtual electrons and antielectrons surround any isolated charge, such as an electron. Because of electrostatic forces the positively charged antielectrons tend to remain nearer the negative electron charge and thereby cancel part of it. The observed electron charge is the difference between the "bare" charge and the screening charge of virtual antielectrons. Similarly, pairs of virtual quarks diminish the strength of the force between a real quark and a real antiquark. In quantum chromodynamics, however, there is a competing effect not found in quantum electrodynamics. Because the gluon also has a color charge (whereas the photon has no electric charge), virtual gluons also have an influence on the magnitude of the color force between quarks. The gluons do not screen the quark charge but enhance it. As a result the color charge is weak and the quarks move freely as long as they are close. At long range infinite energy may be needed to separate two quarks.

move almost independently, but at a greater distance, where the bands are stretched taut, the quarks are tightly bound.

The polarization of virtual gluons leads to a reasonably precise account of the close-range behavior of quarks. Where the binding is weak, the expected motion of the particles can be calculated successfully. The long-range interactions, and most notably the failure of quarks and gluons to appear as free particles, can probably be attributed to the same mechanism of gluon antiscreening. It seems likely that as two color charges are pulled apart the force between them grows stronger indefinitely, so that infinite energy would be needed to create a macroscopic separation. This phenomenon of permanent quark confinement may be linked to certain special mathematical properties of the gauge theory. It is encouraging that permanent confinement has indeed been found in some highly simplified models of the theory. In the full-scale theory all methods of calculation fail when the forces become very large, but the principle seems sound. Quarks and gluons may therefore be permanently confined in hadrons.

If the prevailing version of quantum chromodynamics turns out to be correct, color symmetry is an exact symmetry and the colors of particles are completely indistinguishable. The theory is a pure gauge theory of the kind first proposed by Yang and Mills. The gauge fields are inherently long-range and formally are much like the photon field. The quantum-mechanical constraints on those fields are so strong, however, that the observed interactions are quite unlike those of electromagnetism and even lead to the imprisonment of an entire class of particles.

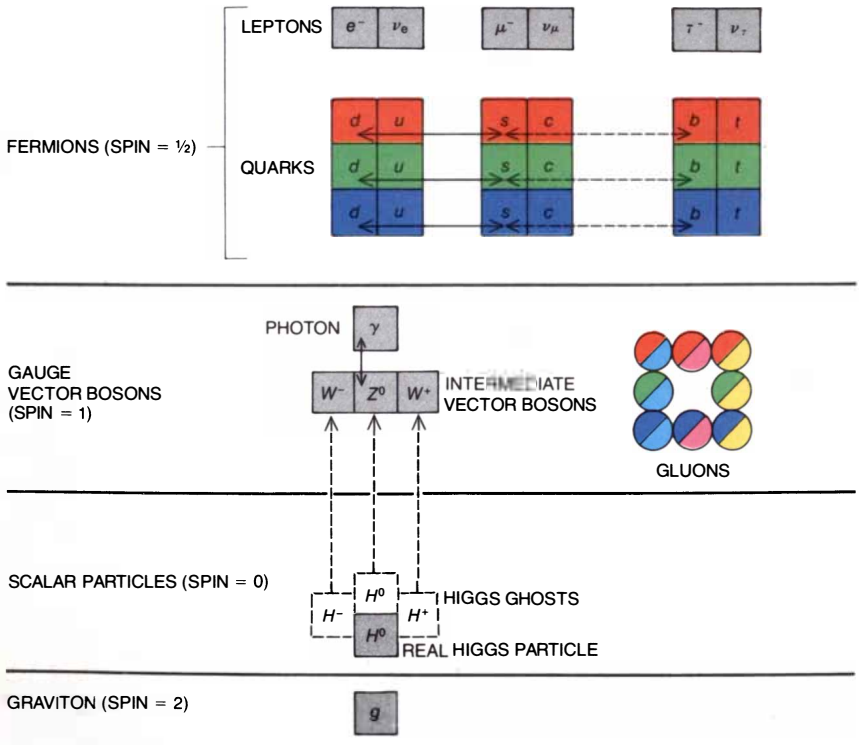
Even where the gauge theories are right they are not always useful. The calculations that must be done to predict the result of an experiment are tedious, and except in quantum electrodynamics high accuracy can rarely be attained. It is mainly for practical or technical reasons such as these that the problem of quark confinement has not been solved. The equations that describe a proton in terms of quarks and gluons are about as complicated as the equations that describe a nucleus of medium size in terms of protons and neutrons. Neither set of equations can be solved rigorously.

In spite of these limitations the gauge theories have made an enormous contribution to the understanding of elementary particles and their interactions. What is most significant is not the philosophical appeal of the principle of local symmetry, or even the success of the individual theories. Rather it is the growing conviction that the class of theories now under consideration includes all possible theories for any system of particles whose mutual interactions are not too strong. Experiment shows that if particles remain closer together than about 10^{-14} centimeter, their total interaction, including the effects of all forces whether known or not, is indeed small. (The quarks are a special case: although the interactions between them are not small, those interactions can be attributed to the effects of virtual particles, and the interactions of the virtual particles are only moderate.) Hence it seems reasonable to attempt a systematic fitting of the existing gauge theories to experimental data.

The mathematics of the gauge theories is rigid, but it does leave some freedom for adjustment. That is, the predicted magnitude of an interaction between particles depends not only on the structure of the theory but also on the values assigned to certain free parameters, which must be considered constants of nature. The theory remains consistent no matter what choice is made for these constants, but the experimental predictions depend strongly on what values are assigned to the constants. Although the constants can be measured by doing experiments, they can never be derived from the theory. Examples of such constants of nature are the charge of the electron and the masses of elementary particles such as the electron and the quarks.

The strength of the gauge theories is that they require comparatively few such free parameters: about 18 constants of nature must be supplied to account for all the known forces. The tangled phenomena of the strongly interacting particles, which seemed incomprehensible 15 years ago, can now be unraveled by means of a theory that includes only a handful of free parameters. Among these all but three are small enough to be safely ignored.

Even if the free parameters have been reduced to a manageable number, they remain an essential part of the theory. No explanation can be offered of why they assume the values they do. The fundamental questions that remain unanswered by the gauge theories center on these apparent constants of nature. Why do the quarks and the other elementary particles have the masses they do? What determines the mass of the Higgs particle? What determines the fundamental unit of electric charge or the strength of the color force? The answers to such questions cannot come from the existing



STANDARD MODEL of elementary-particle interactions describes the four forces of nature by means of three non-Abelian gauge theories. The fundamental particles of matter are six leptons and six flavors of quark, each of the flavors being present in three colors. Electromagnetism and the weak force are mediated by the gauge particles of the Weinberg-Salam-Ward model, namely the massless photon and a triplet of very massive vector bosons, the W^+, W^- and Z^0. The strong force is attributed to the eight massless gluons of quantum chromodynamics. Gravitation results from the exchange of a massless spin-two particle, the graviton, which is described by another local gauge theory: the general theory of relativity. In addition there is one surviving Higgs particle, which is massive and electrically neutral. In the coming years the search for the massive vector bosons and the Higgs particle will serve as tests of this synthesis.

gauge theories but only from a more comprehensive theory.

In the search for a larger theory it is natural to apply once more a recipe that has already proved successful. Hence the obvious program is to search for global symmetries and explore the consequences of making them local symmetries. This principle is not a necessary one, but it is worth trying. Just as Maxwell's theory combined electricity and magnetism and the Weinberg-Salam-Ward model linked electromagnetism and the weak force, so perhaps some larger theory could be found to embrace both the Weinberg-Salam-Ward model and quantum chromodynamics. Such a theory might in principle be constructed on the model of the existing gauge theories. A more sweeping symmetry of nature must be found; making this symmetry a local one would then give rise to the strong force, the weak force and electromagnetism. In the bargain yet more forces, exceedingly weak and so far unobserved, may be introduced.

Work on such theories is proceeding, and it has lately concentrated on symmetries that allow transformations between quarks and leptons, the class of particles that includes the electron. It is my belief the schemes proposed so far are not convincing. The grand symmetry they presuppose must be broken in order to account for the observed disparities among the forces, and that requires several Higgs fields. The resulting theory has as many arbitrary constants of nature as the less comprehensive theories it replaces.

A quite different and more ambitious approach to unification has recently been introduced under the terms "supersymmetry" and "supergravity." It gathers into a single category particles with various quantities of angular momentum; up to now particles with different spins were always assigned to separate categories. The utility of the supersymmetric theories has yet to be demonstrated, but they hold much promise. They offer a highly restrictive description of some hundreds of particles, including the graviton, in terms of only a few adjustable parameters. So far the results do not much resemble the known physical world, but that was also true of the first Yang-Mills theory in 1954.

The form of unification that has been sought longest and most ardently is a reconciliation of the various quantum field theories with the general theory of relativity. The gravitational field seems to lead inevitably to quantized theories that cannot be renormalized. At extremely small scales of distance (10^{-33} centimeter) and time (10^{-44} second) quantum fluctuations of space-time itself become important, and they call into question the very meaning of a space-time continuum. Here lie the present limits not merely of gauge theories but of all known physical theories.

The September 1980 issue of

SCIENTIFIC AMERICAN

will be devoted to the single topic of

Economic Development

The issue will explore the role that the scientific-industrial technology will need to play in the progress toward a new international economic order.

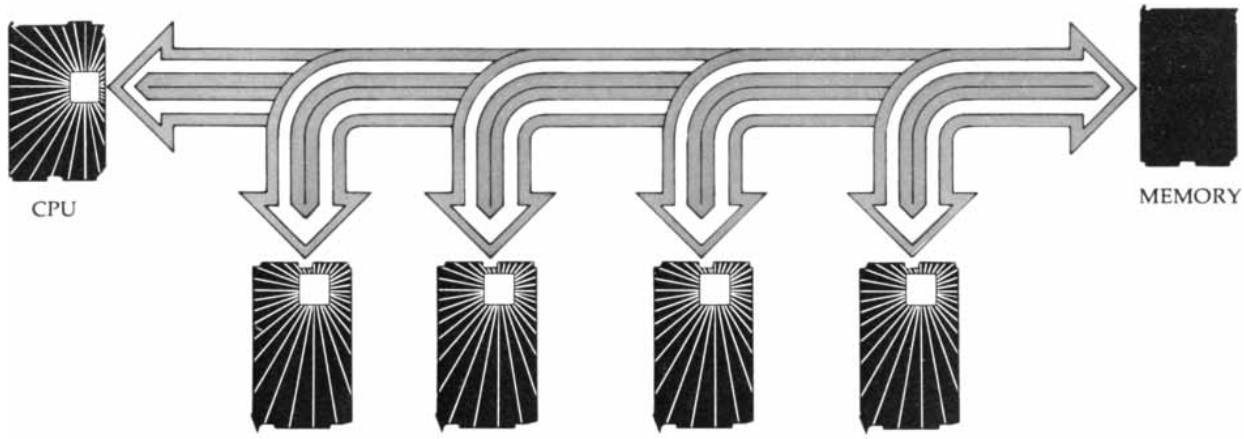
THE ARTICLES

ECONOMIC DEVELOPMENT • PEOPLE • WATER • FOOD • ENERGY • CHINA • INDIA • TANZANIA • MEXICO • THE WORLD ECONOMY AT 2000 A.D.

Earthworks excavation in India carried on by hand, hoe and woven basket. UNITED NATIONS

What if you chose HP products to

For example: A new, low-cost series of HP 1000 real-time computers whose "distributed intelligence" architecture commands exceptional I/O performance.



I/O PROCESSORS

The HP 1000 L-Series is based on two new single-chip custom processors—the result of HP's proprietary CMOS/SOS (silicon on sapphire) large scale integration manufacturing process. CMOS/SOS gives the L-Series the advantages of fast processing speed, small board size, and low power consumption.

One of these SOS processors serves as the L-Series CPU; the other—an input/output processor—is used on every L-Series interface board. The I/O processors relieve the CPU of the time-consuming task of controlling I/O operations, freeing it for its main job of computation. CPU, I/O processors, and memory all communicate with each other over a common bus. This distributed intelligence architecture provides a "multistreamed I/O" capability that gives the L-Series exceptional I/O performance and throughput.

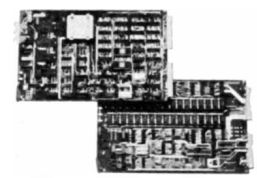
Each I/O processor can monitor and control multiple high- or low-speed direct data transfers to memory without CPU intervention, through a self-configuring or "chained" direct memory access mode. This reduces interrupt response times, reduces CPU overhead, and simplifies interface design. As a result, an HP 1000 L-Series computer can perform I/O-intensive jobs that computers costing several times as much can't do.

The L-Series provides a powerful, low-cost entry to the HP 1000 family. Applications developed on the L-Series can easily be expanded on larger HP 1000's.

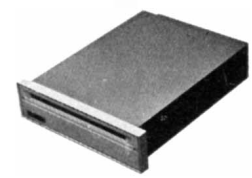
A full set of I/O interfaces, including a Hewlett-Packard Interface Bus, is available to solve most applications; and a set of development tools is available to shorten OEM development time.

L-Series configurations: from board to box to system.

A board-level computer, the HP 2103LK consists of a processor board containing a CPU, time-base generator, and memory protection on a single chip, and a 64k-byte memory board. Price starts at $2250*.



A rack-mountable computer, the HP 2103L is housed in an enclosure only 5¼ inches (13.3 cm) high, and contains a processor board, 64k bytes of memory, power supply, and eight I/O slots. Price starts at $4450*.



A complete system, the HP 1000 Model 10 consists of an HP 2103L computer, a CRT terminal, a flexible disc drive, and a 12M-byte Winchester-technology disc. A 36-inch-high cabinet houses the system. Price is $22,500*.

enhance your productivity?

For example: Now you can create and manage technical data bases on the HP 9800 System 45 computer—with HP's award-winning IMAGE data base management.

HP's System 45 computer has proved its worth as a powerful workstation for scientists and engineers. Now, HP's user-tested and highly rated data base management system (previously available only on the HP 1000 and HP's family of business computers) has been extended to the System 45, making data base management a practical, easy-to-implement tool for local technical applications.

The heart of System 45's data base management is IMAGE / 45, a set of highly efficient, enhanced BASIC system routines and statements. With it, you can create and maintain a data base tailored precisely to your data entry and retrieval requirements, even if you have little computer background.

QUERY / 45, a user-oriented inquiry program, provides interactive access to the data base for programmer and nonprogrammer alike. Simply by typing in English-like commands and responding to user prompts, you can read, enter, delete, or modify your data—without writing any application programs.

The package also contains a Data Base Design Kit in workbook form that takes you step by step from the definition of your data management requirements through the creation of a data base that will give you information in the form you want it.

The price of HP's data base management package for the System 45 is $5000*.

For more information, mail the coupon to Hewlett-Packard, 1505 Page Mill Road, Palo Alto, CA 94304. Or call the HP regional office nearest you: East (201) 265-5000, West (213) 970-7500, Midwest (312) 255-9800, South (404) 955-1500, Canada (416) 678-9430.

These are only two of many thousand product reasons for choosing HP.

HEWLETT PACKARD

Mail to: Hewlett-Packard, 1505 Page Mill Road, Palo Alto, CA 94304
Please send me further information on

( ) HP 1000 L-Series computers
( ) IMAGE/45 data base management

Name _____
Company _____
Address _____
City _____ State _____ Zip _____

*Domestic U.S. prices only.

00043

Ice-Age Subsistence in Northern Spain

A 12,000-year record of man's quest for food in Pleistocene times has been found in a cave near the Bay of Biscay. Changes in the use of resources suggest a response to increasing demographic pressure

by Lawrence Guy Straus, Geoffrey A. Clark, Jesus Altuna and Jesus A. Ortea

At the height of the last ice age the human population of western Europe included bands of hunters and gatherers that lived along the coast of Spain facing the Bay of Biscay. Preserved in the caves where they camped are the remains of the animals they pursued or collected for their subsistence. La Riera, one such cave site midway between the cities of Oviedo and Santander, holds a particularly rich record of the human diet over a span of some 12 millenniums beginning more than 21,000 years ago. The recovery of these animal remains, together with other evidence of human occupation and environmental fluctuation at La Riera, has been a joint effort involving the four of us and many of our colleagues in the past four years. Our reconstruction of the human dietary record over these thousands of years of Upper Paleolithic and Mesolithic time is what we shall present here. This record may well, however, bear on a larger question: how it was that later human populations shifted from hunting and gathering to agriculture and animal husbandry.

The northern provinces of Guipúzcoa, Vizcaya, Santander and Asturias form the Cantabrian region of Spain. A strip of the Biscay coast running for some 350 kilometers from the Rio Nálon in central Asturias eastward to the Pyrenees is where the evidence of Paleolithic occupation is most abundant. The strip is between 25 and 60 kilometers wide and is separated from the high, barren tableland immediately to the south by the mountains of the Cantabrian cordillera. Many of the summits in the highest massif of the region, the Picos de Europa, rise some 2,600 meters; during the last glacial period they were capped with ice. At glacial maximums the sea level was some 100 meters lower than it is today, but because the continental shelf here is narrow and steep the coastal plain was generally widened by no more than 10 kilometers. The temperate maritime climate of the Biscay coast, compared with the harsher environment of the mountains and the high plateau to the south, together with the abundance of game and other foodstuffs along the coast, evidently made the area attractive to hunters and gatherers.

The pollens from a number of Cantabrian archaeological sites indicate that open vegetation predominated in the region during the glacial maximums. Grasses, herbs and low-growing shrubs such as heaths were abundant, and there were also a few pines. In milder periods deciduous trees such as birch, hazel, oak and elm appeared. The animal population included mammals adapted to open-country conditions, among them the European bison, the horse and an occasional reindeer. The red deer was abundant even in essentially treeless intervals, both on the coastal plain and in the broad mountain valleys to the south. A wild goat, the ibex, and its smaller relative the chamois seem to have thrived on the rocky hillsides and in unglaciated mountain areas. (An adult red-deer stag would have weighed between 200 and 250 kilograms; an adult ibex would have weighed less than half as much.) Along the rocky shore mollusks were locally abundant and fishes of the salmon family were present in coastal estuaries and streams.

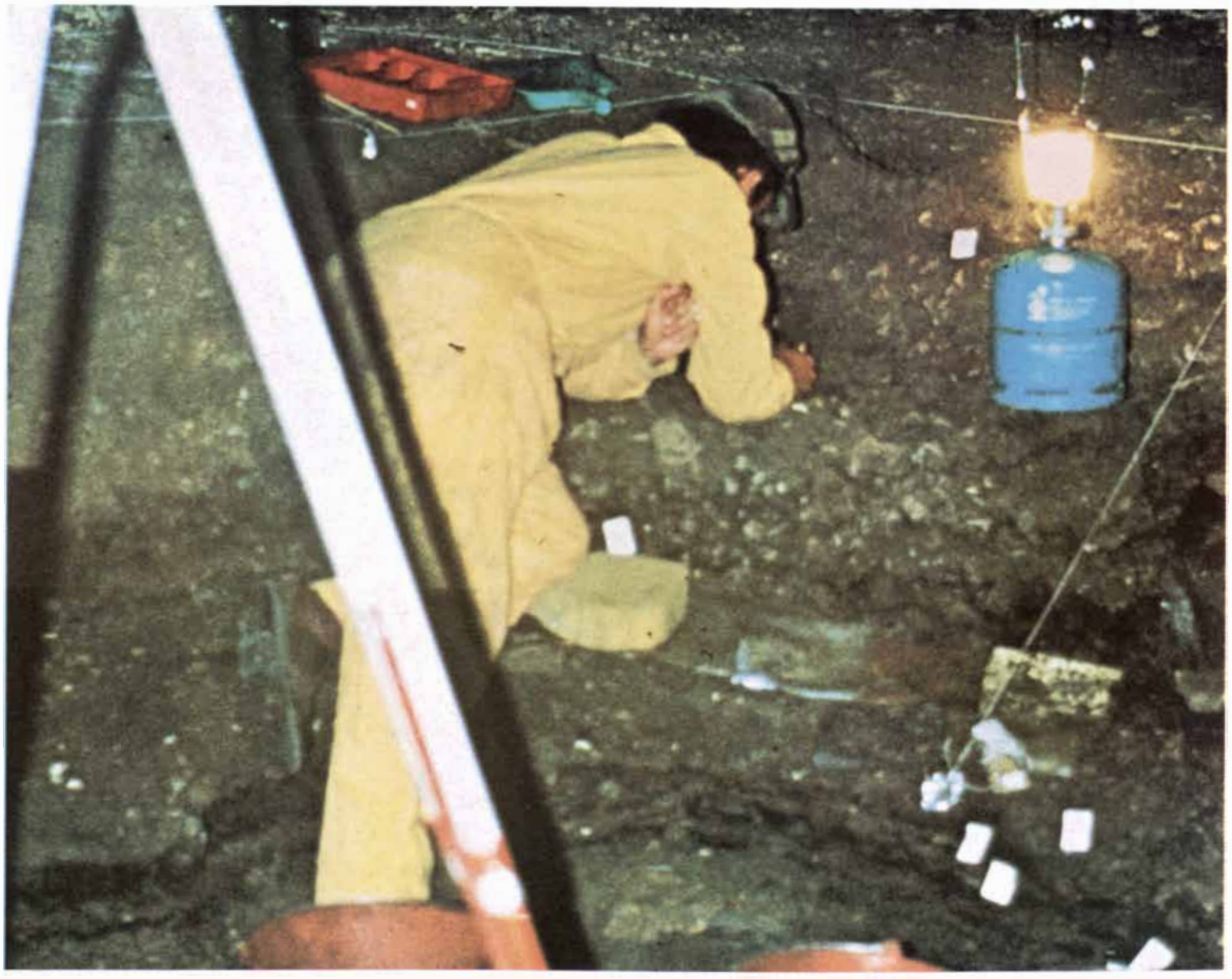
Before Upper Paleolithic hunters appeared in Cantabria the area was populated by men whose characteristic stone tools are classified as Mousterian and whose remains show them to be Neanderthals, or anatomically premodern men. Two of us (Altuna and Straus) have analyzed the animal remains from several Mousterian sites in the area and have found that the hunters of the Middle Paleolithic killed few red deer and ibexes. They evidently relied opportunistically on the larger game: horses (adult weight 350 kilograms), bovines (adult weight 800 kilograms or more) and two species of rhinoceros (weight not estimated). Such advanced techniques as game driving seem not to have been known to these hunters, and scavenging may have supplied them with a significant amount of their food. There are only 13 known Mousterian sites in Cantabria, and one is left with the impression that the human population of the region in Middle Paleolithic times was small. As a result the Neanderthals may not have needed sophisticated strategies for subsistence. Quite the opposite impression is given by the archaeological record of the Upper Paleolithic.

The cave site of La Riera is on the south face of a low ridge that rises from the coastal plain about 1.5 kilometers from the modern coastline in eastern Asturias. It is near the entrance to a mountain pass that leads through a coastal mountain range, the Sierra de Cuera, to the east-west valley at the foot of the Picos de Europa. The cave was discovered and first excavated some 60 years ago by an eminent Spanish prehistorian, the Conde de la Vega del Sella. It is a site notable for the richness of its prehistoric record.

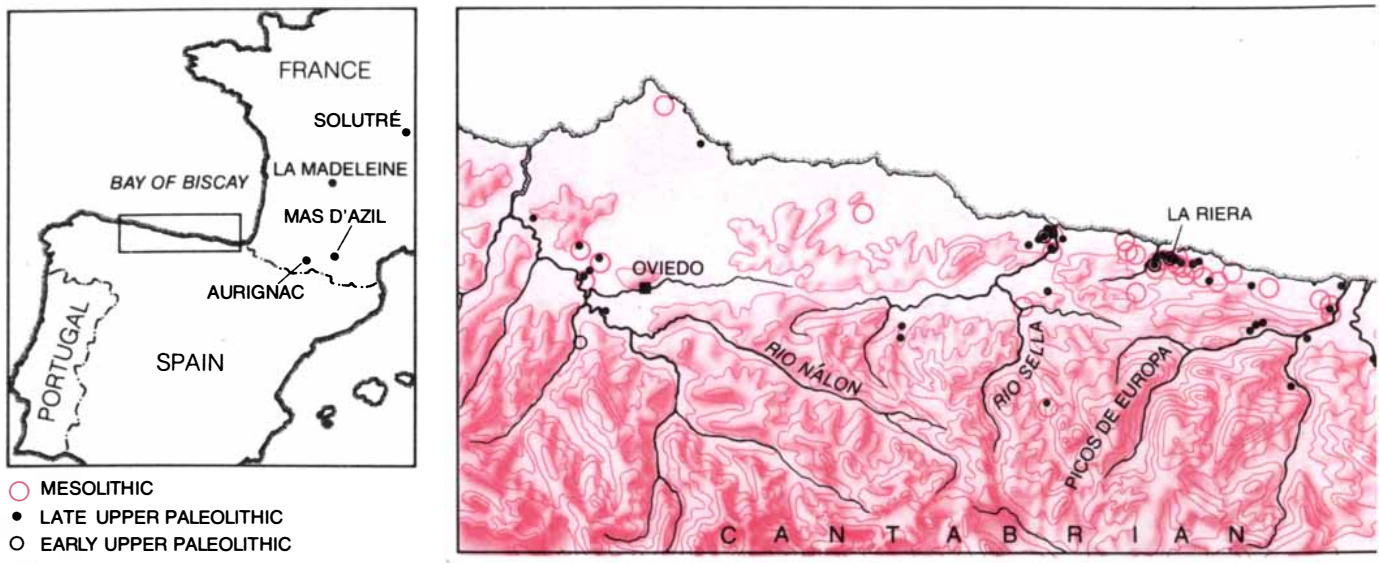
Two of us (Straus and Clark) have directed the current excavations at the cave. A third (Altuna) has been responsible for the analysis of the mammalian remains and the fourth (Ortea) for that of the molluscan ones. In addition 18 colleagues, specialists in such fields as oxygen-isotope analysis of shell and travertine, carbon-14 analysis, sedimentology, petrology, botany, pollen analysis and the like, have contributed to the project. They include Henri Laville of the University of Bordeaux, who is analyzing the sediments, Arlette Leroi-Gourhan of the Musée de l'Homme in Paris, who is analyzing the pollens, and M. M. de la Hoz of the University of Oviedo, who has analyzed fish remains.

Our four seasons of excavation, concentrating on an undisturbed section at the rear of the cave vestibule, have uncovered 36 separate levels within a vertical range of a little more than 2.5 meters. Many of these levels included

CAVE ENTRANCE AT LA RIERA, 100 kilometers from the city of Oviedo in northern Spain, is almost screened by foliage. Used as a shelter by visiting bands of hunter-gatherers in the late Paleolithic and the Mesolithic, the cave holds the remains of their animal foods.



EXCAVATOR AT WORK by lantern light in La Riera cave examines a freshly exposed living floor. The overhead strings outline the excavation control grid. The site has yielded many stone artifacts and some 32,000 identifiable mammalian teeth and bone fragments.



BISCAY COASTS of Spain and France (*left*) differ markedly. The Spanish coastal plain is narrow and the French plain is broad. The section inside the box is shown in detail at the right. French sites that have lent their names to late Paleolithic and Mesolithic cultures include Aurignac and Mas d'Azil in the Pyrenees near the border with Spain, Solutré to the northeast and La Madeleine in the Dordogne

distinct occupation surfaces, or living floors, littered with artifacts of stone, bone and antler, together with animal remains and cobblestones for cooking pits. The stone inventory now totals more than 55,000 artifacts, about 3,000 of which are retouched tools. The number of mammalian bone fragments and teeth exceeds 200,000, some 32,000 of which can be identified by species.

At the bottom of our stratigraphic sequence is a stratum that could perhaps be assigned, on the basis of a few stone and bone artifacts, to an early Upper Paleolithic culture known as the Aurignacian. At Cueto de la Mina, an adjacent site in eastern Asturias, an Aurignacian level definitely underlies deposits of the Upper Paleolithic culture known as the Solutrean, but the exact identity of the bottom level at La Riera remains to be determined. In any case it is obviously older than the levels just above it, which date to about 21,000 years B.P. (before the present) and are separated from it by a hiatus in deposition.

Pollen analysis indicates that the environment of Level No. 1 was relatively temperate and humid. The vegetation included such trees as hazel and oak along with many herbs and shrubs of the composite family. In spite of this evidence of partially wooded conditions, the animal bones are principally those of open-country species: horses and bovines (most probably the European bison). The remains of red deer are also fairly abundant.

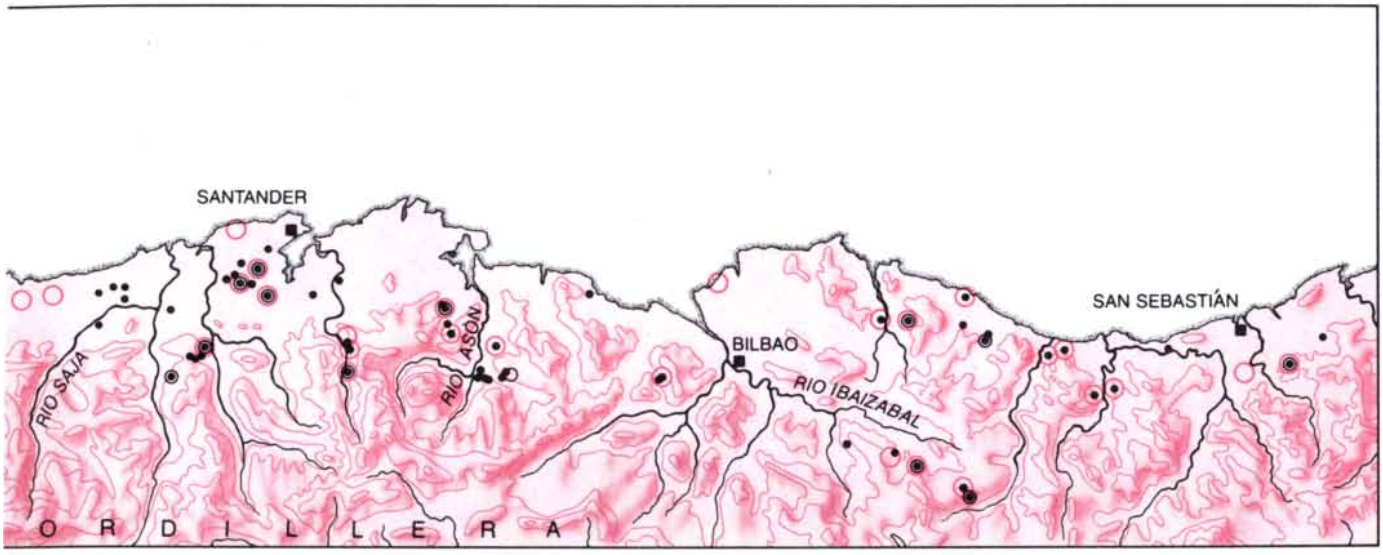
The next 16 principal levels at La Riera contain artifacts that assign them to the Solutrean. The first two Solutrean levels (Nos. 2 and 3) were deposited during cold and humid conditions and are poor both in artifacts and in animal remains. Among the latter the bones of horses predominate, followed by those of ibexes, red deer and bovines.

The contents of the next three levels (Nos. 4, 5 and 6) are quite different. They suggest that more specialized hunting techniques were in the process of development, techniques that would eventually combine in the sophisticated and diversified subsistence strategies of late Upper Paleolithic and Mesolithic times in Cantabria. The environment at the time these levels were deposited was typical of a glacial maximum. The associated drop in the sea level had probably moved the coast some 10 kilometers away from the cave. The climate was quite cold, and with the exception of a few pines the vegetation consisted primarily of heaths, composites and grasses. The three cave levels that provide this information are thin and limited in extent; such residential features as pits or dug-out hearths are absent. Many of the stone artifacts found here are unique in being made of varieties of flint and quartzite that are seldom found in the other levels at La Riera. Cores and large surface flakes, the primary waste materials in the manufacture of stone implements, are also scarce, whereas the small waste chips produced in the final stages of manufacture or in the process of retouching are abundant. This suggests that many of the artifacts were made from blanks brought to La Riera from elsewhere.

Most of the stone artifacts are small Solutrean "shouldered" points. Only a few of them are intact; many consist of the shouldered base. Present in exceptional numbers for this relatively early phase of the Upper Paleolithic are tiny blades that have been "backed": blunted along one edge. The scarcity of other kinds of tools gives these assemblages a specialized appearance, as if the cave was being used for a series of brief hunting visits and other activities at the site were limited in scope.

The animal bones reinforce this impression. Those of the ibex predominate: a minimum of 28 animals are represented in the three layers combined. Some of the ibexes were juveniles and a few were fairly old, but most were adults of prime age. This suggests that the hunters of the period did not stalk individual ibexes but drove a group of them, perhaps "spooking" the animals upslope to within range of men lying in wait for them. Relatively few ibex head parts—horn cores, upper teeth and bits of skull and jawbone—are found in the deposits, implying that the animals were butchered near the site of the kill and their heads left behind. (The opposite is the case at Rascaño, a Magdalenian site at the face of a cliff in Santander province. There ibex skulls and horns are plentiful, presumably because the hunters' camp was near the kill sites.) In addition to the plentiful remains of ibexes in these levels are those of at least two chamois. The fact that both animals are adapted to life on rocky slopes strengthens the hypothesis that at this time visiting hunters used La Riera as a base camp for expeditions to the slopes of the Sierra de Cuera, 1.5 kilometers away.

The ibex and the chamois were not the only prey. The hunters continued to take horses and red deer, although in small numbers. The remains of bovines, however, are almost entirely absent from these levels. At the same time two marine foods make their first substantial appearance. The less important of the two were freshwater-spawning fishes of the salmon family: the salmon, the sea



area. Cantabrian Spain between the Rio Nálon and the French border (*right*) has more than 100 Upper Paleolithic and Mesolithic sites (*see key*). Late Upper Paleolithic and Mesolithic sites are the most numerous and occupy a variety of ecological niches. La Riera cave, north of the Picos de Europa, was discovered early in the century by an eminent Spanish prehistorian, the Conde de la Vega del Sella.

trout and the trout. The more important are edible mollusks, most of them large limpets (the species *Patella vulgata*) that preferentially inhabited estuaries and at full growth averaged four centimeters across. The limpet shells are so numerous that their aggregate weight is more than 70 percent that of the mammal bone in Level No. 4. Further evidence of the ibex hunters' visits to the shore is the presence in Level No. 4 of two seal bones, possibly from a scavenged carcass. This evidence of the exploitation of marine resources is surprising when one considers that a visit to the shore from La Riera may then have called for a round trip of as much as 20 kilometers.

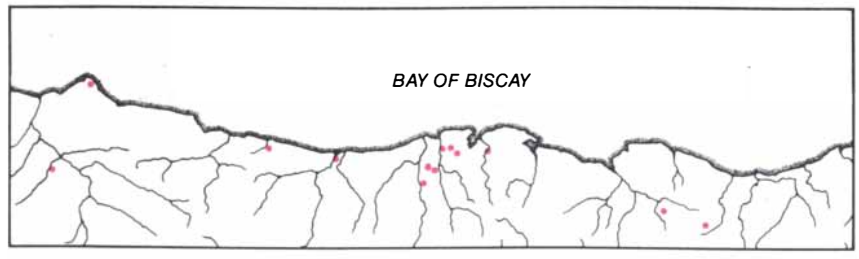
The next two Solutrean levels (Nos. 7 and 8) have provided samples for carbon-14 analysis, which makes it possible to date them to between 21,000 and 20,000 B.P. The climate was still cold; heaths were present and the landscape was generally treeless. The two levels contained a varied assemblage of flint artifacts. Level No. 7 also provides evidence suggesting a meat-processing technique of early Solutrean times. A pit had been dug down below the living surface of this level and lined with cobblestones. The stones are cracked by fire, and among them we found broken and charred animal bones, including identifiable fragments of deer skull and antler. It appears that the hunters cooked at least some of their game by putting the dismembered bodies, including the heads, into the pit and roasting them with fire-heated stones.

The animal bones from both levels show that the ibex was still commonly hunted. The horse, however, is not much in evidence: the levels hold the remains of no more than seven individual animals. The bones of bovines continue to be rare, and those of the chamois are now rarer. A few roe deer were taken; these animals, much smaller and more specifically adapted to woodland than the red deer, would seem ill-suited to the open landscape of the period. Indeed, it is the red deer that predominates in these levels: the remains of 34 individuals were found in Level No. 7 and those of 19 in Level No. 8. The majority of the red deer were juveniles, but the number of them that were mature or old suggests that, as with the ibexes of the lower levels, the animals were driven or surrounded in groups rather than hunted individually.

The hunters who took shelter in the cave at this time continued to make the long trip to the shore to collect limpets. In Level No. 7 the quantities of *Patella vulgata* shells are particularly impressive, although the large number of mammal bones in this level makes the ratio of shell weight to bone weight relatively low. Level No. 7 also yielded a single seal bone. The variety and quantity of artifacts and animal debris in levels No. 7 and No. 8, particularly in Level No. 7, testify to a more intensive occupation or series of occupations of La Riera in this period compared with the more specialized and more fleeting occupations earlier.

The next seven levels (Nos. 9 through 15) represent a 2,000-year continuation of the Solutrean. The climate was now relatively temperate and humid, and trees such as birch, hazel and holm oak grew up to form at least localized patches of forest. The mildness of the interval is attested to both by the appearance of the pollen of these trees and by the deposition and weathering of sediments that indicate increased warmth and humidity. Furthermore, one mollusk, the common periwinkle *Littorina littorea,* which is relatively intolerant of warm conditions, disappears from the cave debris.

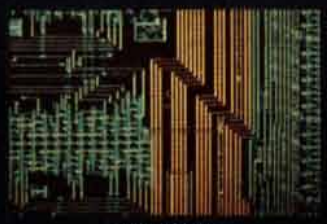
Some of these seven levels are thick and some are thin, some represent brief visits to La Riera and some suggest a more protracted habitation. All seven, however, have one characteristic in common. Between 80 and 90 percent of all the mammal remains are those of the red deer. This majority status is maintained whether one calculates the minimum number of individual animals



MIDDLE PALEOLITHIC SITES in Cantabria are few and form no clear-cut settlement pattern. Animal bones indicate that the hunters killed and scavenged small numbers of large game.

hexa·photo·cybernetic

Six-mode exposure control. System versatility. Newer electronics for wider applications.



The incredible Canon A-1. It's on the cutting edge of technology, with state-of-the-art electronics and computerized operation.

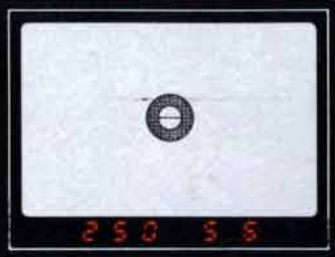
Yet, although the way we build it is complex, the way you use it is the ultimate in simplicity. If pushbutton-easy fine photography is what you're after, the A-1 can give it to you six ways.

1 Shutter-Priority automation: You pick the speed to freeze or blur action or prevent camera shake, the A-1 picks the perfect aperture automatically.

2 Aperture-Priority automation: Select the aperture you want for a soft background or total overall sharpness, the A-1 will give you the speed that's correct.

3 Programmed automation: On the A-1, this unique exposure mode picks both aperture and speed in ideal combinations depending on the light. You don't have to set *anything*.

4 Stopped-Down automation: This mode lets you get automatic exposure with any lens or accessory you can mount on the camera. Great for astrophotography, photomicrography, close-ups.



5 Flash automation. The A-1 has the easiest electronic flash of any camera of its type. With special Canon flash units, your aperture *and* speed are set automatically. Just mount the flash, turn it on and shoot for perfect exposures every time.

6 For any type of photography that's not already covered, there's manual.

There's more. Digital control and viewfinder display. Versatile control features. Accessories like a rugged motor drive, compact motorized film winder and interchangeable date/data back. Plus forty Canon FD lenses for unsurpassed image quality and scope.

You won't find another camera like it on the face of the earth. Because only Canon has the technology to make it.

Luckily, you don't have to go to the ends of the earth to get an A-1. Only as far as your local Canon dealer.

Canon® A-1

So advanced, it's simple.

Canon USA, Inc., 10 Nevada Drive, Lake Success, New York 11042 · 140 Industrial Drive, Elmhurst, Illinois 60126 · 6380 Peachtree Industrial Blvd., Norcross, Georgia 30071 · 123 Paularino Avenue East, Costa Mesa, California 92626 · Bldg. B-2, 1050 Ala Moana Blvd., Honolulu, Hawaii 96814 · Canon Optics & Business Machines Canada, Ltd., Ontario

represented by the remains, the weight of bone per species or simply the total number of bones per species. The remaining 10 to 20 percent of mammal remains are principally those of the ibex. The horse now equals the bovines in scarcity, and even though there is now some timber cover, roe deer are also scarce.

Except in Level No. 14 mollusks are also poorly represented, even though at this time the sea level was probably higher and the trip to the shore easier. The mollusk shells found in Level No. 14, an important deposit that is particularly rich in human artifacts and animal remains, are those of the same large estuarine limpet, *Patella vulgata,* gathered by the earlier hunters. Numerous fire-cracked cobblestones are also present, together with several informal hearths. Evidently one of the food-processing activities that occupied these later hunters was roasting meat.

The stone tools found in all seven levels suggest that food processing of various kinds was in fact a major activity of these site occupations. In addition to blades, presumably for cutting, and scrapers that suggest the preparation of hides, the inventory of tools includes many toothed "denticulates" and notched flakes perhaps suited to certain tasks of butchering or to the processing of plant materials. The few Solutrean points in these levels are those of the "laurel leaf" type, possibly spearpoints or knives. This is the reverse of the situation at the classic Solutrean site of Laugerie-Haute in France, where laurel-leaf points precede shouldered points in the stratigraphy.

The next two levels (Nos. 16 and 17) contain the last Solutrean material at La Riera. Analysis of the sediments suggests that the lower of the two levels was deposited in a period of cold climate and that the upper one was deposited when conditions were once again relatively temperate. Even during the cold episode, however, the hunters continued to take mostly red deer. Level No. 16 yielded the remains of 27 of these animals, together with those of 11 ibexes. Virtually no other mammals are represented. Even the exploitation of ocean resources was limited to the capture of a few salmon and sea trout and the gathering of relatively few limpets.

Level No. 17 was occupied in about 17,000 B.P. Its stone tools include a single Solutrean willow-leaf point, but 70 percent are of one kind: backed bladelets. (In Level No. 16 backed bladelets account for 24 percent of the tools.) The predominance of a single kind of tool suggests either a shift in the human activities at La Riera at this time or the adoption of a new technology, possibly one for the manufacture of projectile points.

The next levels at La Riera introduce a new culture: the Magdalenian. The lowest Magdalenian levels (Nos. 18 and 19) appear to have been deposited during a continuation of the relatively temperate climate that prevailed during the deposition of the last of the Solutrean levels. They are dated to about 16,000 B.P. Backed bladelets continue to dominate the inventory of tools and red deer dominate the animals hunted. Next most abundant among the mammalian remains are those of the ibex, and there are traces of the roe deer, the chamois, the horse and bovines. Limpet shells are few, and the only fish remains are those of the sea trout.

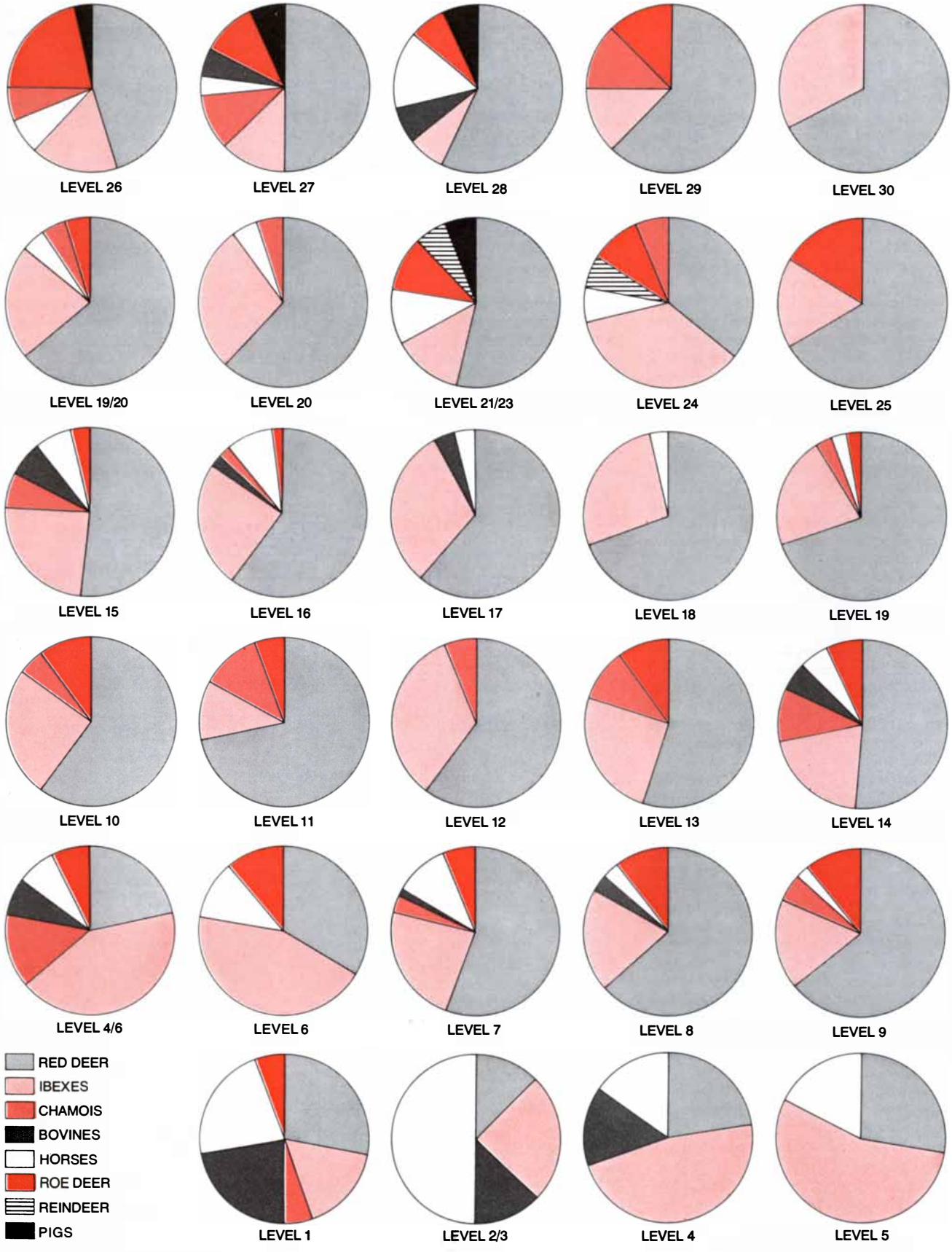
A long hiatus separates the two early Magdalenian levels from the next: Level No. 20. Dating to the interval between 13,000 and 12,000 B.P., this level was formed during an episode of cold, dry climate. Nevertheless, the hunters who found shelter in the cave again killed more red deer than any other game animal. Of the minimum of 21 individual mammals represented by the bones the red deer accounts for 13. Of the remaining eight, six are ibexes, one is a chamois and one is a horse.

The quantity of marine foods is still small but the variety is now much greater. In addition to the large estuarine limpets a smaller species, *Patella intermedia,* was collected. So was a species of top shell, *Monodonta lineata.* Like the smaller limpet species this mollusk inhabits the rocky open shore rather than the sheltered estuaries. For the first time periwinkles were gathered in quantities large enough to represent a significant fraction of the mollusk crop. Mussels and sea urchins were also gathered, further evidence that the Magdalenian visitors at La Riera were collecting food along the open shore as well as in the estuaries.

Also for the first time the shells of the periwinkles are found intact, and so are the *Monodonta* shells. The implication is clear. Large numbers of both mollusks had been boiled or steamed in some kind of container and their meat was then

LEVEL		YEARS BEFORE PRESENT (B.P.)	TREE POLLEN (PERCENT)	CLIMATIC INDICATIONS (POLLEN, SEDIMENTS, FAUNA)	
30(T)			48–64	INCREASINGLY WARM AND HUMID	
29/C	ASTURIAN	8500 B.P.	12–53		PERIWINKLES ABSENT
28	AZILIAN		(NO SAMPLE)		
27		10,500 B.P.	8–22	TEMPERATE, HUMID (COLD EPISODES)	NORDIC ROOT VOLE
26			37		
25			(NO SAMPLE)		
24		10,750 B.P.	4.5–16		REINDEER
21/23	MAGDALENIAN		5–11	COOL, HUMID	PINE AND BIRCH
20		13,000 B.P.	4.8	COLD, DRY	
		DEPOSITIONAL HIATUS			
19/20					
19		16,000 B.P.	11	WARMER, DRY (LOCALLY HUMID)	OAK, ELM, BIRCH, HAZEL, PINE
18			2		
17			3.5		
16		17,500 B.P.	6	COLD, DRY (SEDIMENT DATA)	
15			1.5		
14			2.8		BIRCH, HAZEL, HOLM OAK
13			5.5	WARMER, MORE HUMID	
12			3.3		
11			4		
10		20,000 B.P.	.3		PERIWINKLES ABSENT
9	SOLUTREAN		4		
8		20,500 B.P.	1.6		
7			3.5		
4/6				COLD, DRY (WARM, HUMID EPISODES)	NORDIC ROOT VOLE
6			.3		
5			7		
4		21,000 B.P.	4		
2/3			3	COLD, HUMID	
		DEPOSITIONAL HIATUS			
1	AURIGNACIAN?	+21,000 B.P.	10.5	TEMPERATE, HUMID	

STRATIGRAPHIC RECORD at La Riera spans an interval from about 21,000 B.P. (years before the present), or 19,000 B.C., to 8650 B.P., or 6650 B.C. During the better part of 12 millenniums Solutrean and Magdalenian hunter-gatherers were the chief occupants of the cave.



REMAINS OF LAND MAMMALS are found in varying quantities in the different main levels at La Riera cave. This series of pie charts shows the minimum number of individuals of each of eight mammalian species present in the level. The minimum number is expressed as a percent of the total number of animals present (*see key at bottom left*). The series should be read from left to right and bottom to top. Most of the meat in Level No. 1 came from horses and bovines. Thereafter red deer (*light gray*) often predominate over ibexes (*light color*), but none of the other species, except for horses in levels No. 2 and No. 3, is more frequent prey than either ibexes or red deer.

picked out of the shell, probably with some kind of pin, just as is done today.

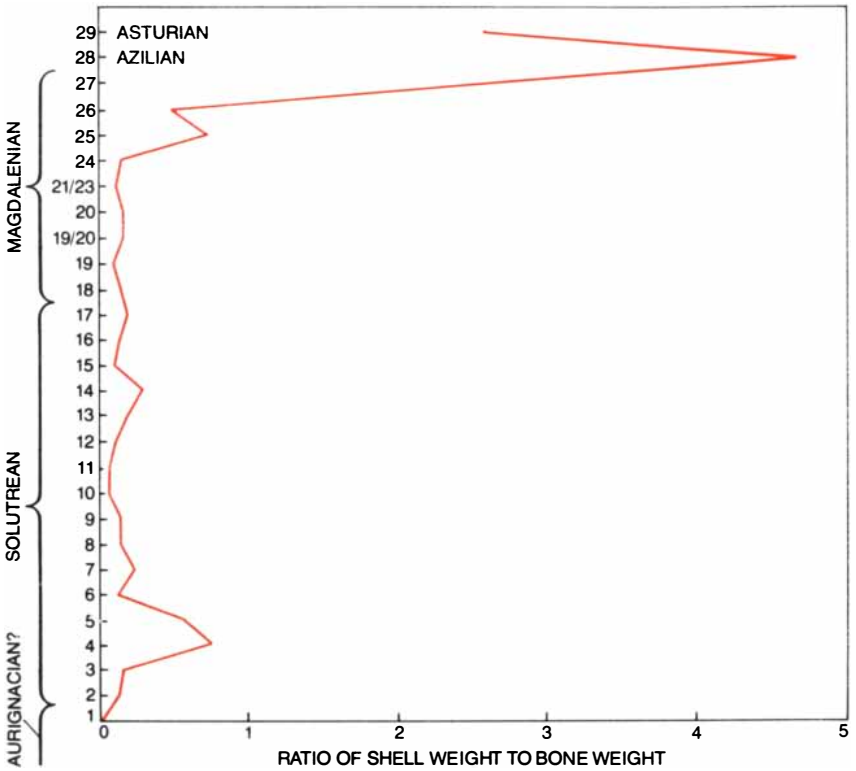
The contents of the next three Magdalenian levels (Nos. 21, 22 and 23) indicate that La Riera was sought out for shelter relatively seldom during a period of cold but very humid climate. The deposits are thick clays, suggesting that the cave was subject to occasional flooding. At the beginning of this interval, perhaps some 1,000 years in duration, the sediments were strongly frost-heaved. The landscape was marked by patches of forest that included some birches and pines. At the start of the interval there were also a few hazels, and at its end juniper pollen had become abundant.

The mammalian remains from these levels are limited in quantity, but they show great variety. For the first time at La Riera the wild pig and the reindeer appear; the bones indicate two of each. The presence of both species is puzzling. The reindeer generally lives in an open, cold environment, and its remains are rarely found in this part of Spain. Wild pigs live in quite the opposite kind of environment: temperate woodland and dense brush. The apparent coexistence of the two mammals suggests that at the end of the ice age Asturias was a region supporting a complex mosaic of plant types influenced by variable factors such as exposure, altitude and the availability of water. As for the other game animals, red deer continue in the majority: the remains of a minimum of 16 individuals were found in levels No. 21 through No. 23. No fewer than three roe deer, three ibexes and four horses are also represented.

With Level No. 24 we reach the final phases of the Magdalenian occupation at La Riera. The presence here of an antler harpoon head, circular in cross section, defines the level as Upper Magdalenian; the deposit was formed sometime after 11,000 B.P. The climate continued to be cold and humid. Pines were the principal trees and there were also patches of fern.

The mammalian remains preserved in Level No. 24 show that the same game animals were hunted. The bones include those of a few horses and fewer roe deer and chamois. Reindeer make their second and final appearance at La Riera. The principal animals represented in the remains are again the red deer and the ibex. A minimum of 11 of each were found. Most of the ibexes were juveniles.

We found few mollusk shells in this level, but here for the first time appear the remains of ocean fishes, probably including the sea bream. Members of the salmon family continue to be exploited; presumably they were trapped or netted in tidal inlets and streams as before. The ocean fishes, in contrast, may have been taken by fishermen working with lines or nets from rocks along the shore. And for the first time the bones of birds, which are rare in the earlier levels at La Riera, make an abundant appearance.



IMPORTANCE OF SEAFOOD in the diet of the sojourners at La Riera is traced in this graph in terms of the ratio between the gross weight of mammalian bone and the gross weight of mollusk shell. Such a ratio does not, of course, reflect the actual yield in vertebrate protein and invertebrate protein. The numeral 1 on the ordinate indicates a one-to-one weight ratio. This was much exceeded at La Riera during the Azilian phase. Both in the early Solutrean and in the later Magdalenian, however, the weight of shells occasionally reached 70 percent of bone weight.

Immediately above Level No. 24 at La Riera cultural distinctions tend to become fuzzy. Should the culture be called Final Magdalenian or Azilian? The latter is a transitional culture that provides a technological bridge between Paleolithic and Mesolithic times. Magdalenian and Azilian stone tools, however, look very much alike. Whatever the cultural assessment should be, Level No. 24 is separated by about 250 years from Level No. 27, and levels No. 25 and No. 26 lie in between.

The climate evidently continued to be relatively cold, but the woodlands were expanding. Pollen analysis shows that by the time of the deposition of Level No. 27 in about 10,600 B.P. oaks, elms and walnuts had joined pines, birches and hazels. Nevertheless, ferns and composites are particularly abundant.

The dietary details that can be deduced from the animal remains in these transitional levels are reasonably straightforward. In Level No. 25, where animal bones are scarce, those of the red deer predominate. Of the mammals represented in Level No. 26 red deer again rank at the top, although in terms of the minimum possible number of individuals they are not quite in the majority. There are 13 red deer, six roe deer, five ibexes, two chamois, two horses and one pig. In Level No. 27 the proportion of individual red deer has increased; they account for 28 of the total of 56 individual animals. A study of their teeth by one of us (Straus) indicates that among them were a large number of fawns.

Remains of the ibex, the chamois and the roe deer are next in abundance, followed by those of the horse, the pig and the bovines. These are the first bovines to appear since Upper Solutrean times (Level No. 17). Levels No. 26 and No. 27 also hold fairly large numbers of bird bones.

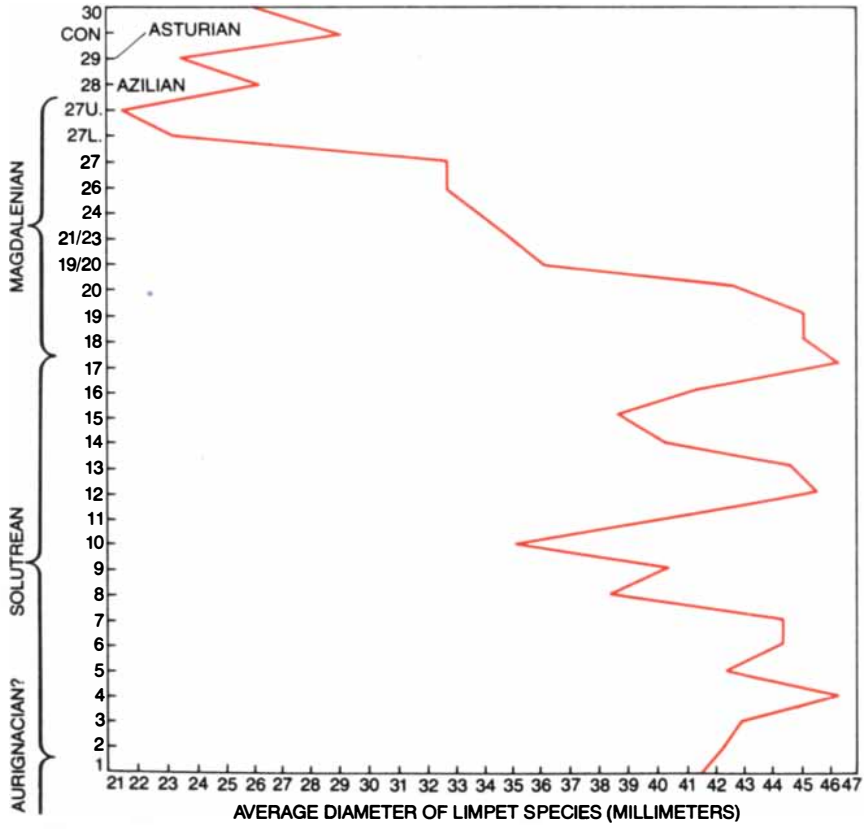
In this period the exploitation of marine foods shows some significant variations. Even earlier, within Level No. 24, the most commonly collected limpet, *Patella vulgata,* had begun to decline in size, probably as a consequence of overfishing. Such heavy late Pleistocene exploitation may have led to the limpets' being collected from the more open shore where the conditions for maximum growth were less than optimal. These limpets are still overfished today and are therefore small in size. Where pollution prohibits their collection, however, they easily attain their

optimal ice-age dimensions in spite of today's warm water temperatures.

In levels No. 25 and No. 26 there is evidence for continued intensive shellfish exploitation: the weight of mollusk shell increases substantially in proportion to the weight of mammal bone. The trend accelerates: in Level No. 27 shell outweighs bone by more than 1.3 to one, and the average size of *P. vulgata* declines further. Both the smaller limpet *P. intermedia* and the top shell *Monodonta lineata,* which were not exploited at all until the mid-Magdalenian (Level No. 20), now contribute substantially to the total mollusk catch; Level No. 27 is virtually a shell midden. In this level crab shells make their first appearance, and the bones of ocean fishes are common.

Just as the antler harpoon head with a round cross section in Level No. 24 defined that level as being Upper Magdalenian, so does another antler harpoon head, this one with a characteristically flattened cross section, define La Riera Level No. 28 as being Azilian. The inventory of mammalian remains here includes the same species found in Level No. 27, except that horses are absent. More important, the emphasis on mollusk collecting continues to accelerate and shell outweighs bone by more than 4.6 to one. The shells of the small limpet species are now as abundant as those of the large one, and for the first time there are more top shells than periwinkles. The bones of ocean fishes are also more abundant than before.

It is now less than 10,000 years before the present. The last glacial period of the Pleistocene epoch has come to a close, and the cave at La Riera is surrounded by woods flourishing in a warm and humid climate typical of early Holocene times. Red deer and roe deer, ibexes, chamois and horses are still available as prey, as is indicated by our limited sampling of Level No. 29 and of a separate section of the shell midden, dating to 8650 B.P., that is literally cemented to the ceiling of the cave. In these deposits, related to a regional Mesolithic culture named the Asturian, the mammalian remains are few but the mollusk shells are abundant and varied in species. The periwinkle, intolerant of warm water, has disappeared from the masses of shell but the other mollusk species now total nine and include land snails. Of the two limpets the larger one has become scarce and *Patella intermedia* finally predominates. In addition there are the spines and shells of sea urchins, the shells of crabs and among the bones of ocean fishes those of the bottom-dwelling sole. And so, although the major foodstuff was probably still venison, and plant foods such as acorns and hazelnuts may also have been eaten, our record of more than 10,000 years of human diet ends with an emphasis on seafood.



INTENSIVE USE OF THE MOLLUSK FISHERY at La Riera is reflected in this graph, which shows an average of the maximum diameter of the two limpet species whose shells are found in the cave. Whereas some of the decrease in size reflects the exploitation of the smaller limpet species starting in Magdalenian times, part of it is probably also due to overfishing.

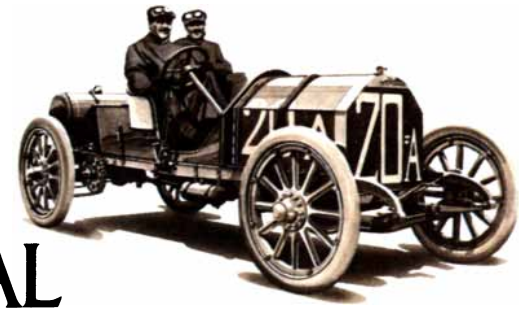
Why, after many hundreds of millenniums of subsistence by hunting and gathering, did man only quite recently adopt the alternate strategy of cultivating crops and husbanding animals? The reasons for this dramatic shift remain a topic of debate. Some prehistorians relate the change in strategy to environmental changes at the end of the Pleistocene; others relate it to pressures of increased population at that time. What is perhaps overlooked is that Paleolithic populations had long been subjected to environmental changes affecting their subsistence strategies and were able to take these changes in stride.

The cultural sequence in Cantabria provides an excellent case history of several such subsistence shifts. The few Mousterian sites preserve a record of opportunistic dependence on small numbers of large mammals. The Upper Paleolithic record at La Riera and at other Cantabrian sites, in turn, begins at a time when marine resources were ignored and ends at a time when these resources were being overtaxed. Over a span of many millenniums other food resources were also increasingly exploited by means of specialized strategies based on campsites selected to fit into the various complex settlement-subsistence systems of the late Upper Paleolithic. As one example, the presence of many ibex remains in early Solutrean times at La Riera (levels No. 4 through No. 6) suggests that the cave served as a base for specialized hunting of the animal in its nearby cliff habitat.

The record at La Riera and elsewhere in Cantabria does not support the hypothesis that environmental factors are primary forces of change in subsistence strategy. Warm or cold, wet or dry, wooded or open, the environment evidently supported two principal game animals—the ibex and the red deer—throughout the last millenniums of the Pleistocene. The larger game animals—the horse and the bovines—were staples in Mousterian times. Although they were still hunted in small numbers during the Upper Paleolithic, these animals represented only a part of an elaborate food-base strategy that included the intensive hunting of ibexes and red deer and the exploitation of shellfish, fishes, birds and plant foods. Perhaps horses and bovines played a large role in the Middle Paleolithic because the few hunter-scavenger bands of that time did not need to invent the efficient mass hunting techniques required for the taking of red deer and ibexes in quantity.

The Upper Paleolithic hunters show a steady trend toward broadening their resource base regardless of environmental variations. The trend is evident, for example, once limpets and other mollusks

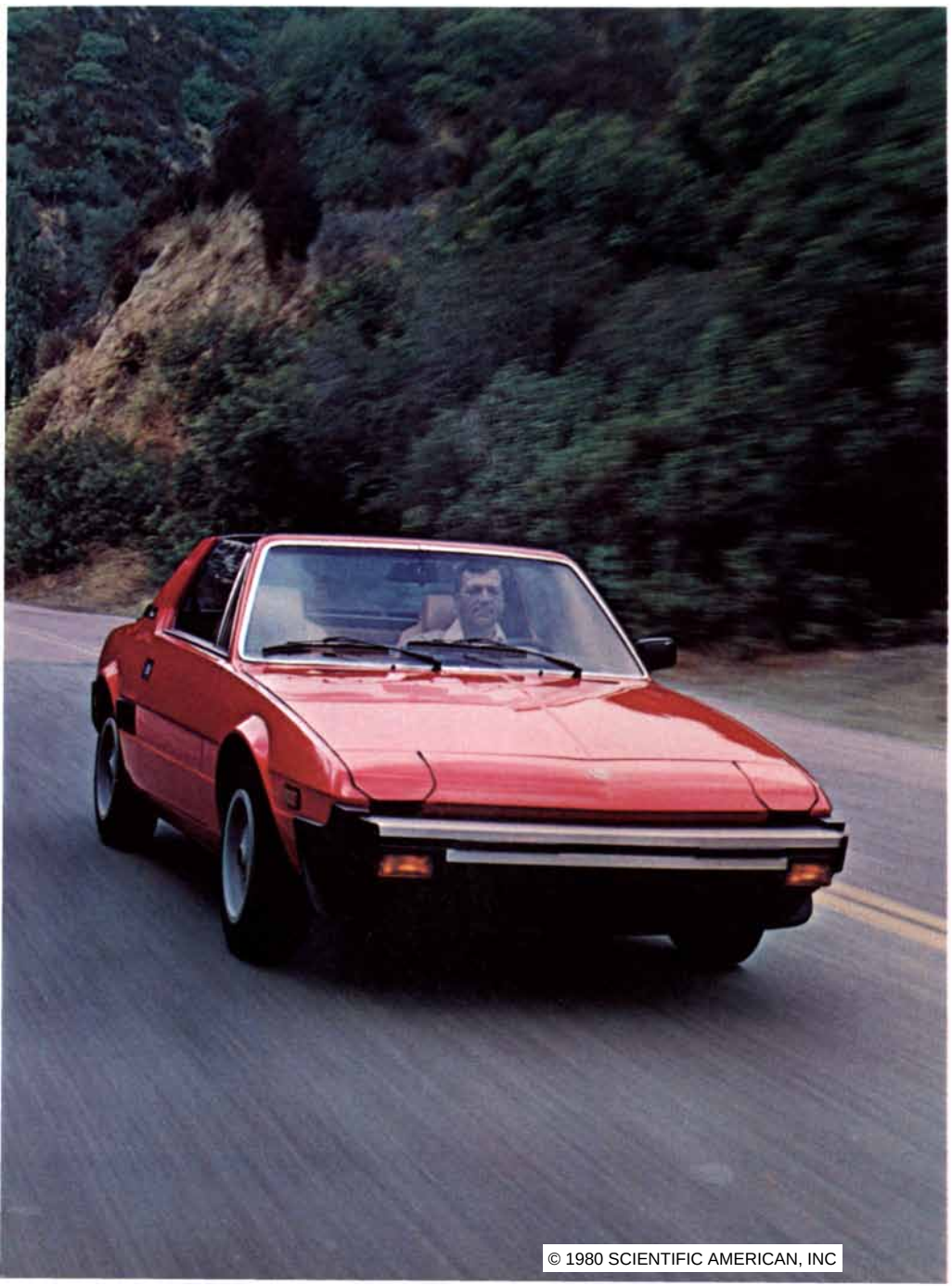
FROM A TRADITION OF RACE CARS, AN UNTRADITIONAL SPORTS CAR. THE MID-ENGINE FIAT X1/9.



FORERUNNER OF FIAT'S ECONOMICAL, HIGH-PERFORMANCE X 1/9, THE 1907 CORSA DELIVERED 19 MPG AND THE GRAND PRIX.

Motor cars had no sooner been made than the great European tradition of racing began. And practically from the start, Fiats were finishing first.

Heir to those famous early Fiats is the Bertone-designed X 1/9. The X 1/9 shares with many of today's most successful race cars, and most expensive sports cars, the precision handling and road-hugging traction of mid-engine design. Yet it costs thousands less than any of its rivals on the road.

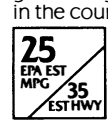


X 1/9. LOWEST-PRICED MID-ENGINE SPORTS CAR IN AMERICA.

The X 1/9 has wedge-shaped, wind-cutting styling much like the Ferrari. But it costs $36,000* less. It has a removable Targa roof much like Porsche 911. But it costs $15,000* less. And its equal weight distribution lets it hold the road much like a Masserati Khamsin. But the X 1/9 costs $35,000* less.

X 1/9. BEST GAS MILEAGE OF ANY 2-SEATER IN AMERICA.

And the 1980 Fiat X 1/9 gets the best gas mileage of any two-seater sports car in the country. Remember:



compare this estimate to the estimated MPG of other cars. You may get different mileage depending on speed, weather, and trip length. Actual highway mileage will probably be less and mileage varies in California.

Add a five-speed overdrive transmission, all disc braking system, rack and pinion steering, independent suspension, all for less than $8,500.* and you have it. The 1980 Fiat X 1/9. Probably the best all-around sports car value in America.

For name of nearest dealer, call (800) 447-4700 or in Illinois (800) 322-4400. Specifications subject to change without notice.

*Based on manufacturer's suggested retail POE east coast prices.

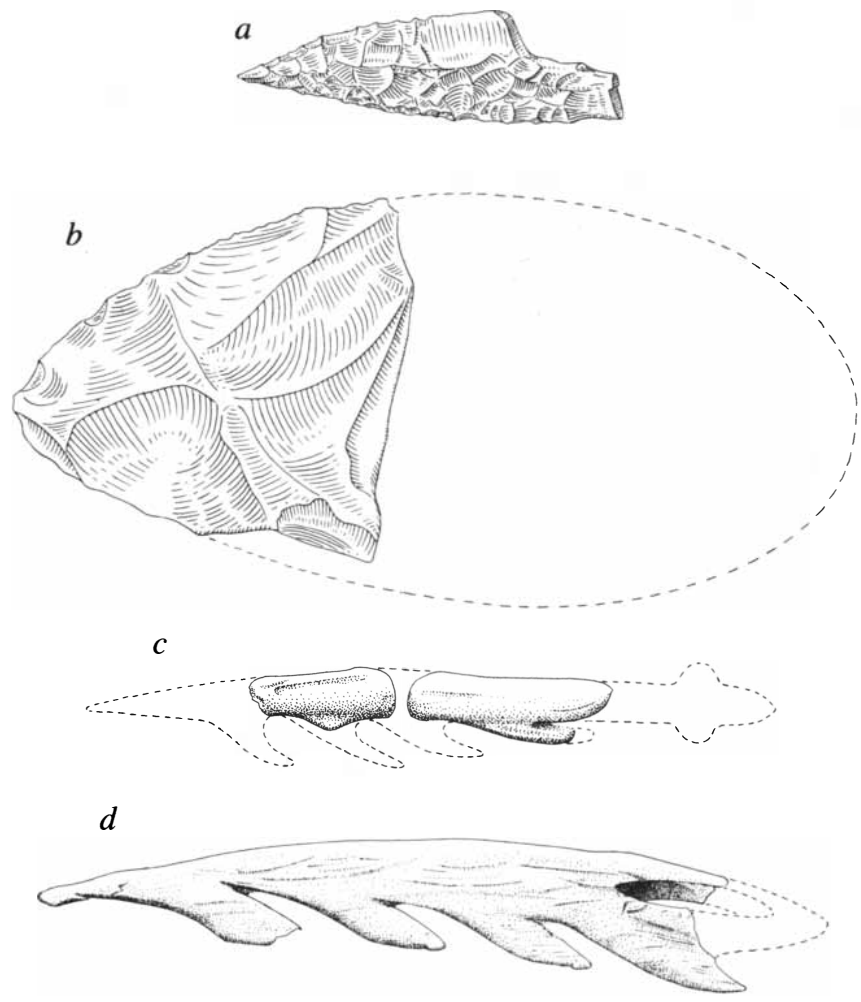
FIAT

MOTOR CARS IN THE GREAT EUROPEAN TRADITION.

began to be exploited in early Solutrean times. The climate may have been cold and the shore a long way from the cave, or it may have been warm and the shore closer, but whether the trip was long or short did not seem to determine whether shellfish were collected or in what quantity. Such factors as division of labor, seasonal scheduling and need may have been more significant than environmental considerations. As an example, some of the periods in which mollusks were most actively gathered were cold ones, when such gathering would have called for a greater investment of labor.

The only time that environmental change directly affected the hunters' strategy seems to come toward the end of the Pleistocene, when an increase in woodlands gave rise to a corresponding increase in the hunting of roe deer and pigs. How can one account for the greatly increased exploitation of marine foodstuffs at about the same time?

We suggest both increases were part of a terminal event in a long record of intensified and diversified subsistence strategies that began to be applied on the Biscay plain in Solutrean times, 10,000 years before the end of the Pleistocene. Accompanying these evolving strategies were specific technological improvements in hunting and gathering equipment: nets and traps, harpoons, spear-throwers and, certainly by the Mesolithic, the bow and arrow. This long record of intensified resource exploitation cannot be correlated with environmental changes. If, however, the sharp increase in the number of archaeological sites in Cantabria dating to the late Upper Paleolithic is a meaningful indication of an increase in population density, then demographic pressures could have forced the overexploitation of the marine resources and the expanded exploitation of food resources in general that is evident at La Riera and throughout Cantabria. The same pressures seem ultimately to have led to the adoption of crop cultivation and animal husbandry in Cantabria, as in the rest of Europe, five millenniums or so after the end of the Pleistocene.



TIME MARKERS AT LA RIERA include the four kinds of artifact shown here. Projectile points (*a*) with a "shouldered" base were found in the earlier Solutrean levels, whereas the last of the Solutrean levels held a few leaf-shaped points (*b*). Similarly, the antler harpoon with a circular cross section (*c*) is typical of late Magdalenian harpoons, whereas the harpoon with a flattened cross section (*d*) is typical of the post-Paleolithic culture named after Mas d'Azil.

Come backstage with us...

Yes, come backstage. Wander through the music stands. Look in on the performers warming up. The stage manager. The anxious composer.

Keep going. Wander to the performer's studio. Share the final preparations the day before the concert. Be there the month before the concert. The year before.

Go to the rehearsals. The auditions. The lessons. The exercises. The selection of a teacher. The making of a repertory. The promotion. The choosing—and arranging for—the concert hall.

What makes this performance happen? Even more intriguing—**What (besides talent) makes this PERFORMER happen?**

Now you can find out from the artists themselves in—

Virtuoso

The new bi-monthly magazine for concert- and opera-goers, for performing professionals and serious students, for teachers and coaches.

Every issue, you'll explore the "how-to's" of daily musical life—in penetrating articles often written by virtuosi themselves. For example, the premiere issue alone includes these inside stories that you just won't find anywhere else:

- Flutist Paula Robison tells how she prepares and stages her famous concert series ("Paula and..."), now in its 4th season
- An exclusive in-depth article on how the New York Philharmonic auditions to fill a place for one violinist
- Pianists Emanuel Ax and Ann Schein affectionately remember their master teacher Mieczyslaw Munz
- A dynamic picture story on a recording session with English horn player Thomas Stacy
- A special 16-page guide to summer festivals throughout the country: artists, dates, locations, public transportation, driving directions, and a lot more
- How it feels to be a child prodigy grown up—from one who knows

In every issue, you'll learn from accomplished artists how they develop the techniques that define virtuosity. How to design exercises for a particular repertory. How different artists prepare for their concerts.

Successful teaching techniques—as seen by both the master teachers and their virtuoso students. How composers **make** opportunities for having their work performed. What goes into selecting a recital hall. How to produce a recording. The special challenges of editing and performing early music.

There will be regular features about new books, recordings and performances throughout the country, as well as...

Visits to concert halls in major cities—and reports on their sound quality, audience comfort, frequency and types of concerts, and more.

Reviews of **reviewers.**

Now you can subscribe to Virtuoso at the special charter member rate of only $9.97/year (6 issues). **That's a saving of over 15% off the regular subscription rate!**

There's no risk. Fill out and mail the coupon and we'll rush you your first issue by return mail. We'll bill you later. If you choose to cancel your subscription, simply write "cancel" on the bill and return it to us.

So to start "coming backstage with us" right away—and to take advantage of our special Charter Subscription offer—subscribe now.

Special Charter Subscription Rate— If You Subscribe **Now!**

introducing **Virtuoso**

the new magazine for the music activist of the '80's

✓ **Concert- and Opera-Goers**

✓ **Performing Professionals and Serious Students**

✓ **Teachers and Coaches**

Virtuoso
352 Evelyn Street
Paramus, New Jersey 07652

YES! Please enter my subscription for Virtuoso at the special low-cost Charter member rate. I understand that, if I choose to cancel my subscription, I can simply write "cancel" on the bill and return it to you.

☐ One-Year Subscription (6 issues) $9.97 (A saving of over 15% off the single-copy price!) ☐ Payment Enclosed ☐ Bill me

☐ Please charge to my credit card:
☐ Visa/BankAmericard ☐ American Express ☐ Master Charge

Account # _____ Expiration Date _____

Signature _____

Name _____

Address _____

City _____ State Zip

A3-01-60

The Deep-Earth-Gas Hypothesis

There is much evidence indicating that earthquakes release gases from deep in the earth's mantle. Such gases may include methane of nonbiological origin, which could be a vast resource of fuel

by Thomas Gold and Steven Soter

It is widely believed that the earth's supply of hydrocarbon fuels will be largely used up in the foreseeable future, the most desirable ones (oil and natural gas) within a few decades and coal within a few centuries. Diverse evidence leads us to believe that enormous amounts of natural gas lie deep in the earth and that if they can be tapped, there would be a source of hydrocarbon fuel that could last for thousands of years. The hypothesis that there is much gas deep in the earth also provides a unified basis for explaining a number of otherwise rather puzzling phenomena that either give warning of earthquakes or accompany them.

The exact composition of the gas is not known, since the observational evidence is scattered and not easily interpreted. Volcanic eruptions bring gas out from the interior of the earth; the emissions consist mainly of water and carbon dioxide, but carbon monoxide, methane, ammonia, molecular hydrogen, hydrogen sulfide and others are frequently detected. It is not possible, however, to deduce from such observations the initial composition of the gas while it was still deep in the earth because (1) an unknown proportion of the volcanic gas may consist of volatiles that have been recycled from crustal sediments rather than of juvenile gas arriving for the first time from the mantle, (2) reduced, or hydrogen-rich, gases will have been mostly oxidized in the liquid magma as they rose to the surface and (3) most of the gas samples have necessarily been obtained from volcanoes that were in a relatively quiescent phase, so that the samples may be chemically unrepresentative of the larger volumes of gas emitted in explosive eruptions.

Gases released during earthquakes are probably more reliable samples of what resides in the deep crust and the upper mantle. The sampling of such gases is just beginning, and the data will not yet support confident conclusions. One can assume that the composition of the deep-earth gases varies from place to place, since the location of mineral deposits in the crust suggests that the underlying mantle is quite heterogeneous. For a variety of reasons we think methane of nonbiological origin is one of the principal deep-earth gases, and it will be the focus of our discussion here, although we do not mean to minimize the possible importance of other deep-earth gases in the phenomena associated with earthquakes.

The notion of nonbiological methane runs counter to the prevailing view in petroleum geology that virtually all the oil and natural gas in the earth is of biological origin. In that view the carbon in hydrocarbon fuels was all originally derived from atmospheric carbon dioxide, and the energy to dissociate the carbon and the oxygen came from sunlight in the course of photosynthesis by green plants. The burial of some of these organic compounds before they could become oxidized would then have provided the source materials for oil and gas. It cannot be doubted that this process contributed to the genesis of much of the petroleum that has been recovered, but there may be more to the story.

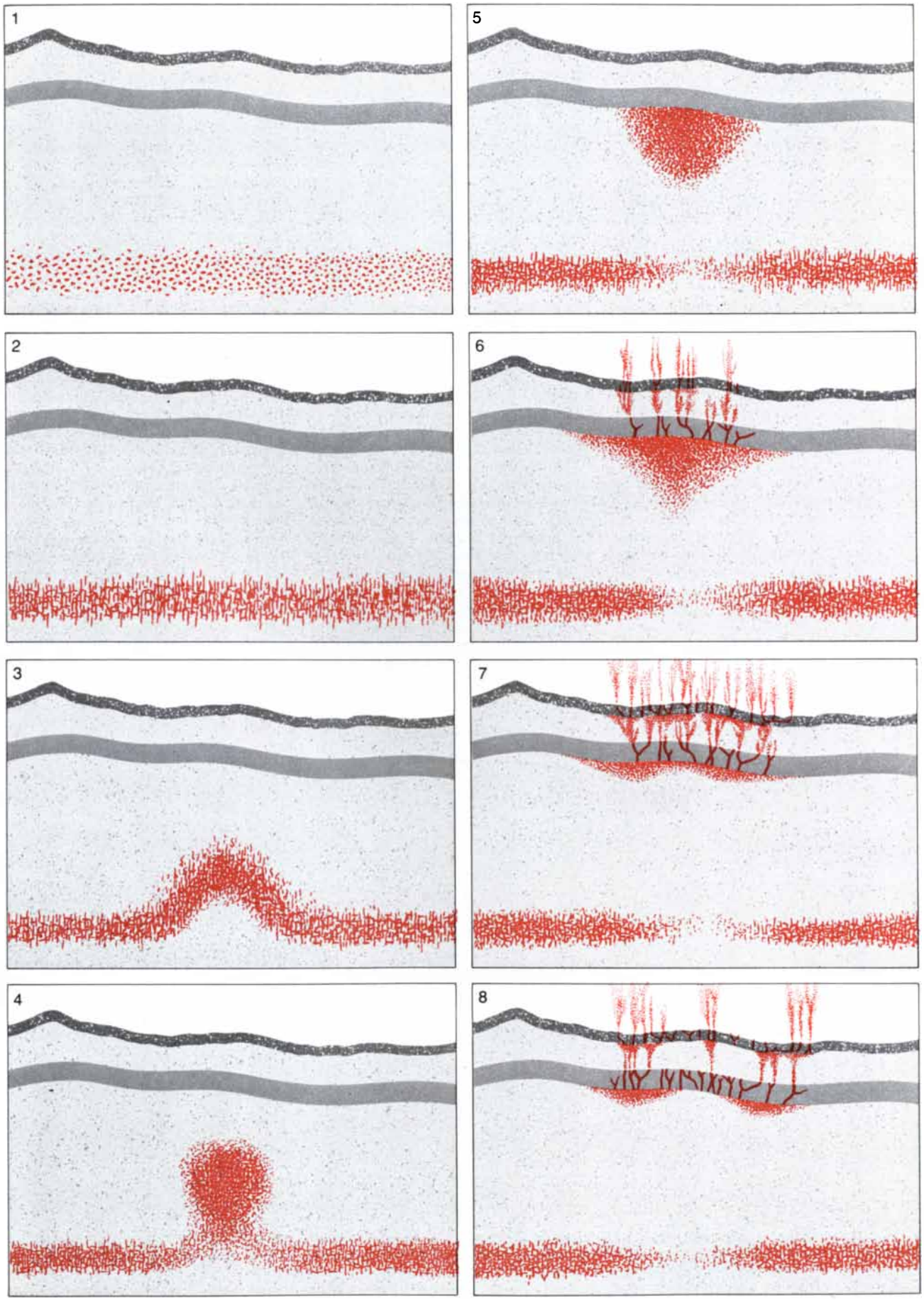
The hypothesis that the earth contains much nonbiological hydrocarbon begins with the observation that hydrocarbons are the dominant carbon-containing molecules in the solar system. The universe is made mostly of hydrogen, and the evidence of cosmochemistry suggests that the earth and the rest of the solar system originally condensed out of a hydrogen-saturated nebula. Most of the carbon in meteorites, which provide the best clues to the original composition of the inner planets, is in the form of complex hydrocarbons with some chemical similarity to oil tars.

It seems plausible that the earth acquired much of its carbon in the form of such hydrocarbons. The earth's primitive atmosphere probably held most of its carbon as methane (CH_4). The early stages of life on the earth are thought to have required such an atmosphere. With the subsequent production of free oxygen by photosynthesis the atmosphere gradually attained its present oxygen-rich composition, which today makes hydrocarbon fuels a useful source of chemical energy, since oxygen, one of the components needed for combustion, is present everywhere in the atmosphere.

What happened to the earth's primordial supply of hydrocarbons? We suggest the following hypothesis. Buried under conditions of high pressure and temperature, the hydrocarbons would liberate methane as the principal mobile component. This gas, often together with gases from other source materials, tends to migrate up toward the surface, mainly along zones of weakness in the crust, leaving the bulk of the heavy hydrocarbons behind. Where the pathway leads through hot volcanic lava the methane will be oxidized to carbon dioxide (by oxygen from water and from some of the oxides of the rock) just before it enters the atmosphere.

Where the pathway allows a reduction of pressure in a cooler nonmolten region, as along a cold fault, the gas can reach the surface in its original reduced state. (In the atmosphere it will survive

HYPOTHETICAL RISE OF GAS from deep in the earth is depicted schematically on the opposite page. Gas liberated from the earth's original store of hydrocarbons diffuses slowly into pore spaces (*1*), which can be envisioned as bubblelike openings between grains of the rock. The pore spaces distend and become interconnected (*2*), creating a "pore-space domain" that, because of pressure instability, begins to ascend (*3, 4*). As the pore-space domain reaches rock that is cooler and harder (*dark band in 5*) its movement is arrested (*6*). The gas facilitates brittle fracture of the rock, and some of the gas leaks to the surface. Large amounts of gas can escape into the atmosphere through fractures created by an earthquake (*7*). Slow leakage of gas thereafter (*8*) gives rise to a widening area of aftershocks. Leakage during the last three steps may account for many precursors of earthquakes and phenomena associated with earthquakes.



for only a few years before it is oxidized, eventually to carbon dioxide.) Other pathways will cause the methane to be trapped temporarily below relatively impermeable strata, where it will then contribute to the known deposits of natural gas. Finally, some of the methane, traveling on pathways that convey it through hydrocarbon deposits, including oil of biological origin, will become dissolved in those deposits. If, as is likely, it is held there for a long time, chemical changes will probably occur, including some that will cause the carbon and the hydrogen to polymerize onto the existing hydrocarbon molecules.

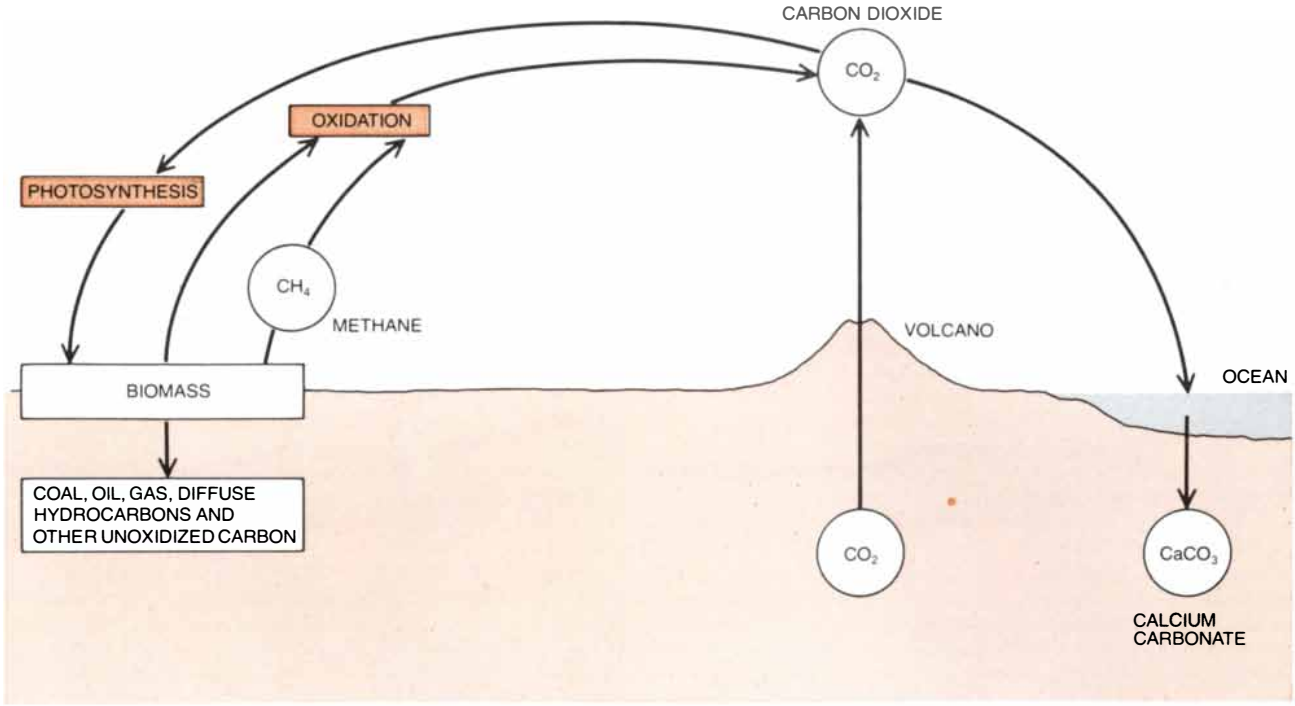
Most of the carbon in the methane that is migrating upward will eventually enter the atmosphere, either directly as methane or oxidized as carbon dioxide. From the atmosphere the carbon dioxide is largely removed by being dissolved and precipitated in the oceans. The sedimentary rocks of the earth's crust contain an enormous amount of carbon, mostly in the form of limestone (calcium carbonate, $CaCO_3$). Carbon is much more abundant in sediments than it is in the igneous rocks from which the sediments derived. This "excess" carbon must have been brought from the interior to the surface in the form of the principal stable carbon gases (carbon dioxide and methane), but what the proportions of the two gases may have been cannot yet be determined.

If all the reduced sedimentary carbon originated from degassed carbon dioxide, a corresponding excess of oxygen should be found in the sediments and the atmosphere. That much oxygen does not seem to be present. The supply of carbon in the form of hydrocarbon would avoid the problem. Indeed, the degassing of methane may be an important global process that is still going on. If the amounts remaining below are comparable with the amounts that must have come up to supply all or a substantial portion of the surface carbon, the quantity of methane still deep in the earth would be enormous compared with all biological deposits of carbon. The main reservoirs are doubtless too deep to drill, but even the quantities of methane that are temporarily arrested at accessible levels on the way up are likely to be very large. It will therefore be important to identify the pathways by which the gas reaches accessible levels.

An objection sometimes raised against the existence of hydrocarbons deep in the earth is that such materials would be oxidized readily to carbon dioxide because of the high temperatures there. The argument neglects two important considerations. First, the enormous confining pressure even at modest depth favors the stability of methane and hinders oxidation. Second, even if the rocks contain oxygen in a form that could oxidize methane, it is only in liquid rock that the oxygen would be available in significant quantity. If the pathways of the continuously streaming gases are confined to fissures through solid rock, the accessible surfaces will soon be depleted of oxygen; the gas will thereafter remain largely unoxidized.

It is also often said that the presence of porphyrins and other molecular residues of living organisms in many oil formations is proof that all the oil was derived from the decay of organic sediments. Many sedimentary rocks, however, are rich in biological residues. If such a rock is invaded from below by nonbiological oil and is left to soak for a few million years at elevated pressures and temperatures, the oil would surely become contaminated with biological substances derived from the sediments.

The British chemist Sir Robert Robinson has written that "it cannot be too strongly emphasized that petroleum does not present the composition picture expected of modified biogenic products, and all the arguments from the constituents of ancient oils fit equally well, or better, with the concept of a primordial hydrocarbon mixture to which bioproducts have been added." Indeed, we do not believe that any of the evidence usually invoked in favor of an exclusively biological origin for petroleum is compelling. The picture we favor is of a dual origin, with some hydrocarbons derived from buried organic sediments and a probably much larger amount added to those hydrocarbons



CARBON BUDGET of the earth is depicted according to the conventional explanation (*left*) and as it would be if methane deep in the earth were contributing both to the atmosphere and to the growth and maintenance of deposits of natural gas, coal and oil (*right*). In the conventional view all such deposits are of biological origin, the carbon in hydrocarbon fuels having been derived from carbon dioxide in the atmosphere. Plants dissociated the carbon and the oxygen by the process of photosynthesis, and the burial of some of these plants before

by augmentation from a stream of nonbiological methane. Although methane is usually assumed to be chemically unreactive, it may well be able to polymerize into crude oil under suitable conditions of temperature, pressure and catalytic action (including perhaps microbial action). If such a process does occur, an ascending stream of methane could slowly augment an existing deposit of biological material and enlarge it to a commercially valuable deposit of petroleum. The process need not be very efficient; even if most of the gas is not captured but goes on up to escape at the surface, a modest flow persisting over geologic periods of time could still be responsible for the large masses of hydrocarbons found in the commercial deposits.

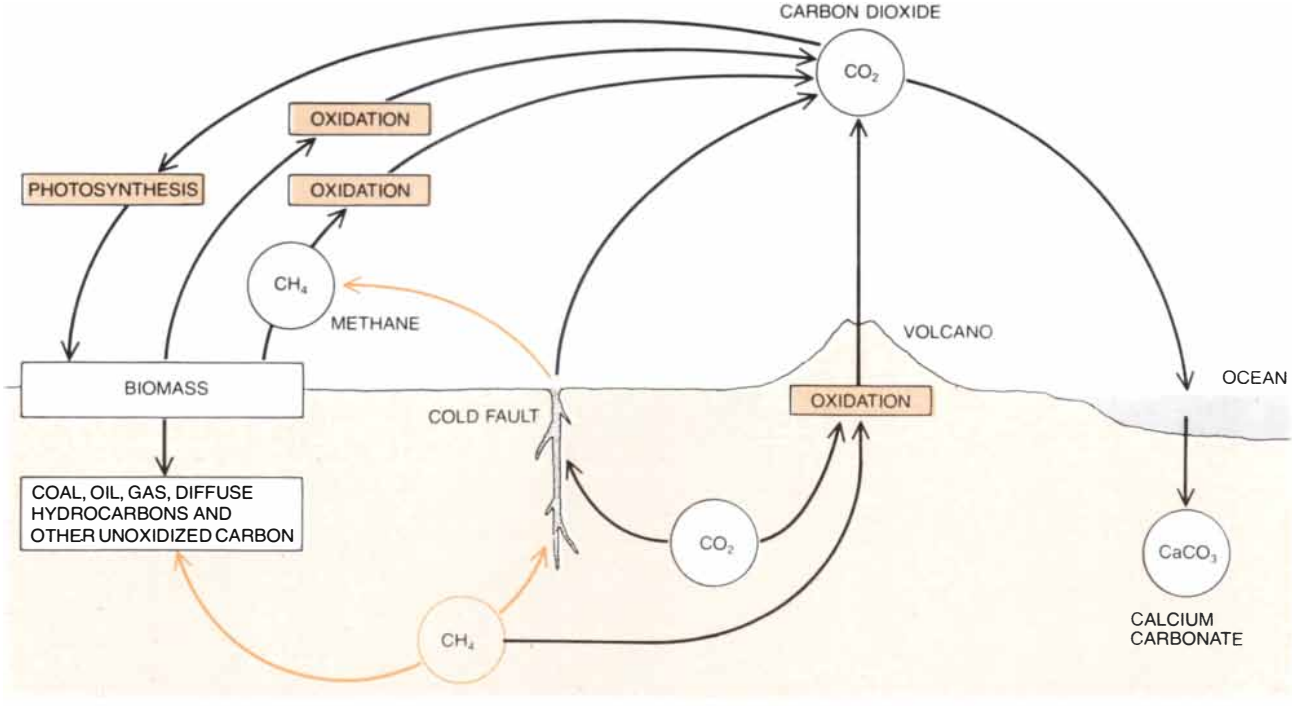
The chemical augmentation of hydrocarbon deposits would have a positive feedback, because the larger the deposit became the more probable the capture of a rising molecule of methane would become. Such a mechanism might help to explain why the few largest petroleum fields are so vast compared with all the rest. Of the many thousands of commercial oil fields, 33 (25 of them in the Middle East) contain about half of the world's known recoverable crude oil.

Let us now examine some of the evidence for the escape of methane from the interior of the earth. A likely place to look is along the crustal faults and fissures of the tectonic-plate boundaries, which ought to provide the best access to the deep interior. Indeed, hydrocarbons appear to be clearly associated with such places. Large concentrations of dissolved methane have been measured in waters overlying plate boundaries and rift zones. For example, the deep brines of the Red Sea contain about 1,000 times more methane than normal seawater does. Hydrothermal plumes found issuing from sea-floor vents on the East Pacific Rise contain high concentrations of methane. Lake Kivu, which occupies part of the East African Rift Valley, contains some 50 million tons of dissolved methane for which there is no adequate microbial source. We think it probable that all these waters are supplied by nonbiological methane seeping up through deep crustal fissures.

Another line of evidence connecting nonbiological hydrocarbons with such features is the striking correlation between the major oil and gas regions and the principal zones of past and present seismic activity. Oil fields often lie along active or ancient fault lines. Most of the known natural seeps of oil and gas are found in seismically active regions. The most spectacular seeps of gas are the "mud volcanoes," which are hills (if not substantial mountains) built up from sediments by the intermittent and occasionally violent eruptions of gas, sometimes carbon dioxide but most often nearly pure methane. Almost all the mud volcanoes are found on or near the major active fault lines and sometimes running parallel to lines of real volcanoes.

In seismically active regions many thousands of major earthquakes are likely to occur in the course of a few million years. One might think the repeated fracturing of the rocks in such a place would release or severely deplete any nearby accumulations of oil and gas in times that are short in relation to the age of the confining strata. The fact is that oil and gas fields show a distinct association with such earthquake-prone regions. The association suggests to us that the deep faults may provide a conduit for the continuous input of nonbiological methane streaming up from below. Moreover, the upward migration of methane and other gases in fault zones may contribute to the triggering of earthquakes.

An earthquake results from the release of stress in subsurface rock owing to a sudden brittle fracture, involving the rapid propagation of a crack and a sudden slippage between the two sides. (Such stresses seem to accumulate slowly, but the driving forces have not yet been clearly identified.) Seismologists have long recognized a difficulty in accounting for deep earthquakes. At a depth of more than about five kilometers the pressure from the overburden of rock is so great that a crack cannot open



they could become oxidized gave rise to hydrocarbon deposits. The second hypothesis assumes that in addition to the reduction of carbon dioxide by photosynthesis a deep source of nonbiological methane contributes directly to hydrocarbon deposits. Some methane is oxidized to carbon dioxide as it reaches the surface through hot volcanic lava at low pressure. Methane can also enter the atmosphere through cold faults, mainly during earthquakes. In both models the main carbon sink is through seawater to sedimentary carbonates.

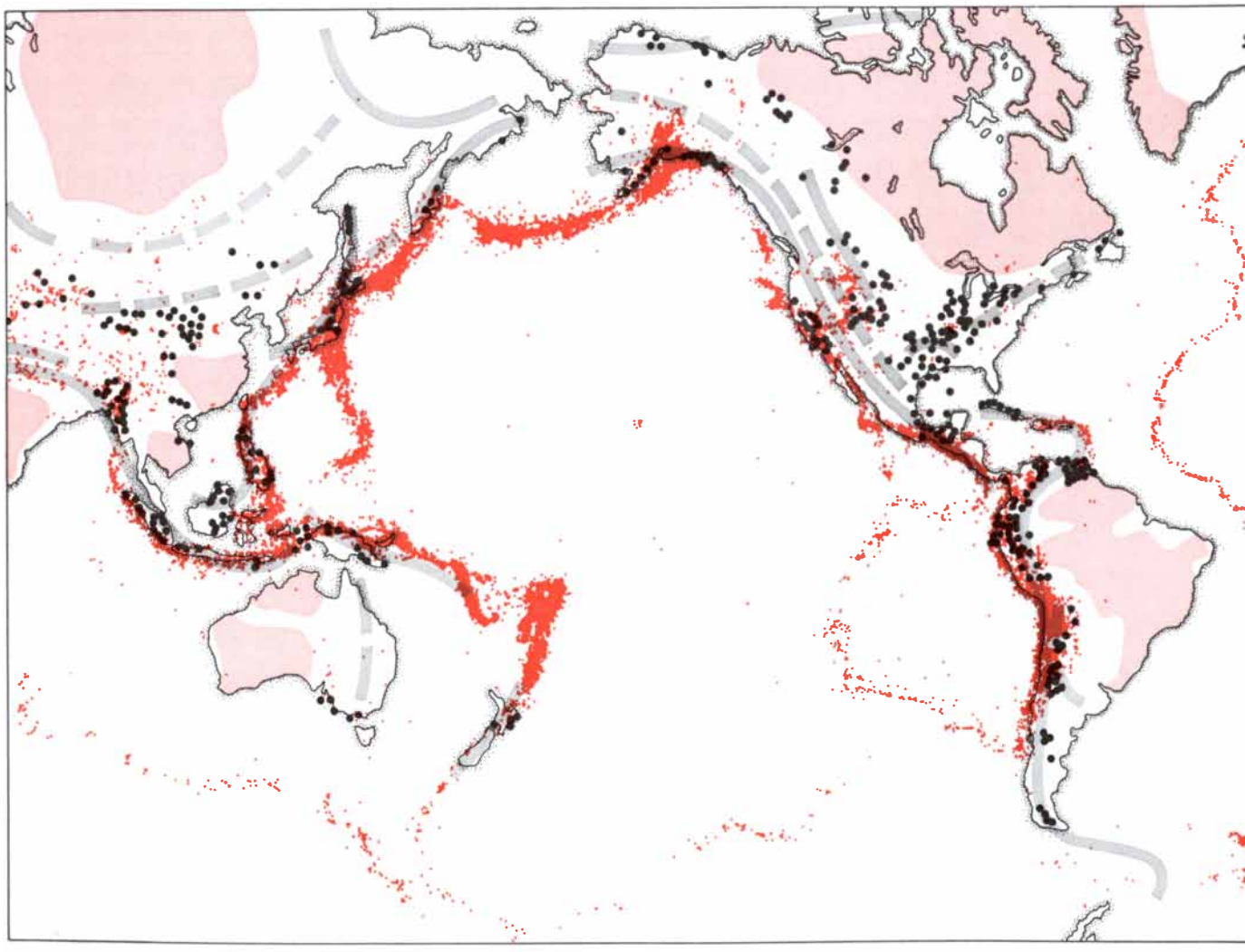
up by itself. Instead of breaking suddenly by brittle fracture, rock at such pressures simply deforms when excessive shear is applied. At even greater depths the increase in temperature further reduces the ability of the rock to form cracks. Continuous plastic flow would relieve the stress and no fracture could occur. Yet earthquakes have been recorded from depths of as much as 700 kilometers, and their seismographic "signatures" show that, like shallow earthquakes, they involve a sudden discontinuous fracture and slippage.

The presence of deep-earth gas could resolve this contradiction. If the deep rocks have interconnecting pores held open by gas at the ambient pressure, the pores can supply a crack as it is forming with enough gas pressure to hold it open and enable the two sides to slide. The gas effectively unburdens the rock and discontinuous slippage is again possible, as it is when the confining pressure is low. A crack can then propagate, releasing the strain energy and causing an earthquake.

If the earthquake is strong enough to fracture the ground up to the surface, the same gas will find an escape route and may generate some of the peculiar phenomena that have been reported to accompany many major earthquakes. The phenomena include flames that shoot from the ground, "earthquake lights," fierce bubbling in bodies of water, sulfurous air, loud explosive and hissing noises and visible waves rolling slowly along alluvial ground. We have collected from all parts of the world hundreds of independent reports of such phenomena that have been made over a period of centuries.

The flaming phenomenon indicates that the gas erupting during earthquakes is frequently combustible; most likely it is methane or hydrogen. According to newspaper accounts of the Owens Valley earthquake in California in 1872, "immediately following the great shock, men whose veracity is beyond question... saw sheets of flame on the rocky sides of the Inyo Mountains but a few miles distant. These flames, observed in several places, waved to and fro, apparently clear of the ground, like vast torches; they continued for only a few minutes." The reality of the flames is verified by the physical evidence that is sometimes left behind. For example, during the Sonora earthquake in Mexico in 1887 a number of people reported flames and later burned branches were found overhanging fissures in the ground.

The gas would be self-igniting because of sparks generated by the electrostatic charging of dust grains carried along in the flow, as is the case in the spontaneous ignition of gas in the eruption of mud volcanoes. The flaming phenomenon, seen at a distance of a few



CORRELATION between major regions producing oil and gas and zones of present or past seismic activity is indicated. The map shows the major shields, or rock masses (*light color*), the principal deformation belts (*gray*), the locations of major earthquakes (*colored dots*) and the sites of a number of oil seeps (*black dots*). Many of the known hydrocarbon reservoirs, including those of Alaska, Texas, the Caribbean, Mexico, Venezuela, the Persian Gulf, the Urals, Siberia and southeastern Asia, lie on deformation belts. The correlation is consis-

kilometers, may also be responsible for some of the earthquake lights that are often reported during seismic shocks taking place at night. Other phenomena of a similar kind, including sharp flashes, fireballs and diffuse luminosity in the sky, may be due to electrostatic effects from the sudden emission of large amounts of gas into the atmosphere.

One also finds many accounts of the vigorous bubbling of the sea and other bodies of water during major earthquakes. For example, during the great Chilean earthquake of 1960 observers on the shore over a range of 450 kilometers reported that the sea appeared to be boiling. This spectacle would be expected if large quantities of gas were liberated in an earthquake.

Although methane is odorless, hydrogen sulfide is a common constituent of natural gas and may account for the sulfurous odor after an earthquake. Since hydrogen sulfide is soluble in water and is highly toxic to fishes, the eruption of natural gas containing it may also account for some of the many reports of dead fish found floating on the water after major earthquakes at sea.

The propagation of slow surface waves on alluvial ground has been reported from many major earthquakes. Invariably the description is of waves like the waves at sea, usually some tens of centimeters in height and rolling along over distances that are many times the length of the wave. We believe such slow waves of large amplitude can occur only if the alluvial blanket is lifted from the bedrock; the phenomenon may then be due to gas at pressures of hundreds or thousands of atmospheres shooting up through the cracks in the bedrock that are created at the moment of the earthquake. This gas can easily lift the alluvial fill, which is less brittle than the rock and therefore does not open up cracks as readily. Once the layer has been lifted it can propagate slow gravity waves.

Tsunamis (large, earthquake-caused waves at sea that are often highly destructive) may be an analogous phenomenon. It is usually assumed that they are generated by a sudden displacement of an enormous area of the sea floor over a vertical distance comparable to the height of the wave. One would then have to conclude that a slab of rock, in some cases more than 100 kilometers across, had been raised (or lowered) by as much as one meter. Presumably such a slab extends down to the focal region of the earthquake (10 kilometers or more in most cases), meaning that the gravitational work necessary would be tens of thousands of times more than the energy resident in the sea wave. Yet the total energy ascribed to the earthquake, as judged by the radiated seismic energy, is only between 10 and 100 times that of the wave. One cannot ascribe a much larger energy content to the earthquake without far exceeding the maximum elastic-strain energy the rocks could have stored.

A different mechanism seems to be needed to account for the large tsunamis. An eruption of gas from the ocean floor and its ascent to the surface would create a wave motion of the required kind. It also would call for far smaller amounts of energy. An earthquake energy only about 10 times larger than the energy of the tsunami then appears to be a possibility.

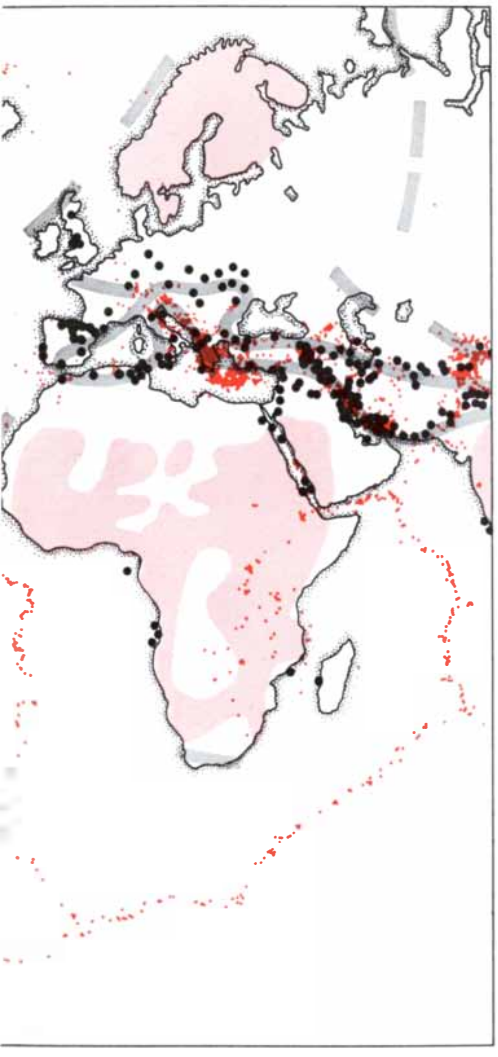
There is as yet no proof that any of the effects we have mentioned are caused by eruptions of gas during earthquakes, but at least for the flame and bubbling-water phenomena it is difficult to imagine a likely alternative. Even in the conventional view, however, it might be argued that gas eruptions are occasionally to be expected during major earthquakes because the shattering of the bedrock ought to liberate any local pockets of confined gas derived from the adjacent strata. In contrast one can cite evidence that the gas plays more than a passive role in the earthquake. Indeed, we believe most of the well-known precursors of earthquakes can best be explained in terms of an increase in deep-gas pressure well in advance of an earthquake.

Many of the precursory phenomena are detected only by instruments. Included in this category are changes in the velocity of seismic waves through the ground, in the electrical conductivity of the ground, in the tilt and elevation of the surface, in the chemical composition of gases in the soil and the ground water and in the emanation of radon gas. The time between the onset of a precursor and the earthquake ranges from minutes to years.

These precursors are ordinarily discussed in terms of rock dilatancy, that is, the opening of microcracks in the rock as the shear stress approaches the critical value for fracture. We agree that an increase in the porosity of the rock and a concomitant expansion of its volume would contribute to most of the precursors. The trouble with such interpretations, however, is the fact that at depths of tens of kilometers, where most earthquakes originate, the rock by itself would not have the strength to hold cracks open against the pressure of the overburden. Dilatancy could not even begin without the presence of a high-pressure fluid to hold the cracks open.

We suggest the deep-earth gas does just that. Our model for brittle fracture at high ambient pressure entails two prerequisites for a deep earthquake: (1) a shear stress sufficient to cause brittle fracture if the same rocks were at a shallow depth and (2) a high-pressure gas to hold incipient cracks open and thereby to counteract the enormous friction from the overburden. It is the invasion of the rock by such a gas from below that changes the rock from a ductile material to a brittle one, simultaneously causing its expansion and the associated phenomena of dilatancy.

As the deep-earth gas invades a region where it may later make it possible for an earthquake to occur some of it may move toward the surface, disturbing the ground water and altering the electrical conductivity of the ground and the composition of the gases in the soil. The radon precursor effect in particular seems to require the presence of a carrier gas streaming through the ground. Radon is a minor trace gas produced chiefly by the radioactive decay of uranium in rocks. Its own radioactive half-life is only 3.8 days, so that it could not by itself diffuse more than a few meters through the porosity of the soil before



tent with the view that hydrocarbons of non-biological origin come up from deep in the earth through fissures in the crust. They may augment hydrocarbons of biological origin.

decaying. Yet substantial increases in the emission of radon at the surface have been detected before some earthquakes at distances of as much as 100 kilometers from the epicenter. The simplest explanation is that the radon is merely a convenient tracer for a much more abundant gas that sweeps it along, an otherwise undetected gas with enough flow to travel past the depths of the radon sources and on to the surface in only a few days.

Not all precursors of earthquakes can be detected only by instruments. Some are so obvious to the senses that they have been recognized since ancient times. We believe these effects too are caused by an increased flow of gas through the ground. Among these "macroscopic" precursors are dull explosive noises of unknown origin, the strange behavior of animals, anomalous local increases in temperature, sulfurous fumes (sometimes accompanied by a peculiar fog), bubbling and other disturbances of water in wells and flames from the ground.

It might of course be argued that such gas-related precursory phenomena arise because gas is dislodged from the expanding porosity of shallow rocks being subjected to an increasing strain before an earthquake. Doubtless some gas is attributable to this cause, but the gas cannot easily account for the fact that the characteristic precursory behavior is abrupt and irregular at times when the most sensitive strain gauges measure nothing unusual. Furthermore, the precursors are often prominent at great distances from the epicentral region of maximum strain.

Since the gas responsible for the observed precursors often appears before any change of strain is noted, it must represent a fresh supply each time rather than a merely local redistribution in response to changing strain. Moreover, the precursor effects appear over broad regions simultaneously. Together these observations point to a deep source for the gas.

The well-documented strange behavior of animals before earthquakes can also be understood in terms of a leakage of gas. Many animals have an acute sense of smell that could enable them to detect the "earthy" odors arising as gases push up through the soil. Other animals may hear low-frequency noises generated by the gas, and ground-dwelling animals may respond to the threat of asphyxiation as their habitat is invaded by bad air.

If a deep-seated gas is required both for dilatation and for the subsequent sudden slipping motion of an earthquake, it may well be the same gas that is detected in the precursors. The flaming phenomena in particular suggest that a deep-seated combustible gas is being released, and nonbiological methane is the most likely candidate. Gas of biological origin is not likely to be found at the focal depth of most earthquakes. Moreover, it would soon be exhausted in earthquake-prone regions.

It is often assumed that porous material cannot exist at great depth because the high pressure would crush it and push the fluid in it upward. One should recognize, however, that the lithosphere shows two kinds of porosity. As one

MUD VOLCANO near Baku in the U.S.S.R. is, like others near it and elsewhere in the world, associated with eruptions of gas. This one, named Cheyildag, was quiet for 50 years until 1970, when it exploded through the rock cover. A large flame followed. At the same time a mass of clay began to seep out of the earth, forming the mound (70 meters in diameter) shown here. Mud volcanoes are mainly due to eruptions of gas and are not usually associated with high temperature. Mud-volcano flames have burned to a height of two kilometers.

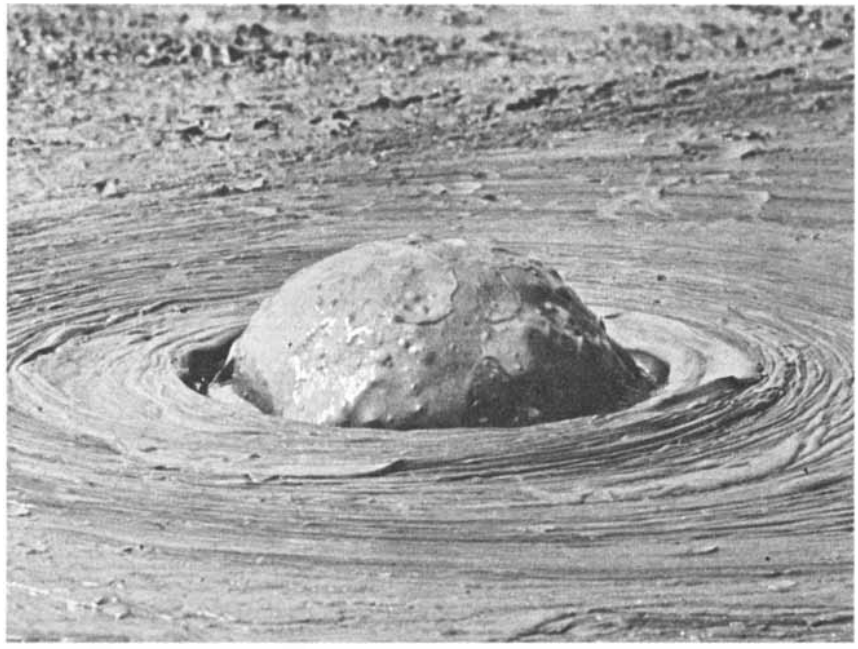
drills down from the surface one encounters pore spaces in the rocks, usually interconnecting and filled with water. The pressure in the pores is hydrostatic (governed by the overburden of water) and is about three times less than the pressure in the adjacent rock. As one reaches deeper levels the porosity slowly diminishes; eventually a level is reached where the rock is no longer strong enough to support the differential pressure. Any interconnected pore spaces there will indeed collapse, and whatever liquid or gas is in them will be expelled upward.

Below this level, however, there can be another domain in which pockets of gas again can exist but with the pore fluids now close to the lithostatic pressure (the pressure in the rock). The depth of the change from one regime to the other is dependent on the strength of the rock but is rarely more than six kilometers and may be as little as four. Since the two domains cannot have any permanent connections, there must also be a closed layer, which we call the critical level.

We assume that at great depths below the critical level gas is generated (in differing amounts from region to region) at a slow, steady rate, either by chemical reactions or by diffusion out of the rock. It begins to open pores. When a "pore-space domain" becomes interconnected over a sufficient vertical distance (probably several kilometers), it becomes unstable in terms of pressure and will begin to ascend. The reason is that the rock is no longer strong enough to support the difference in pressure gradients between the gas and the denser rock.

At this stage the pores at the bottom of the domain will collapse and the pores at the top will be opened; the pore-space domain as a whole will migrate slowly upward. It probably requires some years to work its way from a depth of a few hundred kilometers to the surface. Since the average pressure in the gas decreases during the ascent, the volume of the pore-space domain must increase. This phenomenon may be the cause of the gradual rising of the surface (about 10 centimeters) that has sometimes been detected over a period of years preceding an earthquake. When the pore-space domain penetrates the critical layer and enters the hydrostatic region, rapid venting may lead to precursory effects and to shallow earthquakes.

If both the macroscopic precursors and those involving dilatancy are in fact secondary symptoms of a principal underlying cause (the increasing gas pressure and porosity at depth), it might be possible to monitor the primary phenomenon and thereby obtain a securer basis for predicting earthquakes. Perhaps it will be possible, by seismic mapping of the subsurface, to detect small changes in the velocity of the waves because of changing porosity; by doing precisely repeated surveys in the same location one might actually observe the ascent of a pore-space domain.



ACTIVE ZONE of one of the mud volcanoes near Baku is represented by the bubble in this photograph. Some of the mud volcanoes near Baku are hundreds of meters high and several kilometers in diameter. Mud volcanoes tend to lie along fault zones, and major eruptions frequently coincide with earthquakes. Most of the eruptions consist principally of methane.

Efforts to monitor directly the composition and pressure of the gas in fault zones would be most useful. Several groups in the U.S.S.R. are already engaged in programs to observe changes in the chemistry and isotope ratios of ground gases. Both kinds of change are known to appear before earthquakes. Much of this work is being done by the substantial minority of chemical geologists in the U.S.S.R. who have also taken an interest in the concept of nonbiological petroleum.

We believe that in addition to suggesting new approaches to earthquake prediction the deep-earth-gas hypothesis suggests the possibility that very large amounts of methane from internal sources have accumulated in regions where, on the basis of the conventional biological-origin theory, they would never be suspected. The upper domain, in which the gas is at hydrostatic pressure, has been extensively surveyed (although perhaps not extensively enough). The lower domain, where gas can exist only at pressures closer to the lithostatic pressure, is still largely unknown. In a few places deep gas at such pressure has been tapped, but each time it has been thought to be there only because of an unusual geological configuration. If it turns out, however, that the phenomenon is widespread and that below the critical level of zero porosity is another regime of large porosity resulting from high-pressure gas, the outlook for the world's fuel supplies might have to be reevaluated. The quantities of gas that have been associated with the carbon degassing of the earth as a whole have been enormous. If methane has been a significant contributor, even the fraction residing in the high-pressure domain on the way up may still be very large compared with all other known reserves of fuel.

Many other lines of investigation can elucidate the degassing processes of the earth. Variations of the methane content of the atmosphere may be observable. Changes of fluid pressure in the ground can be monitored. The small differences in the proportion of the heavy isotope of carbon (carbon 13) among hydrocarbons of different origins tell a complex story that requires much further study. No one has any firm evidence on the diverse gas regimes more than a few kilometers below the surface or on the quantity or frequency of the various gases that emerge.

Our present attempt to formulate a relatively simple hypothesis to account for numerous previously unrelated facts will doubtless turn out to be in places oversimplified or overstated. We hope, however, that it will stimulate further research in this fundamental field of geophysics and geochemistry, leading perhaps to the discovery of large new sources of fuel and in any case to an improvement in the understanding of the earth and its resources.

Sexual Selection in the Black-tipped Hangingfly

This species has evolved a striking form of mating behavior: females choose males on the basis of the prey they present during courtship, and males may mimic female behavior to steal such prey from rivals

by Randy Thornhill

Insects, in spite of the relative simplicity of their nervous system, exhibit a diversity of sophisticated and complex forms of mating behavior. Few mating activities are more striking than that of the black-tipped hangingfly *Hylobittacus apicalis,* a relatively primitive insect with a slim, brownish body, long, thin legs and four narrow, black-tipped wings. I first observed the behavior of this species nine years ago on a casual walk through a wooded area in southeastern Michigan. In the early summer, when a population of adult hangingflies numbers in the thousands, it is not difficult to spot them flying through low-lying vegetation or hanging from a plant by their slender forelegs. The males of the species rely on their strong hind legs to capture aphids, houseflies and daddy longlegs, and I could see that once a male had obtained such a prey he would feed briefly and, hanging from a leaf or a twig, wait for a female to join him.

When a female did settle beside a male, he would offer her his prey and often the two would mate. In some instances, however, the female would simply fly away. The females seemed to be choosing among the males, rejecting as mates those with small prey offerings and accepting those with large offerings. It occurred to me that these insects might provide an excellent system in which to test Charles Darwin's ideas on sexual selection, in particular his much contested view of the role of female choice in the evolution of male morphology and behavior.

Darwin developed his theory of sexual selection in *The Descent of Man and Selection in Relation to Sex,* which was published in 1871. He argued that the evolution of secondary sexual characteristics could be attributed to two different selective forces: competition among males for mates and female choice of some males as mates over others. In the first type of selection a male's reproductive fitness depends on his ability to win conflicts with males of the same species; in the second his fitness depends on his ability to induce discriminating females to choose him.

According to Darwin, the evolution of male traits such as complex patterns of courtship behavior, the elaborate plumage of certain birds, the horns of certain hoofed mammals and the hornlike projections of certain insects, all of which jeopardize the survival of the male by costing him energy and increasing his exposure to predators, could be explained in terms of the advantages they confer in one of these two selective processes. The importance of competition among males as a force in the evolution of male traits has never been seriously disputed, but the importance of female choice in sexual selection has been very much so.

Alfred Russel Wallace, who came on the concept of evolution through natural selection independently of Darwin, was one of the first to point out that there were simply not enough observations of female choice operating in nature to support Darwin's proposal. This lack of direct evidence persists today. Most often the existence of female choice is demonstrated indirectly, by studies showing the distribution of females around males of different ages or sizes or with different amounts of some resource such as territory. Or female choice is simply assumed to operate in situations where females mate with some males and not with others, in spite of the fact that females, being generally smaller, less armed and less aggressive than males, may often be forced to stay with individual males regardless of any preference they might have. Furthermore, there is little evidence to show that female choice is actually adaptive in these situations, serving to increase the survival of the females that practice it or, more specifically, the number of offspring they produce.

Ever since my walk in the Michigan woods I have been studying the behavior of hangingflies and scorpionflies (which together make up the insect order Mecoptera) throughout the U.S. and Mexico. My findings show that females of the hangingfly species *Hylobittacus apicalis* do indeed evaluate males on the basis of a gift presented during courtship: a prey insect. Not all black-tipped hangingfly females choose among males in this way, but those that do choose among them choose as mates the males with the larger prey. Moreover, such a choice clearly increases a female's chances for survival and the number of eggs she lays. There is no question that the behavior of the black-tipped hangingfly provides one of the few known examples of adaptive female choice. In addition, I have found that males of the species compete for females in some remarkable ways, including the mimicking of female behavior to increase mating success. The black-tipped hangingfly therefore serves as an ideal model for understanding sexual selection as Darwin described it.

The black-tipped hangingfly is also an excellent subject for a study of behavior under natural conditions. About two centimeters long, it is diurnally active, catching prey and mating throughout the daylight hours. Individuals can be marked by applying a spot of paint to their body or wings, and although the males and the females look alike, they can be distinguished by their flight patterns: the males dart back and forth and the females, weighed down by a heavy freight of eggs, fly steadily and in a straight line. Both sexes are relatively slow fliers, making only short flights through the herbaceous, or low-lying, plant growth of their forest environment, and so they can easily be followed through their frequent interaction with other hangingflies and with the insects and other arthropods they feed on.

The mating sequence of *Hylobittacus apicalis* begins when a male either catches an arthropod or steals one from another male or a mated pair and, hold-

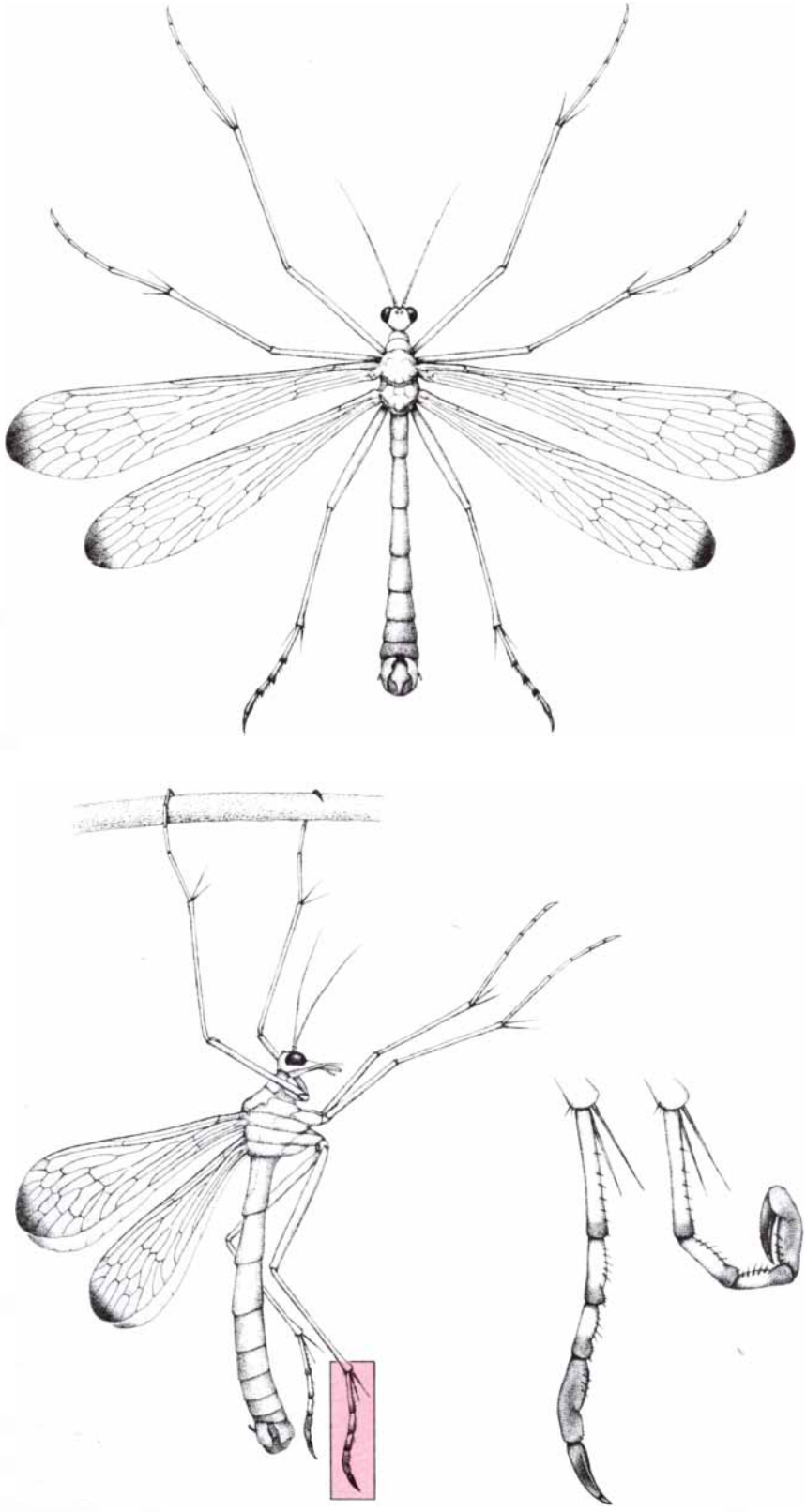
ing the prey in his prehensile hind tarsi (the last leg segments), catches onto a leaf or a twig and begins to feed. (To kill prey the black-tipped hangingfly relies on his sharp proboscis; when this beak-like structure is driven into the body of the prey, enzymes are released that paralyze the prey and then liquefy its body contents so that they can be sucked out.) Not all the prey items obtained by the males are offered to females as a nuptial gift. Indeed, my observations of 42 marked males at two study sites in forests in southeastern Michigan reveal that the males are highly discriminating about the prey they employ for this purpose. Of the 345 insects the marked males were observed to obtain, 110, or about 32 percent, were discarded in the leaf litter on the forest floor after the males had fed on them briefly. All the discarded prey measured less than 16 square millimeters in surface area, which suggests they were too small to be suitable offerings. (In the investigations I am discussing here the surface area of an arthropod is taken to be the product of its width and its length; for example, an average adult housefly has a surface area of about 20 square millimeters.)

Further evidence that males retain prey on the basis of size was obtained by sweeping the herbaceous vegetation at each of my study sites with an insect net. Sweep samples were taken every day for a week to determine the size distribution of the arthropods available at the sites. In addition, immediately after each sweep was made copulating pairs of black-tipped hangingflies and males holding prey were netted so that the prey could be measured. Comparisons of these samples showed that although *Hylobittacus apicalis* males hold small prey (less than 16 square millimeters in surface area) in direct proportion to the abundance of the prey in the vegetation, they hold large prey (16 square millimeters or more in surface area) and offer them as a nuptial gift far in excess of their natural abundance.

In midsummer, when male black-tipped hangingflies are abundant, females of the species are rarely seen catching prey on their own; they depend almost exclusively on the males and the prey they provide. Observations show that when the females do hunt, they do not discard the smaller prey items, and my studies confirm that females outside the context of mating hold different sizes of prey in direct proportion to the prey's natural size distribution. Hence it is the males that are the selective predators, effectively obtaining prey of specified sizes from the range available.

When a male hangingfly has captured a prey item that is sufficiently large, he feeds briefly and then, still holding it in his strong hind tarsi, begins making short flights through the herbaceous vegetation. For the marked males I observed these prenuptial flights were rarely longer than 3.6 meters. The cues that initially attract a female to the vicinity of the male are olfactory cues, not visual ones. At the end of each prenuptial flight the male hangs from a leaf or a twig, everts a pair of glandular sacs from his abdomen and begins releasing

MATING PAIR of black-tipped hangingflies (*Hylobittacus apicalis*) are seen here gripping the nuptial gift (a large blowfly) offered by the male (*left*) to the female (*right*). These hangingflies are shown in the early phase of the mating process, when the female evaluates the male's prey offering and the male tries to mate with the female. A female black-tipped hangingfly judges males according to the size of the prey they offer, refusing to mate or mating only briefly with those males that offer small or unpalatable prey. When the prey offering is sufficiently large (as is the case here), the female will accept the male and mate with him for a period of 20 minutes or more.



BLACK-TIPPED HANGINGFLY, shown here in top and side views, is a medium-size insect (about two centimeters long) found among the low-growing vegetation of wooded areas in the eastern U.S. When the insect is not in flight, it hangs by its long, slender forelegs from a leaf or a twig, as is shown at the bottom left. To capture and manipulate prey the black-tipped hangingfly relies on its strong prehensile tarsi (*color*), the jointed last segments of its hind legs. As is shown in enlarged view at bottom right, the last four joints of each tarsus provide a powerful organ for enfolding prey, with last two joints snapping together to firmly clamp a wing or a leg.

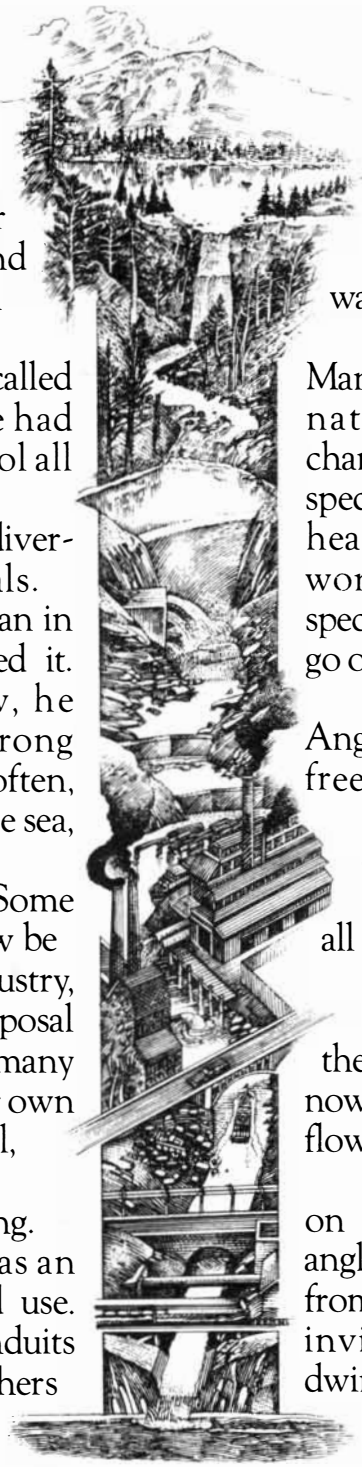
a pheromone: a message-bearing substance that serves to attract females. (The pheromone glands are everted by an increase of blood pressure in the abdomen of the male and retracted by specialized muscles.) Mating does not actually begin until a female is hanging by her forelegs facing the male. Then the male presents his nuptial gift to the female and while retaining his own hold on it allows her to grip it with her hind tarsi. As the female begins to feed the male attempts to mate with her.

If the male's gift is sufficiently large (16 square millimeters or more in surface area), the female accepts him and the two mate for an average of 23 minutes with the female feeding throughout. The mating process is terminated by the male, and a struggle ensues as the male tries to disengage from the female and to pull the prey from her grasp. If, on the other hand, the male's gift is unpalatable (as it is when it is a ladybird beetle, which contains distasteful substances) or too small, the female will either refuse to mate with the male or if mating is initiated will terminate it quickly, flying away after five minutes on the average. In the latter case, then, it is the female that tries to disengage from the male, but if the male wins the ensuing struggle over the prey, he will generally try to present his "undesirable" gift to the female and engage her in copulation once again.

Males were observed to win 64 percent of the struggles between pairs of black-tipped hangingflies for final possession of the nuptial gift and females only 8 percent. On the remaining occasions the prey was dropped and lost in the leaf litter on the forest floor. If the male does retain the prey after copulation is ended, he feeds briefly on it, and if it can still provide adequate nourishment, he utilizes it again to repeat the mating sequence with a different female. Otherwise he discards it and begins hunting for another item suitable for nuptial feeding. Whether the prey can be employed in two successive matings is generally determined by its size. I have found that prey arthropods measuring between 28 and 45 square millimeters in surface area are the ones most frequently employed twice. Smaller prey do not provide sufficient nourishment, and larger ones are difficult for the male to hold on to in the postmating struggle. In fact, it is the females that are the most likely to gain possession of a very large prey item they have been offered as a nuptial gift.

The female black-tipped hangingfly may thus discriminate against males with small prey on two levels: first by rejecting such males before copulation begins and second by accepting such males as mates for a limited period only.

A FUNNY THING HAPPENED ON THE WAY TO THE OCEAN.



Not so long ago most of the water that fell on our continent ran downhill and back to the ocean, from which it came.

No more. Modern man called that "wasting to the sea." He had other ideas. He would control all that free-running water.

He built dams, dikes, and diversions; levees, locks and canals. Where water inconveniently ran in crooked courses, he channeled it. Where it ran too shallow, he dredged. Where it ran the wrong way, he turned it around. And often, where he did let it return to the sea, he filled it with wastes.

Up to a point it worked. Some of America's waters could now be used for irrigation, cities, industry, power generation, sewage disposal and transportation. And still many of our waters were left to their own devices, providing their natural, less tangible benefits to man.

But then the balance swung.

In many places there was an overkill of manipulation and use. Lakes died. Rivers became conduits of sewage and toxic wastes; others were turned into a series of still ponds. Magnificent streams and awesome canyons were drowned. Fresh waters turned salty.

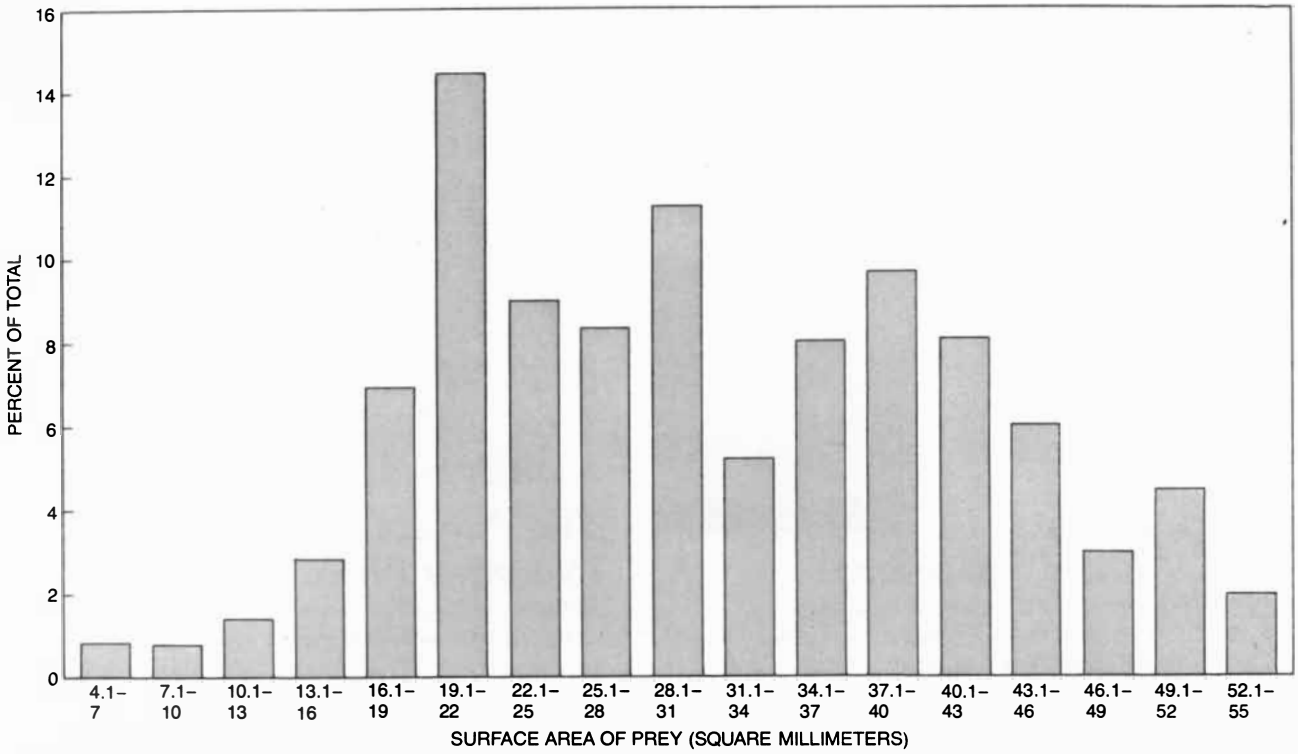
Fish are among the casualties. Many of them chemically contaminated. Much of their habitat changed—fouled and stilled. Those special conditions necessary for the health and propagation of our worthiest sport and commercial species, gone. As our waters go, so go our fisheries.

The American League of Anglers believes that natural and free-flowing waterways are more than pleasant amenities for fishermen. Their ecological health is essential to man as well as to all forms of wildlife.

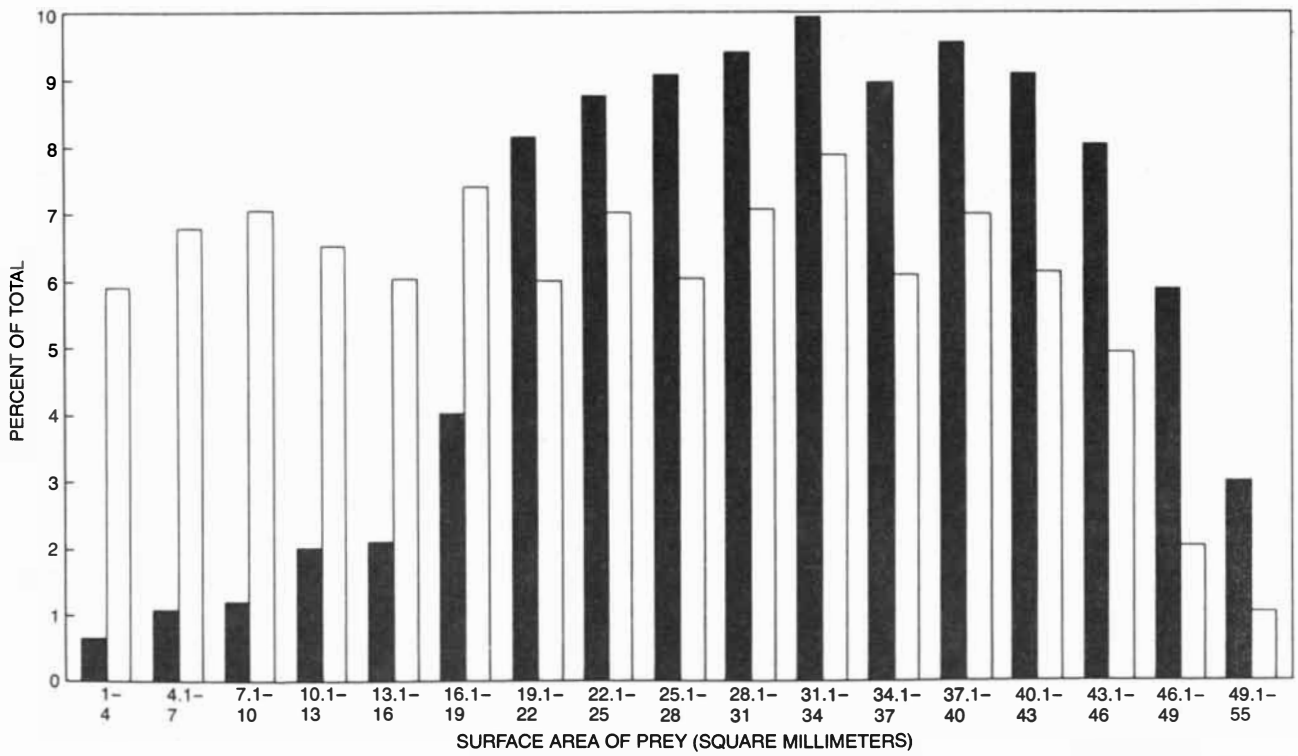
We are committed to preserving a proper balance between the need for water manipulation now and the desire for pure, free-flowing waters forever.

We act and speak for this goal on a national level. We urge all anglers, who receive extra benefits from good water, to participate. We invite all those who revere our dwindling stock of natural waters to support our efforts.

THE AMERICAN LEAGUE OF ANGLERS, 810 18TH STREET NORTHWEST, WASHINGTON, D.C. 20006



MALES PREFER LARGE PREY ITEMS to offer as nuptial gifts. The bar chart shows the size distribution of the prey arthropods employed by 168 male black-tipped hangingflies in mating. Observations of this species in its natural environment indicate that more than 90 percent of all matings involve large prey, that is, insects or other arthropods measuring 16 square millimeters or more in surface area. (For the purposes of these investigations the surface area of an arthropod is taken to be the product of its length and its width; for example, the blowfly held by the hangingflies shown in the illustration on page 163 measures about 30 square millimeters in surface area.)



WHEN FEMALES HUNT, they do not favor larger prey items, as is shown by this bar chart comparing the size distribution of the prey taken from 248 single male black-tipped hangingflies (*black*) and 276 single females (*white*) at forest study sites. Female black-tipped hangingflies are generally well supplied with food by males searching for mates, however, and so they are not usually required to hunt.

Males with small prey generally succeed in mating for no more than five minutes, whereas those with large ones mate for 20 minutes or more. The significance of these numbers was not clearly revealed until I did laboratory experiments to determine when in the course of mating sperm is actually transferred from the male to the female. In these experiments virgin females were mated for periods ranging from one minute to 39 minutes. Their sperm-storage organ was then removed and a sperm-specific stain was applied so that the sperm could be counted.

These studies showed that up to five minutes of copulation is necessary before any sperm is transferred to the female's storage organ. Moreover, for those matings that lasted between five and 20 minutes there was a positive correlation between the duration of copulation and the number of sperm transferred. After 20 minutes there was little increase in the number of sperm transferred no matter how long copulation continued. Hence the brief matings of males holding undersize prey result in little or no sperm transfer and therefore little or no increase in the number of offspring sired by those males. The long matings of males holding large prey, on the other hand, results in a maximum insemination of the female with the obvious consequences for the production of offspring.

Maximum insemination of the female is not the only advantage the male with larger prey derives from his longer mating period. Observations of black-tipped hangingflies both in the laboratory and in the field show that the longer mating period stimulates egg laying and also makes the female less likely to mate again soon. Female black-tipped hangingflies extrude large, visible eggs, which adhere to them for a few minutes before dropping to the forest floor. With this kind of egg laying it is possible to determine the egg output of females after interaction with males offering prey of different sizes.

I have found that after a female has mated for 20 minutes or more she becomes unresponsive to males and does not mate again for about four hours, during which time she lays an average of three eggs. If she continues to encounter males with large nuptial gifts, this cycle of mating nonreceptivity and egg laying may continue uninterrupted throughout the day. When on the other hand a female has mated for only about five minutes, she does not lay any eggs but quickly finds another male and then another, always searching for one with a large prey item. No matter how rich a supply of nutrients the female gets from small prey in the course of these short interactions she will continue to interact briefly with different males until one

with a suitable prey item is found and a long mating can be undertaken.

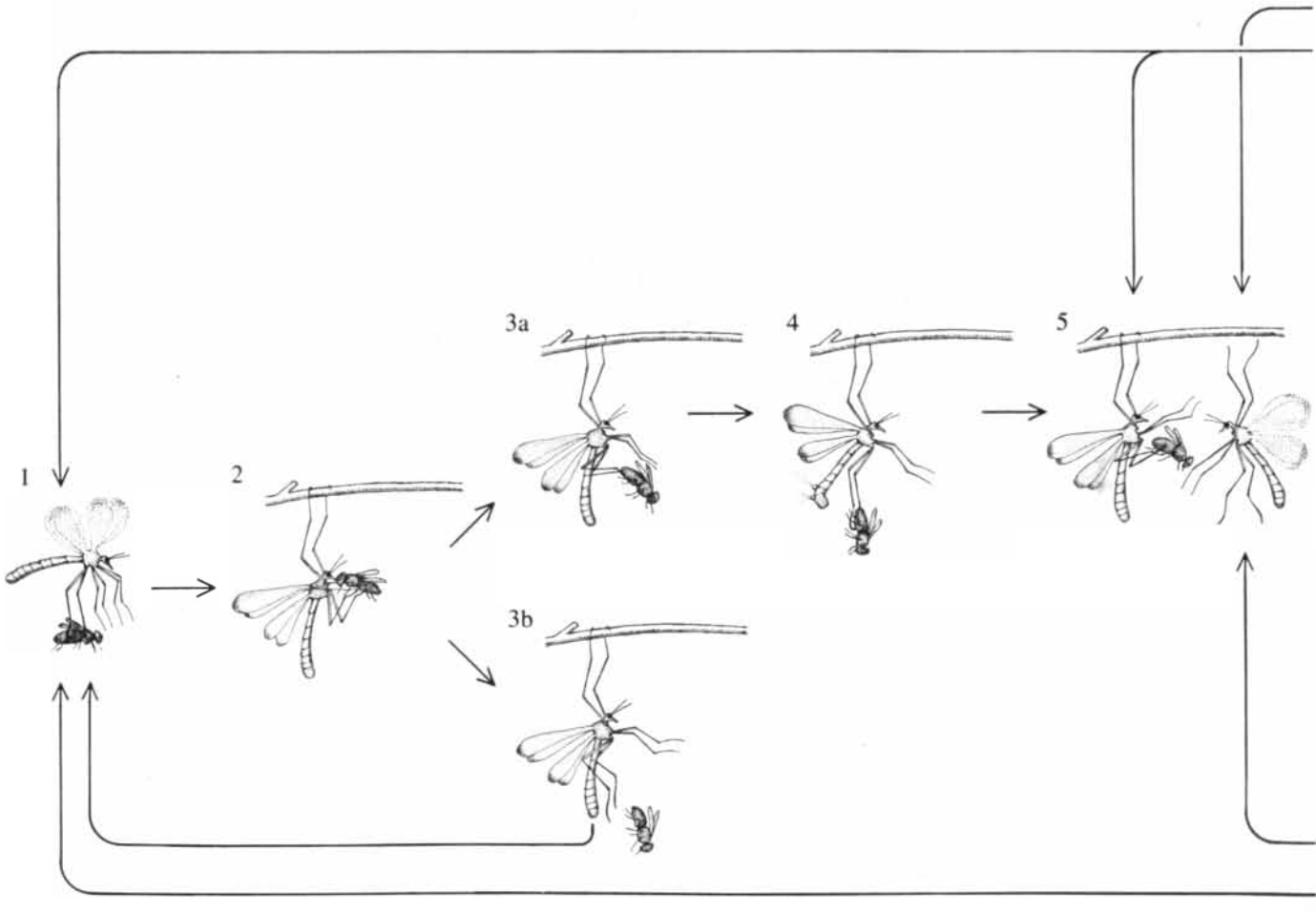
Female choice in the black-tipped hangingfly is clearly adaptive, that is, it enhances the reproductive capacity of those females that practice it. I have found females that discriminate among males on the basis of nuptial offerings lay significantly more eggs per unit of time than those that do not discriminate. Moreover, females that discriminate increase their own chance of survival.

The reason is as follows. A hunting hangingfly moving through its forest environment runs the risk of flying into a spiderweb. Indeed, a substantial fraction of a hangingfly population is lost to predation by web-building spiders. Among black-tipped hangingflies, however, the rate of loss is significantly lower for females than it is for males, a phenomenon that can be attributed to the disparity in the distances traveled by the two sexes in the course of their normal activities. Among the marked individuals I observed the males moved an average distance of about 33 meters in an hour and the females about 16.

This disparity can be traced to the practice of nuptial feeding: the males spend about 50 percent of their time between matings hunting for nuptial prey, whereas the females, being well supplied with food by the males, are rarely required to hunt. Therefore the females are far less likely to encounter spiderwebs. By selecting a male with a large prey item a female further limits her movement and so her risk of being captured by a web-building spider, thereby increasing her chance of survival. The relation between nuptial feeding and female survival in the black-tipped hangingfly is supported by a comparison with another hangingfly, *Bittacus strigosus,* which does not engage in nuptial feeding. In this species males and females participate about equally in hunting, and the mortality rates from spider predation for the two sexes are comparable.

My findings suggest that nuptial feeding evolved in the black-tipped hangingfly as a means of reducing the female's participation in activities involving risk, namely those associated with hunting. In supplying food to the female the male reduces the probability that she will be captured by a spider before laying the eggs he has fertilized. It should be noted that my interpretation of the selective advantage of nuptial feeding for males is based on the assumption, supported by studies of other insects, that the last male to mate with a female for 20 minutes or more fertilizes the majority of the eggs she lays.

The fact that female choice in the black-tipped hangingfly results in some males (those with large prey) mating more frequently and successfully than others (those with small prey) indicates that female choice is potentially an important form of sexual selection, possibly excluding from reproduction a sizable fraction of the males in each hangingfly generation. My findings show that



MATING SEQUENCE begins when a male black-tipped hangingfly either catches a prey arthropod or steals one from a mated pair or another male (*1*) and then, hanging from a leaf or a twig, feeds on it briefly (*2*). If the prey is too small, the male usually discards it in the leaf litter on the forest floor (*3b*), in which case he must obtain a new prey item and start over again. If the prey is sufficiently large, however, the male retains it (*3a*) and, everting a pair of glandular sacs in his abdomen, begins releasing a pheromone, a message-bearing substance that serves to attract females (*4*). When a female black-tipped hangingfly arrives, the male offers the prey to her (*5*), allowing her to grasp it with her hind tarsi while he maintains his hold on it (*6*). The female begins to feed on the prey, evaluating it as the male attempts to mate with her. If the prey is unacceptable (either unpalatable or too small), the female may release it and fly away, refusing to mate

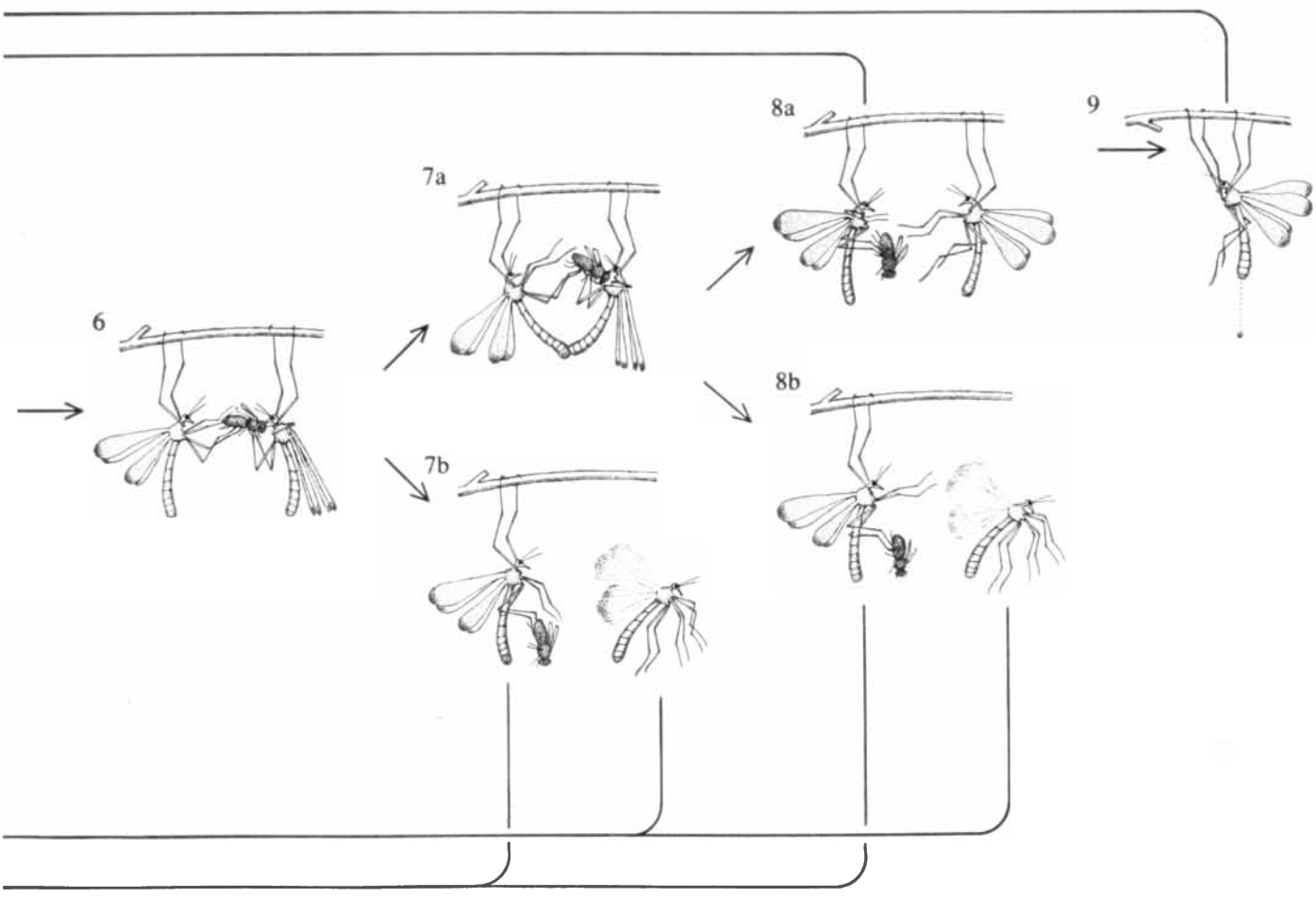
primarily as a result of the limited number of prey available only a small percentage, between 2 and 10 percent, of the adult males in a hangingfly population have prey at any one time.

Of these males the ones that have been seen taking characteristic prenuptial flights or releasing pheromone can be judged to have evaluated their prey for mating purposes. At any given time 90 percent of the males that have evaluated prey are in possession of large prey. In other words, 10 percent of the males that have evaluated prey will be carrying small prey and as a result will be directly discriminated against by females because their prey is unsuitable. Hence female choice may exclude up to 10 percent of all the adult males in the population from reproduction. Moreover, the variation in the ability of males to rapidly find large prey prevents many more males from achieving their maximum reproductive potential.

It is important to understand that the discovery that female choice among black-tipped hangingflies results in a nonrandom variation in male reproduction only indicates the potential for evolution by sexual selection. To show that female choice actually results in evolution, which is defined as changes in gene frequencies within a population, it must be demonstrated that the males chosen by the females differ genetically from those not chosen. It seems this is the case: my work shows that in nature males selecting large prey do so consistently over time and that the same is true for males selecting small prey.

One of the ways male black-tipped hangingflies are able to reduce their movement and thereby the risk of spider predation is by stealing prey from other males or from mated pairs. Prey theft is an important component of the competition among males for mates, the more familiar type of sexual selection, and the reduction of risk is not the only advantage this behavior confers. I have found that a male stealing prey for nuptial gifts spends an average of 42 percent less time in each mating sequence, and so his mating frequency is significantly higher than the frequency of a male that only catches prey. Conversely, to reproduce successfully a male that has been robbed of his prey must obtain another nuptial offering, and there is a positive correlation between the number of times a male is robbed and his average time between matings.

The observations of marked males between matings also indicate that any male may either catch a prey arthropod or steal one. The way a particular male obtains his nuptial prey depends on what he encounters first: a live arthropod or a male or mated pair in possession of prey. This mixed hunting strategy probably evolved because a male's success in stealing prey depends on the availability of other males, which in turn depends on the size of the hangingfly population and its sex ratio, two factors that fluctuate in time and space. When a male does attempt to steal prey,



with the male (*7b*). Or the female may mate with the male (*7a*), but only for a brief time, terminating the interaction after an average of five minutes (*8b*). If, on the other hand, the prey is sufficiently large, the pair of black-tipped hangingflies will mate (*7a*) for an average of at least 20 minutes, in which case it is the male that terminates the interaction (*8a*). The female feeds throughout the period of copulation, which invariably ends in a struggle for possession of the nuptial prey. (The male generally wins the conflict, and if the prey is sufficiently large, he will employ it a second time as a nuptial offering to another female.) A female black-tipped hangingfly that has mated for only five minutes quickly finds another male with a prey offering and starts the mating process over again. A female that has mated for 20 minutes or more, however, becomes sexually unresponsive for about four hours, during which time she lays an average of three eggs (*9*).

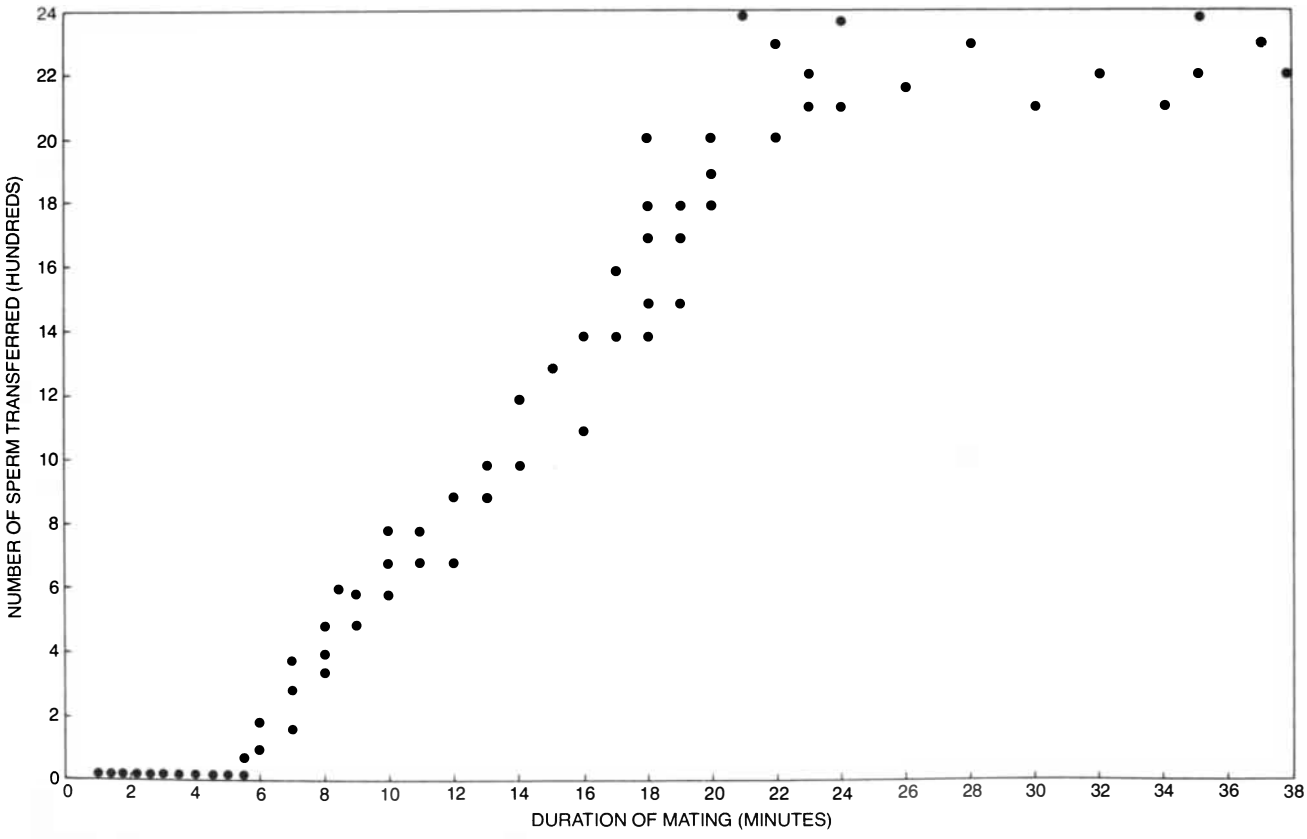
he relies on one of two methods. He either flies forcefully into the male or mated pair holding the prey and engages in a struggle to gain possession of it or he acts like a female to entice another male to give up his prey.

Behavior in which a male appears to be mimicking a female has been observed in a wide variety of animals, including hyenas, mountain sheep, birds, salamanders, fishes and primates. The black-tipped hangingfly unquestionably displays true mimicry of a female by a male. The success of the mimicry is aided by several factors. Males and females are about the same size and color, and the external genitalia of the male are not as large or as conspicuous as those of the males of many other hangingfly species. Furthermore, the mimicry of females by males in the black-tipped hangingfly is clearly adaptive: males that practice it capture prey faster, so that their mating frequency is increased, and they also move about less and probably suffer less predation by web-building spiders.

Males are likely to have prey stolen from them by other males throughout the mating process, but it is when a male is releasing pheromone that he is subject to being robbed by a male mimicking a female, because he is "expecting" the arrival of a female. Since it is only the female that responds to the pheromone, a potential prey thief is drawn to the pheromone-releasing male by visual cues, not olfactory ones, but it is only in the pheromone-releasing context that female mimicry is appropriate.

To mimic the behavior of a female a male flies up to a pheromone-releasing male and lowers his wings. The attempted theft of prey is the only activity (other than resting at night) in which a male lowers his wings, but when a female lowers her wings, it is a signal to the male that she is ready to begin the mating process. It is thus a signal for the male to offer the female his nuptial prey. When a male that is mimicking a female lowers his wings, however, the pheromone-releasing male responds about a third of the time by flying away, apparently because the mimicry was not convincing. The rest of the time the male presents his nuptial gift to the mimic. When both males are gripping the prey, the mimic begins to feed while the owner attempts to mate with him. The mimic keeps his abdomen out of the range of the other male's genitalia, just as the female does during the initial period of feeding and prey evaluation. After about two minutes the owner tries to wrest the prey from the mimic's grasp. Twenty-two percent of the time the effort is unsuccessful and the mimic flies off with the prey. (Only about half of the attempts to steal the prey of pheromone-releasing males involve female mimicry. In the remaining instances the thief makes a direct grab for the prey, a tactic that is successful 14 percent of the time.)

In many animal species there is competition among males for resources needed to attract females: territory, nesting sites, food and so on. Hence the findings I have described here concerning female choice of males and male competition for females in the black-tipped hangingfly *Hylobittacus apicalis* may be applicable to the mating behavior of a variety of animals, both invertebrate and vertebrate. Moreover, the living species of Mecoptera, the minor order of insects to which the hangingflies belong, are relics of an order that was once large and widely distributed. Insect evolutionists believe an ancient mecopteran species gave rise to several of the higher orders of insects, including the Lepidoptera (butterflies and moths), the Diptera (true flies) and the Siphonaptera (fleas). An understanding of the evolutionary pressures that shaped the reproductive behavior of mecopterans should lead to a better understanding of reproductive behavior in general.

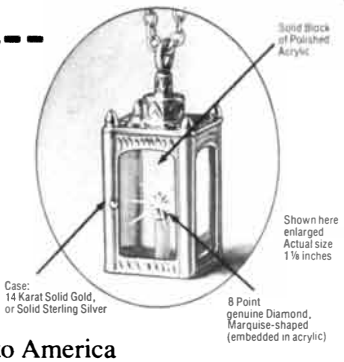


NUMBER OF SPERM transferred from a male black-tipped hangingfly to the sperm-storage organ of a female depends on the duration of mating. As is indicated by this graph showing the results of 66 matings of various durations, little or no sperm enters a female's storage organ during the first five minutes of mating. After this period there is a direct relation between the duration of mating and the number of sperm transferred. For matings that last for more than about 20 minutes, however, the average number transferred remains at about 22,000. It is males with large prey that mate for 20 minutes or more, and so only these males achieve maximum insemination of females.

LIGHT UP HER LIFE--

Give her a Third Century Lantern Pendant — an exquisite gift of rare beauty and historic importance — with its 8 point Diamond encased in 14 Karat Solid Gold

Ideal for Anniversaries — Perfect for Birthdays — and Extraordinary for those "Special" Occasions when you wish to make an Outstanding Impression



A detailed re-creation of the historic Paul Revere - Old North Church Lantern — the famous "light" that gave birth to America

You are part of America's "Third Century" society — so is she. It is the beginning of a New Era — a fresh start. An Era with its own new symbols.

Such a symbol was created, back on April 18, 1975, when the beginning of America's Third Century was officially marked by former President Gerald R. Ford. During a nationally televised ceremony held at Boston's famous Old North Church, the President lighted the "Third Lantern for America's Third Century." It was an authentic Sterling Silver, full-size re-creation of one of the lanterns used back in 1775 when Paul Revere made his famous ride.

Our organization — the Limited Editions Collectors Society — made the authentic re-creation. Our artisans used finite drawings, detailed photos, and wax impressions of the one remaining original lantern because the re-creation *had to be perfect.* After all, the Old North Church Lantern is such an important national symbol — it is the "light" that gave birth to America.

We have since sold hundreds of authentic collector reproductions of the famous lantern, with part of the proceeds going to the Old North Church for their building maintenance fund.

In 1978, we created and introduced a small Limited Edition of a new, beautifully crafted "miniature" of the famous signal lantern in the form of an exquisite piece of jewelry — our *Third Century Lantern Pendant.* Each was an extraordinary gift item that was cast of 18 Karat Solid Gold and utilized a beautiful 10 Point Diamond to represent the lantern's flame. They sold for $450 and were completely sold out in a very short period of time.

Several lower priced Registered Edition versions were also introduced ranging in price from $95 to $350. These are made of Solid Sterling Silver or 14 Karat Solid Gold and use a Crystal or an 8 Point Diamond as the flame. Although the molds and tools have now been destroyed, there are still approximately 50 Gold castings and 75 Silver castings remaining to be made into finished Pendants.

The price of Silver and Gold has increased dramatically since these remaining castings were fabricated; yet these Pendants are being offered at their original price, but — strictly on a "first-come, first-served" basis. Therefore, by acting promptly, before the small remaining supply is exhausted, you still have an opportunity to be among those collectors who will obtain one of these rare and unusual collector pieces.

Wearing this unique and historic Pendant subtly demonstrates pride in America's past and confidence in its future as our nation embarks on its Third Century. It makes a charming and thoughtful gift. And — what pleases a woman more than a gift of Gold or Silver and Diamonds? Whether she is a wife, a mother, a sister, or a daughter — or just a close friend, she will be enchanted when she first sees it and delighted as she displays her Third Century Lantern Pendant in public. It is a great conversation piece.

INDIVIDUALLY HANDCRAFTED

The Pendant is sturdy and solidly constructed, yet very comfortable to wear. An 8 Point Marquise-shaped Diamond, permanently locked into a block of crystal-clear acrylic, represents the flame. It cannot be lost and will keep its lustrous sparkle forever. This dazzling gemstone perfectly symbolizes the warning light sent out from Boston's Old North Church on that fateful night in 1775 marking a most critical moment in America's history.

Twenty-three separate hand-assembly operations are required to assemble each Pendant prior to final inspection by the master Goldsmith. A 12 Karat Gold-filled Chain, 24 inches long, which can be easily adjusted for casual or dress wear, is included with each Gold Pendant, and the Silver Pendants come with a Sterling Silver Chain.

The Limited Editions Collectors Society makes all of its exclusive offerings directly to the public. It is a private organization founded by a group of dedicated collectors, art lovers, and historians. The Society creates and markets authentic reproductions of historic artifacts and has received a number of important awards for excellence. In addition to creating the Official Old North Church Commemorative Lantern, used by former President Ford, the Society has been commissioned by a number of non-profit organizations, including the Winston Churchill Foundation, the United States Capitol Historical Society, the Freedoms Foundation at Valley Forge, and the John F. Kennedy Library Fund, to create and market their official commemoratives to collectors.

In addition to its collector value, each Third Century Lantern Pendant is an extremely outstanding jewelry value. If you visit any jewelry store and examine the variety of mass-produced Pendants using similar materials, you will find that most cost more and some much more. However, none will have our Pendant's unusual combination of handcraftsmanship, rare beauty, unique design, historical significance or value as an important Commemorative.

To subscribe to this offer, just call us — toll free — at 800-225-5252 — or mail the coupon below. You may "charge" your purchase by using one of your major credit cards.

This offer has appeared recently in publications reaching over 4 million readers. Therefore, to avoid possible disappointment or needless delay, we recommend that you place your order promptly before the small amount of remaining Pendants (about 125 pieces) is completely sold out.

The Third Century Lantern Pendant. It is truly a captivating piece of jewelry and a gift sure to be treasured always. It is not available in stores, nor will we accept orders from stores wanting to purchase these Pendants for resale.

UNCONDITIONAL GUARANTEE

We invite you to examine this remarkable Pendant value without any obligation whatsoever. Look it over. If you are not completely satisfied when it arrives, send it back for a full refund (we'll also reimburse you for whatever it costs you for postage and insurance to return it). Or, even after you have given it to that special person, if you find that she is not totally pleased, we'll buy it back. In fact, due to the very limited availability of these Pendants, we'll be glad to repurchase yours anytime within one full year from the date of your order. After all, in the long run, we don't expect Gold, Silver or Diamonds to lose their value — they never have.

Mail To: LIMITED EDITIONS COLLECTORS SOCIETY
10 Heritage Square, Hingham, MA 02043

CALL TOLL FREE 800-225-5252

REGISTERED EDITION

DIAMOND FLAME
- ☐ 14 Karat Solid Gold $375
- ☐ Sterling Silver $275

CRYSTAL FLAME
- ☐ 14 Karat Solid Gold $195
- ☐ Sterling Silver $ 95

Name _____
Street _____
City _____ State _____ Zip _____
☐ CHECK ENCLOSED $ _____
CHARGE TO CREDIT CARD: ☐ Master Charge ☐ Visa ☐ American Express ☐ Diners Club
Confirming Telephone Order ☐
EXP. DATE _____
CARD NUMBER _____
SIGNATURE _____

THE AMATEUR SCIENTIST

Mysteries of rainbows, notably their rare supernumerary arcs

by Jearl Walker

In this department for July, 1977, I described how the common first- and second-order rainbows can be examined in a simple experiment. I did not discuss the extra bands of color, termed supernumerary arcs, that sometimes accompany a natural rainbow. This month I shall describe several experiments by which such arcs can be investigated.

The commonest natural rainbow is called the first-order rainbow because it requires one reflection of light rays inside a falling raindrop. The rarer second-order rainbow requires two internal reflections. Higher-order rainbows, involving even more internal reflections, are probably too dim to be seen in the sky but can be seen in the experiments I described in 1977. My observations were prompted by some questions my grandmother had asked me about a double rainbow she had seen. The questions were simple but the answers were not.

Two of the questions were left unanswered in my earlier discussion. My grandmother asked them after I had likened the colors of a rainbow to the colors thrown by a glass prism held in sunlight. My glib answer obviously did not sit well with her. One question was: If the separation of colors in a rainbow is the same as that in a prism, why do extra bands of color (usually purple) appear next to the expected colors? The additional bands lie just below the first-order rainbow and (more rarely) just above the second-order one. A prism does not yield such extra bands of color. The second question was: How can some rainbows be white? Again a prismatic separation of colors cannot be responsible.

The extra bands of color are the supernumerary arcs, a name that implies they should not be present. Indeed, if one believes water drops separate white light into the component colors as a prism does, the supernumerary arcs are unexpected. The experiments that elucidate the phenomenon are extensions of the ones I described earlier but now include the effects of the wave interference of the light being scattered from a droplet of water. The experiments are not difficult, and they reveal the beautiful optical pattern of which the common rainbow colors are a part.

In the earlier article I described how a water droplet can be suspended from the end of a wire held vertically and then can be illuminated with white light from a projector. Of all the rays of light on the droplet one ray (named the Cartesian ray after René Descartes, who first determined its nature) enters the droplet at the single point that enables it to emerge to form the first-order rainbow. The rays striking the droplet at other points do not contribute to that rainbow.

In the experimental setup shown in the illustration on page 176 the Cartesian ray contributing the first-order rainbow enters on the side of the droplet opposite the observer. After the ray is refracted into the droplet it reflects on the inner surface once and then leaves the droplet on the side of the observer. The path of the ray is sketched from an overhead view in the top illustration on page 178. If the incident beam of light is leveled properly (a task that may require a bit of patience), the ray crosses through a circular and horizontal cross section of the droplet. When the observer's head is in the right position to intercept the emerging ray, the colors of the rainbow are seen.

The Cartesian ray for the first-order rainbow is bent about 138 degrees from its initial direction of travel. All the other rays that enter the droplet and reflect once from the inner surface are scattered by larger angles, up to a full 180 degrees for the ray that enters the center of the droplet and is returned directly to the light source. No rays reflecting once inside the droplet can be scattered by an angle smaller than the angle of the Cartesian ray.

If white light illuminates the droplet, the component colors are refracted by slightly differing amounts and leave the droplet at differing angles. Blue is refracted a little more than red, and so the blue Cartesian ray is turned from its original direction of travel slightly more than the red one. The intermediate colors are bent by intermediate amounts.

When the droplet is viewed at an angle near the rainbow angle, the different colors emerge at different angles and therefore can be distinguished. The scattering angle, measured with respect to the initial direction of the light, is about 138 degrees for red and 139 for blue. If the drop were one of many drops falling through sunlight, an observer would see an arc of colors in the sky: the natural first-order rainbow. No such arc exists for a water droplet suspended from a wire because there is only a single droplet, but the colors can easily be seen on the edge of the droplet (the side opposite the light source) where the rays emerge.

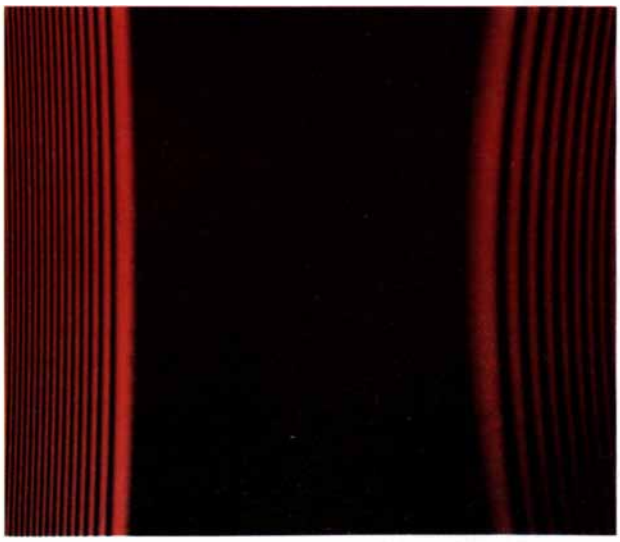
Suppose the white light is replaced with monochromatic light from a source such as a helium-neon laser operating at a wavelength of 632.8 nanometers. One would expect only the red component of the rainbow to emerge from the droplet. What one actually sees, surprisingly, is a series of vertical red bands rather than a single red band. The brightest and widest band lies at the angular position of the red in the rainbow colors generated with white light. The other red bands are fainter and narrower and extend in a series that starts at the widest band and continues toward larger scattering angles. This series of extra bands holds the clue to the nature of the supernumerary arcs.

Sue Foroughi of Council Bluffs, Iowa, has investigated the pattern of red bands scattered by a suspended water droplet illuminated with a helium-neon laser. She improved on my experimental design by substituting a burette for the wire. With careful adjustment of the spigot on the burette she was able to form a water droplet at the lower end of the apparatus. She positioned the droplet over the center of a spectrometer so that she could use the telescope arm of the apparatus to aid her observations of the pattern. (The telescope effectively places the observer at a distance from the droplet. Without it the eye focuses the scattered light to form an image of the droplet, rather than the pattern, on the retina.)

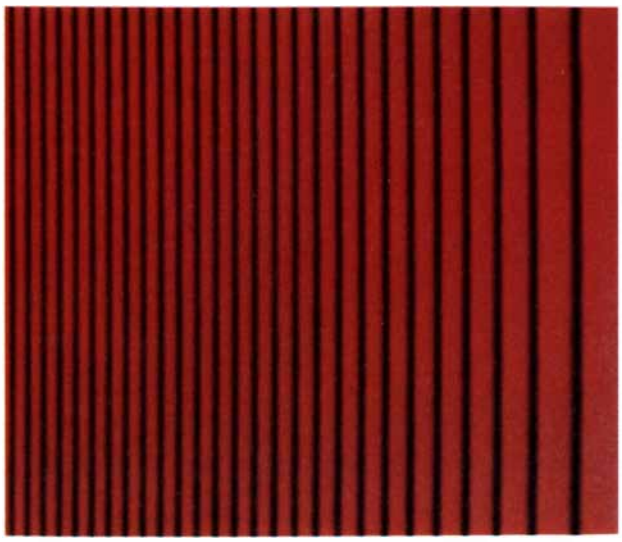
Foroughi was particularly interested in how the size of the droplet affected the number of red bands per degree in the pattern. She formed a fresh droplet at the end of the burette and counted the angular density of the bands in the pattern by moving the telescope arm through an angle of one degree. She had to approximate the diameter of the droplet. After waiting for evaporation to reduce the droplet she repeated the process.

A droplet initially about four millimeters in diameter had a pattern density of 16 red bands per degree near the main rainbow band. After two hours the diameter had been reduced to about 2.5 millimeters and the density had dropped to eight bands. Foroughi found that as the droplet shrank, the bands widened

A rainbow with purple supernumerary arcs photographed in California by Alan L. Falk



The interference pattern of the first-order rainbow



The pattern of the first two orders

and so the number of them per degree decreased. This result is a clue to the nature of the white rainbows my grandmother asked about.

In my experimental setup the ray that will enable an observer to see the second-order rainbow enters the droplet on the same side as the observer. This Cartesian ray is refracted into the droplet, reflects twice off the inner surface and emerges toward the observer. As before, the different colors are refracted by slightly differing amounts and thus emerge at slightly differing angles. An observer moving through the range of angles of these colors will see the spectrum that in the natural environment gives the second-order rainbow.

With the experimental setup for the suspended droplet the colors appear on the edge of the droplet toward the light source. The red Cartesian ray emerges at an angle of about 130 degrees with respect to its initial direction of travel, the blue Cartesian ray at about 127 degrees. I shall call these angles the scattering angles for the second-order rainbow.

If the droplet is fully illuminated, the observer can move through the angles of the first-order rainbow and then those of the second-order rainbow by moving from a scattering angle of about 140 degrees to one of about 126 degrees. The color sequence will be blue through red and then, following a separation, red through blue, with the second-order colors occupying a larger angular range. Between the two rainbow sequences the droplet will be relatively dark.

This dark band, which also appears between the arcs of a natural rainbow, is named Alexander's band. The darkness results from a relative lack of light rays emerging from a water droplet into that angular range. All the rays reflecting once inside the droplet must emerge at scattering angles of about 138 degrees or more. All the rays reflecting twice inside the droplet must emerge at scattering angles of about 130 degrees or less. For this reason the intermediate range of about eight degrees is left relatively dark.

When a source of white light is replaced with a helium-neon laser, the full second-order rainbow is replaced with another pattern of red bands. The brightest and widest band is again at the position of the red in the full rainbow. The vertical bands extend from the angular position of the normal red to smaller scattering angles, becoming progressively narrower as the angular distance from the brightest band is increased.

This type of pattern is distinctive for the first two orders of rainbow. Each additional order displays its own pattern when a droplet is illuminated with monochromatic laser light. For example, the fifth-order rainbow results from five internal reflections of light. Although that rainbow is too dim to see in the sky, its colors are visible on a suspended droplet if the incident beam of light is carefully leveled. The fifth-order Cartesian ray enters on the side of the droplet opposite the observer, reflects five times inside the droplet and emerges from the edge of the droplet opposite the light source. The red emerges at an angle of about 127 degrees from the initial direction of the light, the blue at about 134 degrees. When the white-light source is replaced by the laser, the fifth-order rainbow results in a pattern of red bands with the widest and brightest band at an angle of about 127 degrees. The pattern is dimmer than the patterns of the first two orders are. In general the higher the order of rainbow is, the dimmer and wider the main bands of its pattern are. The same is true for natural rainbows: the higher the order, the dimmer and wider the rainbow.

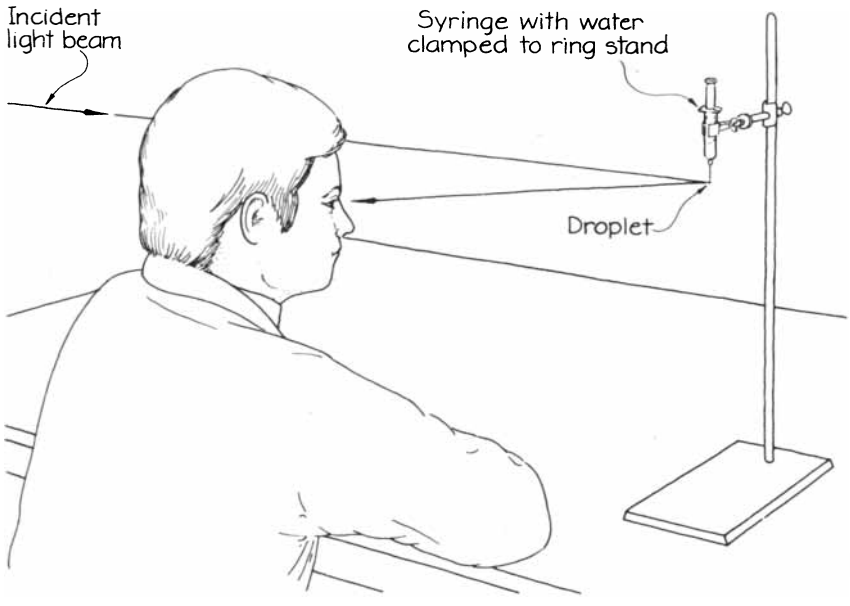
When a water droplet is illuminated with white light, each color produces its own pattern of bright and dark bands near the rainbow angles. The natural rainbow consists of the main (widest and brightest) bands for each color. Although the narrower and dimmer bands in each color's pattern still exist, they are usually imperceptible in a natural rainbow. Occasionally, however, the dimmer bands overlap in just the right way to be visible. These bands are the supernumerary arcs. In the experimental setup and in nature they appear on the blue side of the rainbows.

When I repeated Foroughi's experiments and some of my earlier ones, I arranged for a droplet of water to hang from the needle of a syringe. I had ground the tip flat so that when the syringe was pointed down, a droplet could form and hang properly when I pushed the plunger. The optics of a rainbow become much more complicated than I have indicated if the light rays do not pass through a circular cross section of a water droplet. Hence it is desirable to achieve a droplet that hangs straight down and has a circular and horizontal cross section.

The syringe was held in place by a test-tube clamp mounted on a ring stand. A piece of foam rubber in the clamp made the fit snug around the syringe. By gently depressing the plunger I could form either a droplet or a large drop on the blunted needle. The drops were illuminated with a 35-milliwatt helium-neon laser. If you repeat this work, I suggest that you either use a less powerful laser or put filters in the laser beam in order to dim it. The light reflecting from the needle and even from the droplet was uncomfortably and dangerously bright. If the light from your laser is polarized, the polarization should be vertical to create a proper scattering of light from the droplet.

By adjusting the illumination on the droplet I could make the pattern for either the first- or the second-order rainbow. Illuminating the side of the droplet closest to me created the pattern for the second-order rainbow. Illuminating the other side created the first-order pattern. Because the beam was narrower than the droplet, at least for the larger droplets, I could not get both patterns simultaneously. When I inserted a lens in the beam, however, the beam was spread sufficiently to create both patterns simultaneously.

Because my laser is quite bright the patterns were cast on the walls of my room with considerable brilliance. I could also display them easily by holding a sheet of white paper near the droplet, and I could examine them through the viewer on my camera. If I illuminated the far side of the droplet in just the



A laboratory setup for investigating rainbows

"Chew on the bark of 2 willows and call me in the morning."

At the time of Hippocrates and for two thousand years thereafter, people turned to nature whenever they suffered pain. Thousands of remedies were concocted from herbs, berries and bark.

Today, we have a pain-relieving chemical that's called acetylsalicylic acid (aspirin). Surprisingly, it's chemically related to the same natural remedy that Hippocrates himself used to prescribe: the bark of the willow tree.

And for people who prefer another pain reliever, we have a relative newcomer, acetaminophen.

Whether made by nature or by man, chemicals have always played a major role in reducing pain and improving the quality of life.

No chemical is totally safe, all the time, everywhere. The challenge is to use chemicals properly. To help make life more livable. (And less painful.)

For a free booklet explaining the risks and benefits of chemicals, mail to:
Monsanto, 800 N. Lindbergh Blvd., St. Louis, Mo. 63166. Dept. A3NA-SA1

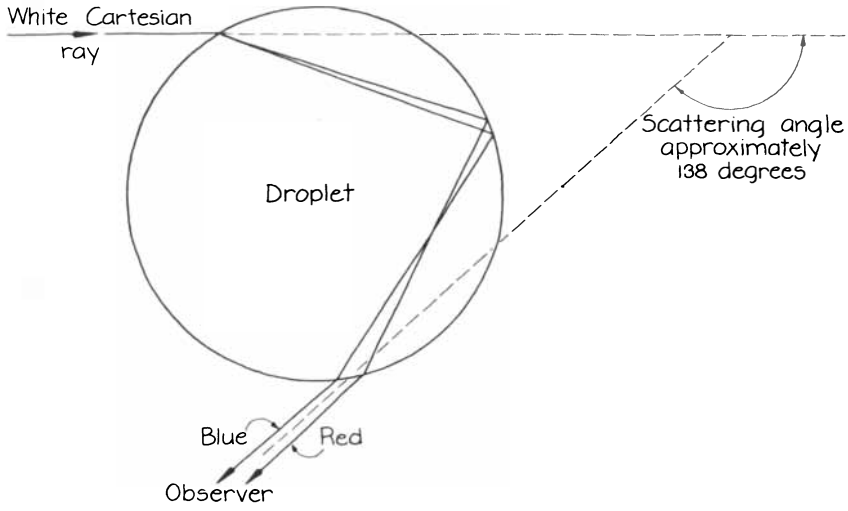
Name _____

Address _____

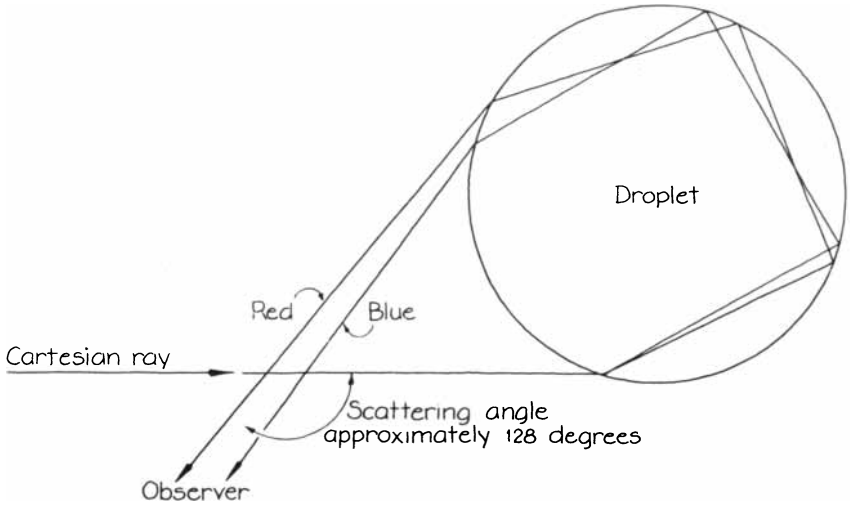
City & state _____ Zip _____

Monsanto

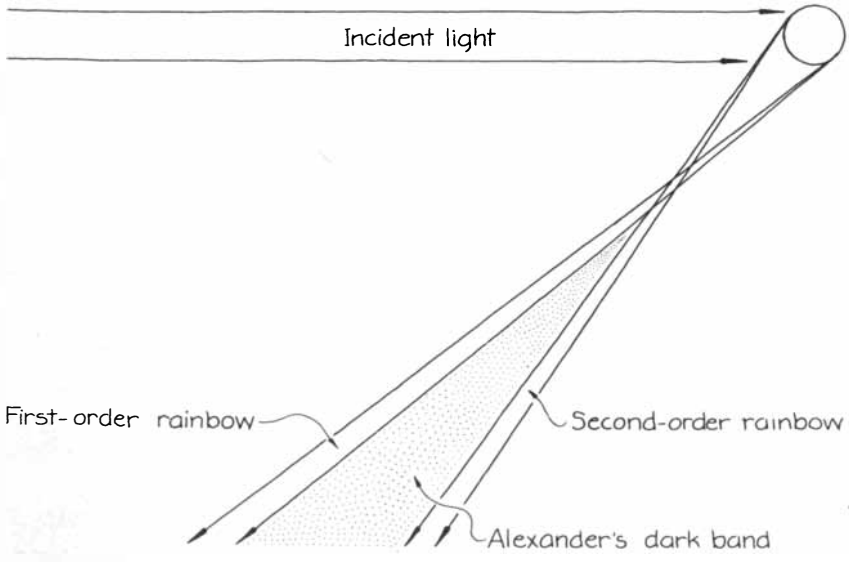
Without chemicals,
life itself would be impossible.



The scattering of light in the first-order rainbow



How the ray is scattered in the second-order rainbow



The circumstances underlying Alexander's dark band

right way, I could see the partly overlapping patterns for the first- and fifth-order rainbows.

The light can best be aligned on the droplet by means of the shadow of the droplet on a wall. As I watched the shadow of the droplet I slowly maneuvered the laser until I had centered the shadow in the beam. If I wanted to illuminate one side of the droplet more than the other, I moved the laser accordingly. Sometimes I put a black card in the laser beam so that it blocked the light falling on one side of the droplet. I could also use the card to shade the needle, which otherwise produced a glare.

I photographed the patterns with my 35-millimeter camera, using ASA 64 film at an exposure of 1/125 second with no lens. To photograph the patterns of the first two orders of rainbow I positioned the camera and the tripod as close to the suspended water droplet as I could without blocking the laser beam with the camera. I could expand the pattern on the film by moving the camera farther from the droplet. This maneuver made the details of the pattern more apparent but enhanced the adverse effects of vibrations of the droplet. Air currents and vibrations of the building shake the droplet and momentarily ruin the ideal circular cross section traversed by the light rays. The pattern wavers. I minimized the vibrations by putting concrete blocks on the ring stand to steady it. The effects could be reduced further by moving the experiment to the basement or by mounting the rig on the kind of vibration-isolation stand employed in making holograms.

When I wanted to photograph the water droplet but not the red bands, I mounted my normal lens (50 millimeters and *f*/1.4) and several closeup lenses on my camera to focus the rays scattered from the droplet. The proper exposure had to be determined by experimentation. To be sure of getting a few good pictures I operated the camera at many exposures.

Instead of waiting for a droplet to shrink through evaporation I watched the patterns of the first two orders of rainbow while slowly pushing the plunger on the syringe. As the droplet grew I could see the bands in the pattern become narrower. I also noted another effect. The angular positions of the main bands (the brightest and widest band in each pattern) shifted. As a droplet grew the main bands of the two orders moved toward each other, thereby narrowing the intermediate dark region. If the drop is large (four millimeters or so in diameter), the patterns are relatively close and consist of relatively narrow bands. As the drop shrinks, the patterns shift away from each other and the bands become wider.

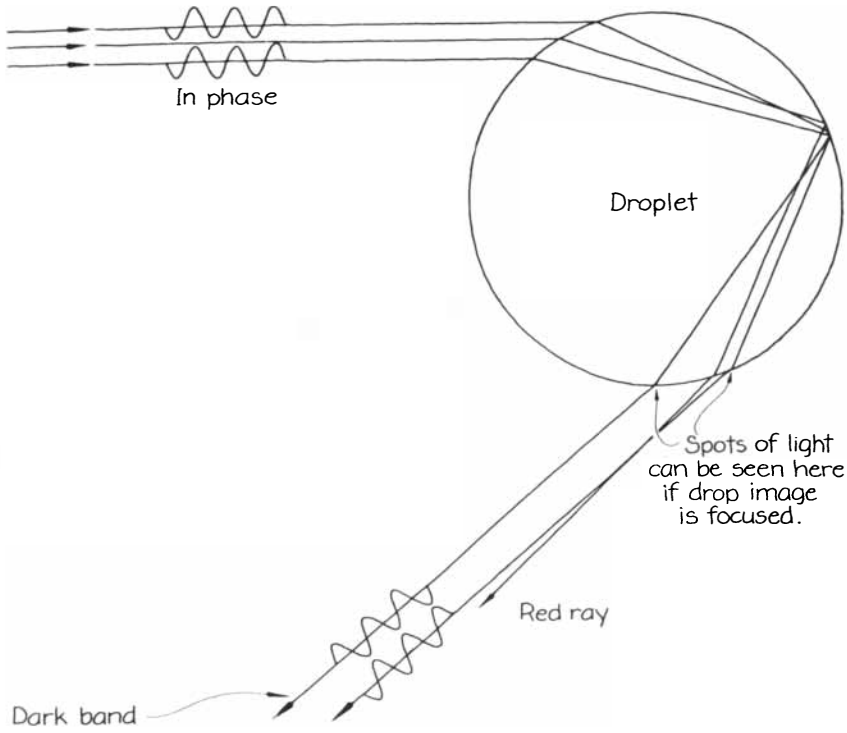
Why does a monochromatic source of light produce a pattern of bright and dark bands near the normal angular po-

Some impressions never fade.

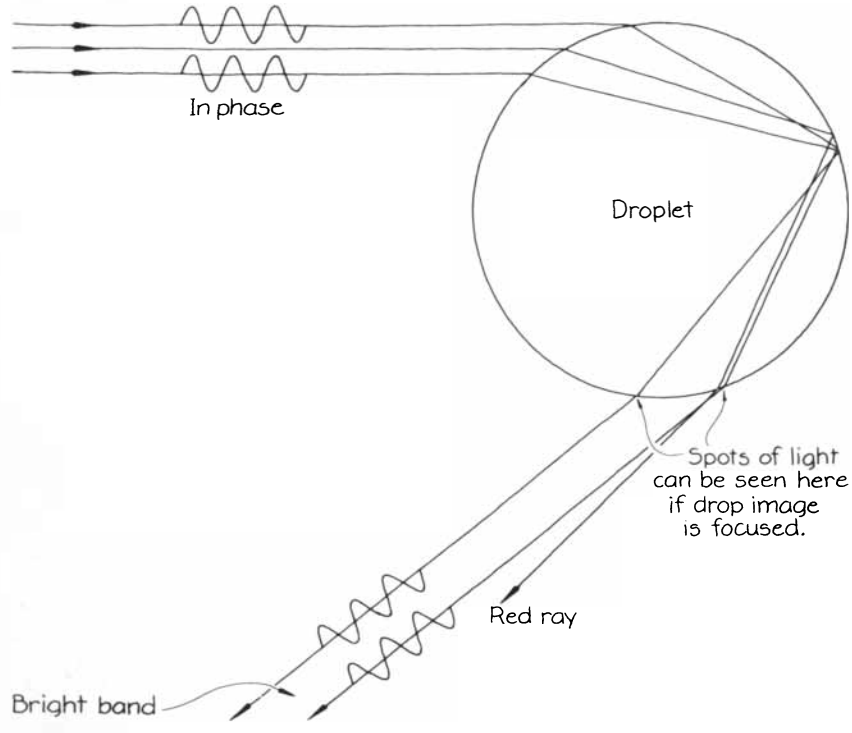
You start out wet behind the ears. Swallow some water. Do a few bellyflops. You keep trying. Again and again. And again. But there's a lot of people behind you. The coaches. Parents. And volunteers. As well as the Amateur Athletic Union. Helping you learn discipline. Gain confidence. And make friends. Each step of the way. Because swimming and diving are more than just time and form alone. And that's why Phillips Petroleum is a long-time sponsor of AAU swimming and most recently of AAU diving. It's a contest where everyone wins. Even though only a few earn medals. Or make it to the Olympics. Because what you learn sticks with you for the rest of your life.

sition of the rainbows? Clearly the droplets are not separating colors as a prism would. In 1803 Thomas Young demonstrated that light waves can interfere with one another to produce patterns of bright and dark bands. The patterns Foroughi and I have seen are due to such an interference of light.

Consider two rays of light illuminating a suspended droplet close to each side of the Cartesian ray that eventually emerges in the first-order rainbow. Choose rays that reflect once inside the droplet (just like the Cartesian ray) and emerge in the same direction. (The direction will not be the same as it is for the Cartesian ray, of course, but if the observer is at the correct angle, the two rays will be seen.) When the rays leave the laser, they are in phase, that is, the waves they represent are exactly in step. In scattering from the droplet, however, the rays travel over different path lengths. As a result they emerge from the droplet with a phase relation that may be changed from the original one.



Two rays interfering destructively



Constructive interference

Suppose one of the rays travels half a wavelength farther than the other ray. (A proper calculation would include the change in the wavelength of the light when it is in the water.) The first ray will lag behind the second by half a wavelength once the two rays emerge. Since an observer at the correct position will see both rays simultaneously, the rays interfere destructively, meaning that the observer sees darkness because the rays (differing by half a wavelength) are exactly out of step.

Next consider the situation when the observer moves slightly toward larger scattering angles. Again two rays of light (different ones this time) can be seen emerging from the droplet. Suppose the extra distance traveled by one of them is a full wavelength. When two identical rays are initially in step, a shift of one of them by a full wavelength puts them in step again. The rays interfere constructively and the observer sees a bright band. If the color of the light is red, the observer sees a bright red band.

At larger scattering angles the bright and dark bands alternate. The first dark band, the one next to the main bright one, arises because two rays are out of phase by half a wavelength. The second dark band is caused by another two rays that are out of phase by 3/2 wavelengths, the third and fourth dark bands are caused by rays that are out of phase by 5/2 and 7/2 wavelengths respectively and so on.

The rays that emerge in the brightest and widest of the bright bands are in phase. The next bright band in the pattern results from two rays that emerge out of phase by a full wavelength. The other bright bands in the pattern result from still other rays that are out of phase by an additional wavelength each time. If an observer stands in the interference pattern cast by the water droplet, he will always see either a bright band or a dark one because of two rays emerging from the droplet. If he looks directly at the droplet, he sees two spots of light where the two interfering rays emerge. As he moves toward the rainbow angle the two spots move closer together and finally merge to form the red of the rainbow.

If the droplet is illuminated with white light, each color produces an interference pattern and only the bright main bands of each color are seen. The first calculations of the intensity of the light in the patterns were made by George B. Airy in 1838. His results for

Jeep Wagoneer *Limited*
The ultimate wagon

Introducing the 1980 Jeep Wagoneer Limited. Never before has such luxury and comfort been combined with the ultimate in 4-wheel drive performance. With all these most wanted options, standard! Rich leather seats, extra thick carpeting, woodgrain trim and...gas mileage that's responsive to the times. Mileage comparable to a full size, 2-wheel drive wagon.* Consider it: The ease of automatic transmission and Quadra-Trac®, our exclusive, automatic 4-wheel drive, combined with fuel efficiency. But there's more. Conveniences like power windows, power door locks and a quartz digital clock. Plus a stereo AM/FM radio with your choice of 8 track or cassette or CB. All standard.

Jeep®

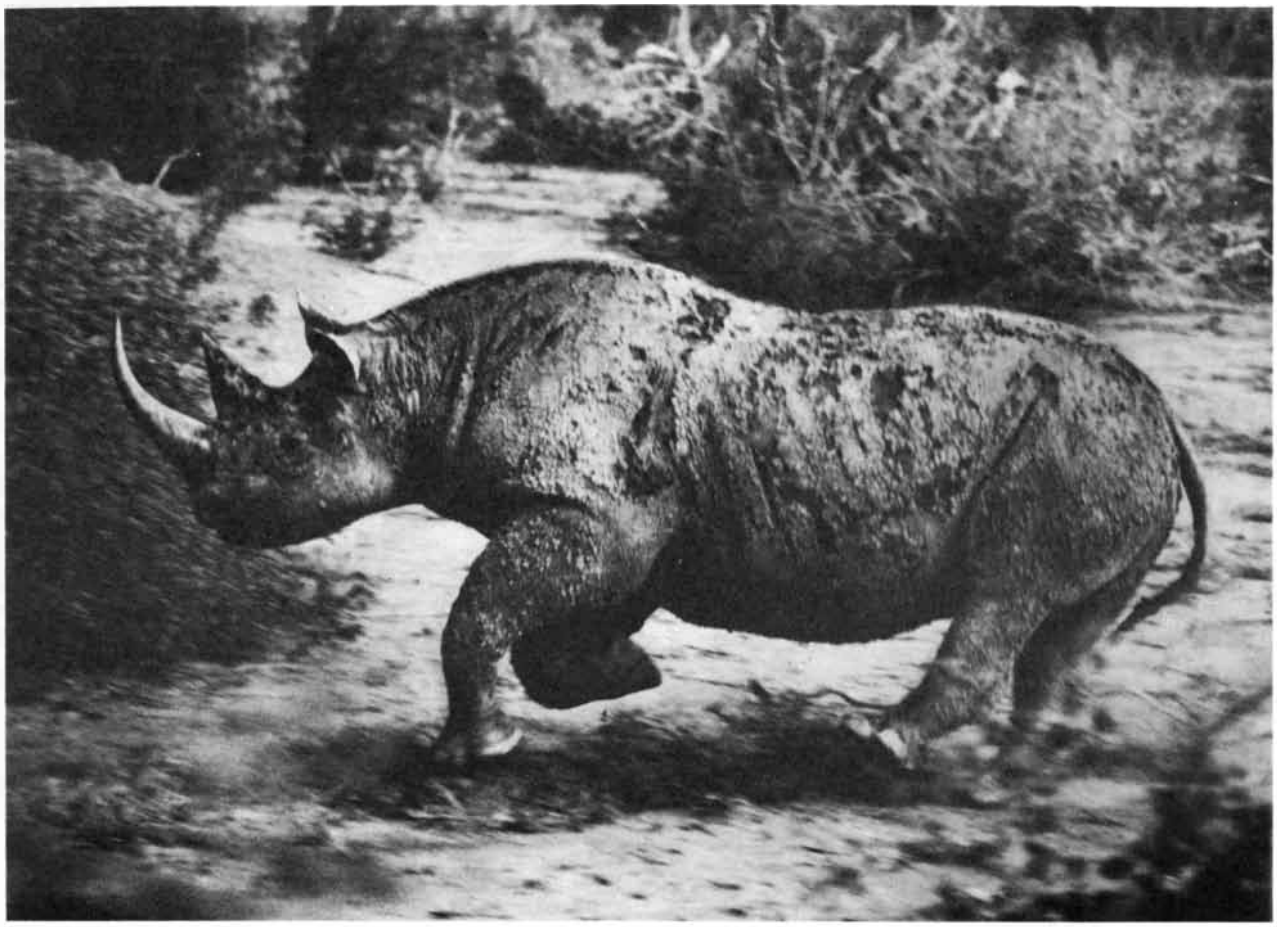
We wrote the book on 4-wheel drive

For luxury, comfort and unsurpassed traction off-road or on, good weather or bad, there is only one wagon. The Jeep Wagoneer Limited. We invite you to test drive the ultimate wagon *and the ultimate in 4-wheel drive.*

*Remember, use these figures for comparison. Your results may differ due to driving speed, weather conditions and trip length. Actual highway mileage will be less. California figures lower.

19	15
HWY EST MPG	EPA EST MPG

Jeep Corporation, a subsidiary of American Motors Corporation



Rhinos are being hunted to extinction—to make fake love potions and dagger handles.

Run Rhino, Run– Extinction is Forever

The Rhinoceros is threatened by immediate extinction. The World Wildlife Fund urgently needs funds to save it.

THE RHINO'S PROBLEM is its horn. Smugglers sell it for $300 an ounce – almost ten times the price of silver. The poachers kill the Rhino just to get its horn.

In Asia, powdered Rhino horn is believed to be an aphrodisiac– which it isn't. In the Middle East, North Yemeni tribesmen carve the horn into decorative dagger handles.

As a result, the total population of the rare Northern White Rhinoceros of Africa has been reduced to less than two hundred and fifty.

In East Africa, illegal slaughter of the Black Rhino has reduced the population by 90 percent over the past five years.

In the Ngorongoro Crater in Tanzania, there were seventy-six Black Rhinos one year ago. Today there are less than twenty-six.

In Kenya's Meru National Park, more than a hundred Rhinos were poached in the past eighteen months.

In Asia, less than two hundred and fifty Sumatran Rhinos survive. The population of the Javan Rhino is down to fifty.

The situation is critical.

The World Wildlife Fund is coordinating an urgent campaign to save all species of Rhino from total extinction.

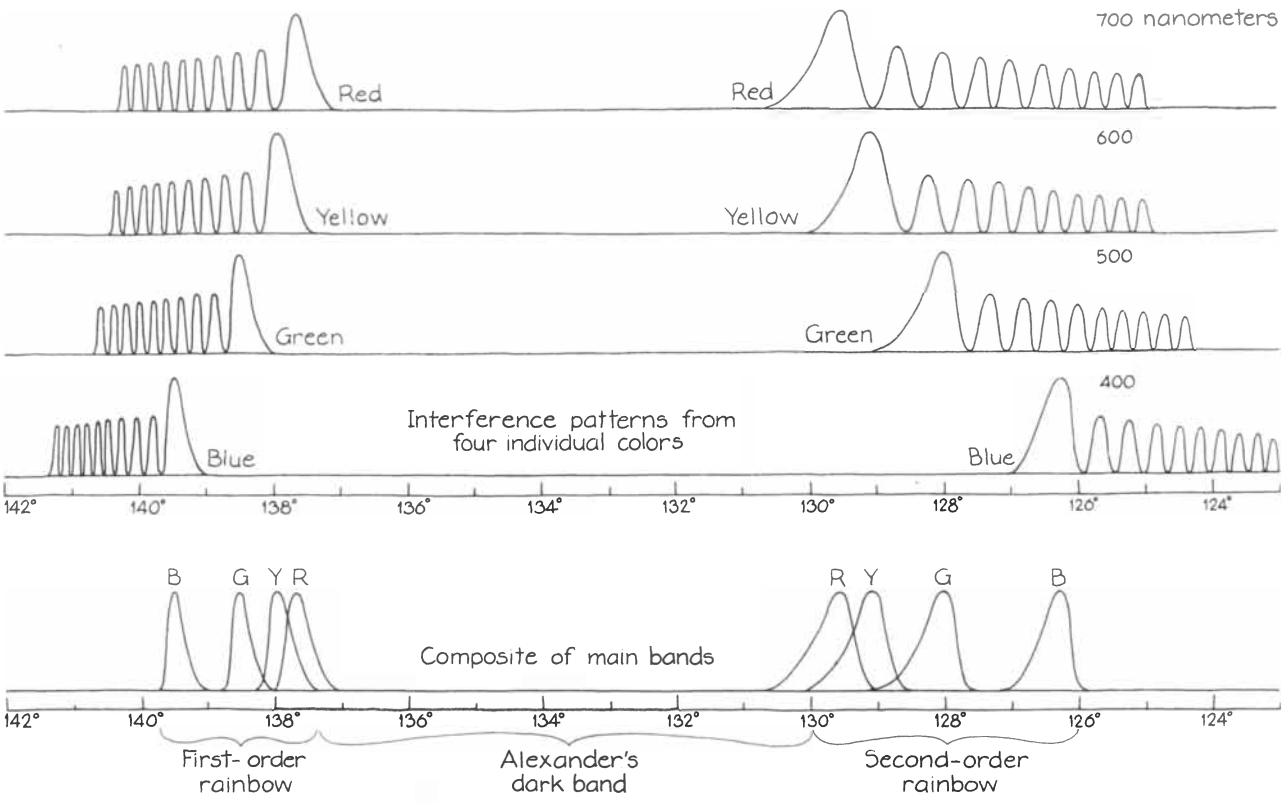
Fifty-nine nations have agreed not to trade in Rhino horn and the Governments of Kenya and Hong Kong have announced a crash effort to stop the trade. But stricter measures are needed:

1. Vulnerable Rhinos must be removed to sanctuaries.
2. More people and better equipment are urgently needed to stop poachers.
3. Ways must be found to stop the illegal trade, and to reduce the demand for Rhino horn. Efforts will be made to persuade other governments to follow the lead of Hong Kong and Kenya.

Your contribution is urgently needed to help finance Operation Rhinoceros and other projects. Send your donation to World Wildlife Fund – U.S., Dept. R, 1601 Connecticut Avenue, N.W., Washington, D.C. 20009.

Thank you.

This advertisement was prepared as a public service by Ogilvy & Mather



The interference patterns forming the first two orders of rainbow

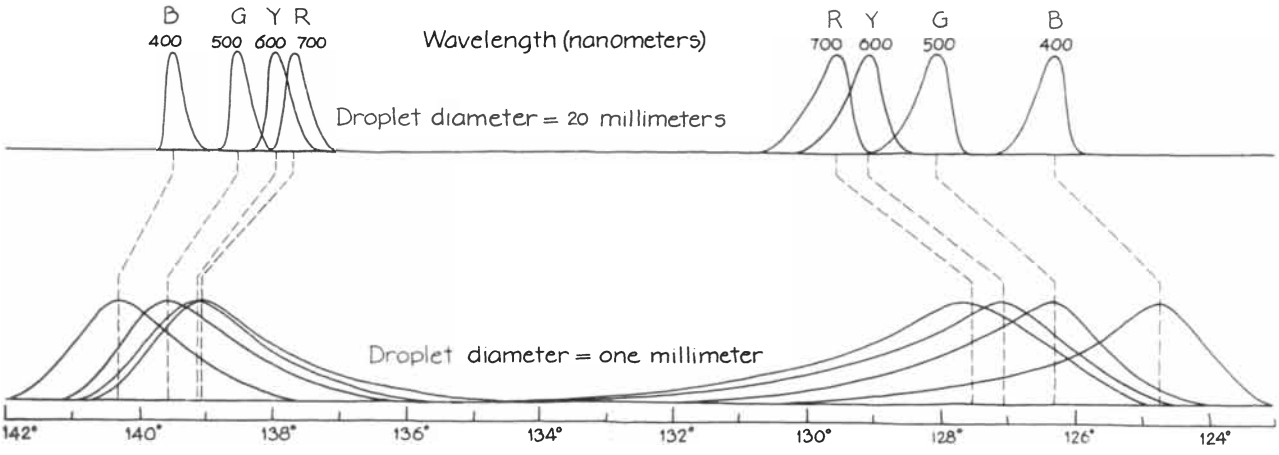
four colors are given in the illustration above. Each wavelength generates an interference pattern with its main band close to the angle that the theories of Young and Descartes had predicted for the corresponding color of the rainbow.

Airy's calculations include the size of the droplet because that determines whether the rays emerging from it at an angle different from the rainbow angle result in brightness or darkness. The size of the droplet also determines the exact angle at which a rainbow appears. The smaller the droplet, the greater the discrepancy between the angles of the colors and the angles predicted by the older theories. As a droplet shrinks through evaporation the patterns for the various colors change in two ways. The patterns for the first two orders of rainbow shift away from each other. All the bright bands become broader. Neither change is predicted by the earlier theories, which did not describe the rainbow as being an interference pattern.

When I depress the plunger on my syringe, I make the suspended droplet larger. The resulting shift of the patterns is easily seen. Since the droplet is growing larger, the patterns of the first two orders of rainbow shift toward each other. I can also easily see that the widths of the individual bright bands decrease. If I allow the droplet to slowly shrink by evaporation, the opposite changes take place, as Foroughi observed.

The dependence of the patterns on the drop size has another result. When the drop is relatively large (several millimeters in diameter), the main bright bands in the separate patterns for each color are distinguishable. Each band for each color is quite narrow. With white light entering the drop the observer sees a rainbow at the rainbow angle. With a smaller droplet the main bands are wider and so overlap. Therefore the observer is less able to distinguish the colors and the rainbow appears to be washed out.

If the droplet is even smaller, say .3



How the main bands overlap in a smaller droplet

millimeter or less, the main bands overlap so much that the rainbow is white. This is the white rainbow my grandmother asked me about. It appears rarely and then only in mists with droplets small enough to produce overlapping of the main bands at the rainbow angle. When I let a droplet suspended from the syringe evaporate, I can see the colors of the rainbow slowly wash out.

Theories of the rainbow more modern and accurate than those of Descartes, Young and Airy have been proposed. In 1908 Gustav Mie devised a scheme for computing the amplitudes of the light waves scattered by a drop. The computation promised more accurate results than the older theories, but it requires so many calculations that even today's high-speed computers cannot complete them. For drops several millimeters in diameter the older theories gave results that were good enough. The trouble appeared when one considered smaller droplets. A more workable approach, called the complex-angular-momentum theory of the rainbow, was discussed in this magazine three years ago [see "The Theory of the Rainbow," by H. Moysés Nussenzveig; SCIENTIFIC AMERICAN, April, 1977]. Other references on theories of the rainbow are listed in the bibliography for this issue [page 186].

The natural rainbow is strongly polarized parallel to its arc. You can test the polarization by rotating a polarizing filter between your eye and a rainbow. At one orientation the rainbow is quite bright; with a 90-degree rotation of the filter the rainbow almost disappears.

A similar observation can be made with the light scattered from a suspended water droplet. If the droplet is illuminated with light from a projector, the incident light is unpolarized, but it can be thought of as composed of two orthogonal senses of polarization. One of them lies in the plane defined by the projector, the observer and the cross section of the droplet traversed by the light ray. The other is perpendicular to that plane. The incident light polarized in the first sense is poorly scattered by the droplet and contributes little to the rainbow. The incident light polarized perpendicularly to the plane is primarily responsible for the rainbow.

The light from my laser is polarized vertically because of the arrangement of the Brewster windows inside the laser cavity, a common arrangement in gas lasers. The light is therefore polarized properly to cross through a horizontal cross section of a suspended droplet and create a bright rainbow. When I rotate the laser tube, the rainbow pattern I see becomes dim. When I turn the laser on its side, the beam is polarized parallel to the plane of the laser, the droplet and the observer. The sense of polarization entering the droplet is hence wrong, and the rainbow pattern is so weak that it is almost invisible.

Some engineers wrestle with the same project for years.

Ours move from innovation to innovation.

It's a way of life here at Hughes.

So if you come to work with us, you'll never get bored. Perhaps more important, you'll never be stuck on one project so long that you reach a learning plateau.

We've got the variety of high-technology projects that will keep you interested. Keep you learning. Keep you growing.

Here at Hughes Electro-Optical & Data Systems, we're involved in remarkable variety of advanced projects for military and commercial applications. From basic research through development, production, and testing.

So obviously we need a broad spectrum of engineers with a broad spectrum of disciplines. All the way from microelectronics to structural dynamics.

For thermal-imaging night-vision systems, infrared sensors, infrared surveillance and electro-optical countermeasure systems, laser rangefinders, laser fire-control systems for tanks, laser target designators, cryogenic refrigerators, on-board computer systems.

And a lot more. Including our own test systems.

We're offering you excellent pay, outstanding benefits, tremendous opportunity. But if you're our kind of engineer, what will really impress you are some more unusual advantages. Variety of assignments is just one.

How about stability? If you look at the record, you'll find we never stopped growing, even during recession years. Our four-*billion*-dollar backlog (based on more than 1,500 contracts!) gives us a mighty leg to stand on.

Facilities? Perhaps the finest of their kind in the world. Including a new 143-acre complex now nearing completion in a Los Angeles suburb near the beach.

We've got a lot more going, too. You can get the full story by calling us at (213) 391-0543.

Or by sending your resume to:

Hughes Aircraft Company 40/M100
Electro-Optical & Data Systems
Professional Staffing Dept. AS-6
Culver City, CA 90230

ELECTRO-OPTICAL & DATA SYSTEMS

HUGHES

HUGHES AIRCRAFT COMPANY

Equal Opportunity M/F/HC Employer. U.S. citizenship required for most positions.

BIBLIOGRAPHY

Readers interested in further explanation of the subjects covered by the articles in this issue may find the following lists of publications helpful.

MATHEMATICAL GAMES

FINITE GROUPS. Daniel Gorenstein. Harper and Row, 1968.

THE SEARCH FOR FINITE SIMPLE GROUPS. Joseph A. Gallian in *Mathematics Magazine,* Vol. 49, No. 4, pages 163–180; September, 1976.

GROUPS AND SYMMETRY. Jonathan L. Alperin in *Mathematics Today,* edited by Lynn Arthur Steen. Springer-Verlag, 1978.

GENETIC AMNIOCENTESIS

EARLY DIAGNOSIS OF HUMAN GENETIC DEFECTS: SCIENTIFIC AND ETHICAL CONSIDERATIONS. Edited by Maureen Harris. Government Printing Office, 1971.

ALPHA-FETOPROTEIN IN THE ANTENATAL DIAGNOSIS OF ANENCEPHALY AND SPINA BIFIDA. D. J. H. Brock and R. G. Sutcliffe in *The Lancet,* Vol. 2 for 1972, No. 7770, pages 197–199; July 29, 1972.

MIDTRIMESTER AMNIOCENTESIS FOR PRENATAL DIAGNOSIS: SAFETY AND ACCURACY. The NICHD National Registry for Amniocentesis Study Group in *The Journal of the American Medical Association,* Vol. 236, No. 13, pages 1471–1476; September 27, 1976.

ANTENATAL DIAGNOSIS OF SICKLE-CELL ANAEMIA BY DNA ANALYSIS OF AMNIOTIC-FLUID CELLS. Yuet Wai Kan and Andrée M. Dozy in *The Lancet,* Vol. 2 for 1978, No. 8096, pages 910–911; October 28, 1978.

BASALTIC METEORITES

PETROLOGY OF EUCRITES, HOWARDITES AND MESOSIDERITES. Michael B. Duke and Leon T. Silver in *Geochimica et Cosmochimica Acta,* Vol. 31, No. 10, pages 1637–1665; October, 1967.

EXPERIMENTAL PETROLOGY OF EUCRITIC METEORITES. Edward M. Stolper in *Geochimica et Cosmochimica Acta,* Vol. 41, No. 5, pages 587–611; May, 1977.

A PETROGENETIC MODEL OF THE RELATIONSHIPS AMONG ACHONDRITIC METEORITES. Edward M. Stolper, Harry Y. McSween, Jr., and James F. Hays in *Geochimica et Cosmochimica Acta,* Vol. 43, No. 4, pages 589–602; April, 1979.

ALLAN HILLS 77005: A NEW METEORITE TYPE FOUND IN ANTARCTICA. Harry Y. McSween, Jr., Lawrence A. Taylor and Edward M. Stolper in *Science,* Vol. 204, No. 4398, pages 1201–1203; June 15, 1979.

PETROLOGY AND ORIGIN OF THE SHERGOTTITE METEORITES. Edward M. Stolper and Harry Y. McSween, Jr., in *Geochimica et Cosmochimica Acta,* Vol. 43, No. 9, pages 1475–1498; September, 1979.

COMPUTER BACKGAMMON

SOME NECESSARY CONDITIONS FOR A MASTER CHESS PROGRAM. Hans J. Berliner in *The Third International Joint Conference on Artificial Intelligence.* Stanford Research Institute, 1973.

ON THE CONSTRUCTION OF EVALUATION FUNCTIONS FOR LARGE DOMAINS. Hans Berliner in *The Fifth International Joint Conference on Artificial Intelligence.* Stanford Research Institute, 1979.

THE FUNCTIONING OF BLOOD PLATELETS

PLATELET PHYSIOLOGY AND ABNORMALITIES OF PLATELET FUNCTION. Harvey J. Weiss in *The New England Journal of Medicine,* Vol. 293, No. 11, pages 531–541, September 11, 1975; No. 12, pages 580–588, September 18, 1975.

PLATELET BEHAVIOR AND BIOCHEMISTRY. H. Holmsen, L. Salganicoff and M. H. Fukami in *Haemostasis: Biochemistry, Physiology, and Pathology,* edited by D. Ogston and B. Bennett. John Wiley & Sons, 1977.

PLATELETS, THROMBOSIS AND ATHEROSCLEROSIS. J. F. Mustard, S. Moore, M. A. Packham and R. L. Kinlough-Rathbone in *Progress in Biochemical Pharmacology,* Vol. 13, pages 312–325; 1977.

GAUGE THEORIES OF THE FORCES BETWEEN ELEMENTARY PARTICLES

CONSERVATION OF ISOTOPIC SPIN AND ISOTOPIC GAUGE INVARIANCE. C. N. Yang and R. L. Mills in *Physical Review,* Vol. 96, No. 1, pages 191–195; October 1, 1954.

UNIFIED THEORIES OF ELEMENTARY-PARTICLE INTERACTION. Steven Weinberg in *Scientific American,* Vol. 231, No. 1, pages 50–59; July, 1974.

QUARKS WITH COLOR AND FLAVOR. Sheldon Lee Glashow in *Scientific American,* Vol. 233, No. 4, pages 38–50; October, 1975.

ICE-AGE SUBSISTENCE IN NORTHERN SPAIN

THE ASTURIAN OF CANTABRIA: SUBSISTENCE BASE AND THE EVIDENCE FOR POST-PLEISTOCENE CLIMATIC SHIFTS. Geoffrey A. Clark in *American Anthropologist,* Vol. 73, No. 5, pages 1244–1257; October, 1971.

THE FOOD CRISIS IN PREHISTORY: OVERPOPULATION AND THE ORIGINS OF AGRICULTURE. Mark Nathan Cohen. Yale University Press, 1977.

LATE AND POST-PLEISTOCENE INDUSTRIES AND FAUNA FROM THE CAVE SITE OF LA RIERA. G. A. Clark and L. Richards in *Views of the Past: Essays in Old World Prehistory and Paleoanthropology.* Ninth International Congress of Anthropological and Ethnological Sciences, edited by Leslie G. Freeman. Mouton, 1978.

THE DEEP-EARTH-GAS HYPOTHESIS

DUPLEX ORIGIN OF PETROLEUM. Sir Robert Robinson in *Nature,* Vol. 199, No. 4889, pages 113–114; July 13, 1963.

BRONTIDES: NATURAL EXPLOSIVE NOISES. Thomas Gold and Steven Soter in *Science,* Vol. 204, No. 4391, pages 371–375; April 27, 1979.

SEXUAL SELECTION IN THE BLACK-TIPPED HANGINGFLY

SEXUAL SELECTION AND NUPTIAL FEEDING BEHAVIOR IN *BITTACUS APICALIS* (INSECTA: MECOPTERA). Randy Thornhill in *American Naturalist,* Vol. 110, No. 974, pages 529–548; July–August, 1976.

INSECT BEHAVIOR. Robert W. Matthews and Janice R. Matthews. John Wiley & Sons, 1978.

MALE AND FEMALE SEXUAL SELECTION AND THE EVOLUTION OF MATING STRATEGIES IN INSECTS. Randy Thornhill in *Sexual Selection and Reproductive Competition in Insects,* edited by Murray S. Blum and Nancy A. Blum. Academic Press, 1979.

THE AMATEUR SCIENTIST

THE RAINBOW: FROM MYTH TO MATHEMATICS. Carl B. Boyer. Thomas Yoseloff, 1959.

MULTIPLE RAINBOWS FROM SINGLE DROPS OF WATER AND OTHER LIQUIDS. Jearl D. Walker in *American Journal of Physics,* Vol. 44, No. 5, pages 421–433; May, 1976.

ANGULAR SCATTERING AND RAINBOW FORMATION IN PENDANT DROPS. Kenneth Sassen in *Journal of the Optical Society of America,* Vol. 69, No. 8, pages 1083–1089; August, 1979.

COMPLEX ANGULAR MOMENTUM THEORY OF THE RAINBOW AND THE GLORY. H. M. Nussenzveig in *Journal of the Optical Society of America,* Vol. 69, No. 8, pages 1068–1079; August, 1979.

1980 FORD BRONCO

A new advance in family 4-wheelers.

Exciting news for 1980: Bronco introduces Twin-Traction Beam, the only truck in its class with independent front suspension. Feel the difference on the road. And off.

Ford's new design Bronco gives you the best estimated mpg of any V-8 4-wheeler. Trim new size outside for easy maneuvering. All-new interior with more front leg room, improved climate control, new anti-theft features.

Bronco's built tough on a truck chassis, tested tough at Ford's Arizona Proving Ground. Test it at your Ford Dealer. Ask about Ford's corrosion perforation warranty. It's a no-cost 36-month limited warranty that excludes exhaust system components. And ask about Ford's Extended Service Plan, too.

Roomy interior has all-new styling, options like tilt steering wheel, reclining Captain's Chairs up front, AM/FM stereo with cassette or 8-track tape player.

BEST V-8 ESTIMATED MPG

15 mpg EPA EST.*

Optional 5.0L (302 CID) V-8 with automatic transmission.

*Compare this estimate with others. Your mileage may differ depending on speed, distance and weather. California excluded.

New Bronco choices include six roof colors. Above: Landau Tu-Tone with accent tape stripe. At top: Free Wheeling Bronco shown with optional tri-color tape stripe, styled steel wheels, RWL tires, and more.

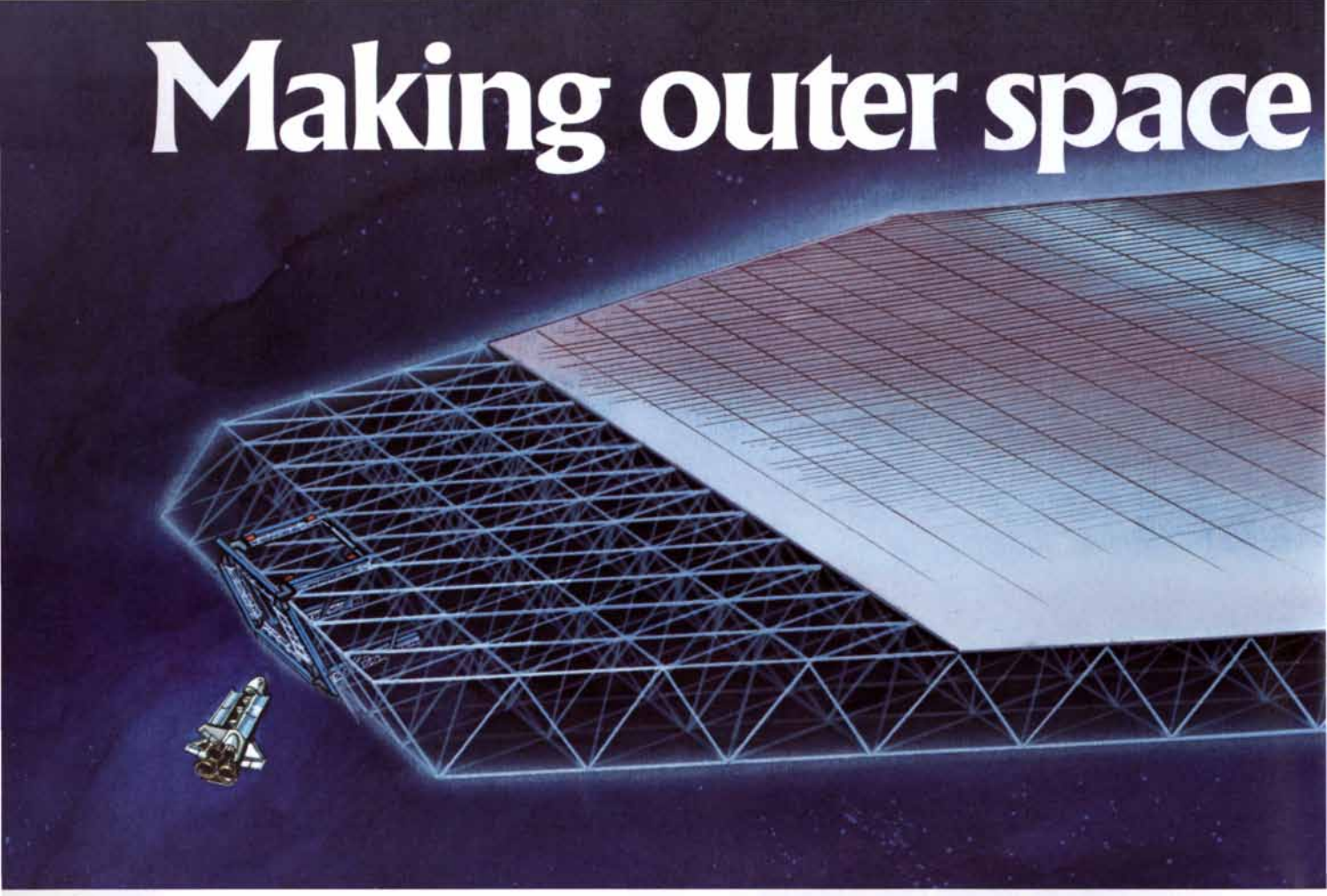
Independent front suspension eases wheels over bumps separately to give a better ride than last year. Helps off-road control.

Built Ford Tough

FORD

FORD DIVISION Ford

Making outer space



Lockheed knows how.

Moving fiction closer to fact.

The vision of erecting power plants, factories, and even entire communities in outer space has been moved a step toward reality.

Under a NASA contract, Lockheed is developing new space construction concepts focused on basics like innovative assembly methods and lightweight, strong joints and columns. Some of these 'parts' have already been made.

Large-scale structures might take form as massive power stations with several square miles of solar cells. Or as factories for items that can be better made in zero-gravity conditions. Or as huge antennas, thousands of yards across. Then, space settlements would be needed to house the people who would build, maintain, and operate the other space leviathans.

The first structures would come piecemeal from Earth. But far-thinking scientists believe much raw construction material could eventually be taken from the moon or from asteroids whose orbits swing them near our planet.

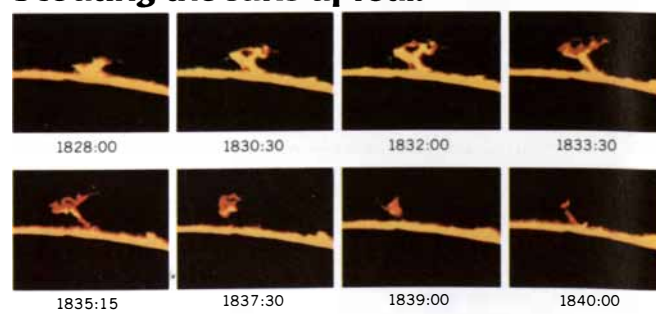
Looking at the origin of the universe.

In 1983, a 43-foot-long telescope system will be slipped into orbit 300 miles above Earth. And man may then look back 14 billion years to where our universe perhaps began.

The NASA/Lockheed Space Telescope will detect objects 50 times fainter and 7 times deeper into space than those ever before seen. It will lock onto stars, galaxies, and other space phenomena with absolute accuracy for as long as 30 to 40 hours. And it will perform ultraviolet and infrared measurements impossible from Earth.

Potential rewards are huge. Scientists may discover new worlds and new energy sources. They may even find ways to protect Earth's delicate environment in a new uncharted age.

Scouting the sun's uproar.



Tucked into NASA's OSO-8 Orbiting Solar Laboratory, a Lockheed-developed Mapping X-Ray Heliometer has successfully finished three years of amassing vital data on the sun's ever-varying X-ray radiation.

work for man.

Illustration shows fully automatic assembly machine working on huge outer-space structure as NASA's Space Shuttle stands by.

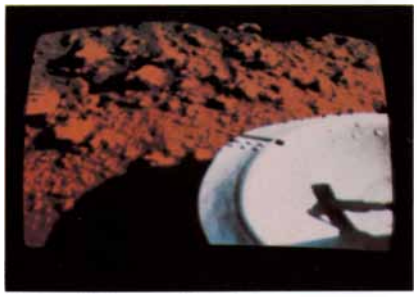
The heliometer was part of the most complete scientific instrument payload ever sent up to study solar and cosmic X-ray sources. And though planned for only one year's work, the OSO-8 package operated in its 350-mile-high orbit for better than three years.

The heliometer experiment again clearly demonstrated Lockheed's unique capability in independent, basic research. And the data will probably unveil dramatic solar facts.

They should set guidelines for better predicting of solar flares and yield new knowledge of exactly how the sun's X-ray emissions affect Earth's weather and climates.

Recorders that talk from other planets.

We've now put "eyes" on Mars, viewed Venus and Jupiter close up, and will get intimate looks at Saturn in late 1980.



Special Lockheed recorders, each no bigger or heavier than a gallon bottle of water, help scientists see the outer planets at close range. Locked within a space vehicle, each recorder can store and transmit more than a half-billion bits of information. Those signals are then turned by Earth-station computers into sharp photos and precise scientific data.

Lockheed recorders have flown on all Apollo moon missions, five Mariner space probes, the flights to Mars, Venus, and Jupiter, and are now headed toward Saturn and beyond.

And if the search that far away reveals no life, there's still the rest of the universe.

The unmatched record of achievement.

Nothing underscores Lockheed's leading place in space technology better than the record of the Agena spacecraft.

The versatile Agena, veteran of more than 300 flights, can count more successful launches than those made by any other spacecraft, and it has been used on nearly half of all United States space missions.

In making space work for man, Agena is one more proof that Lockheed knows how.

Lockheed

"World's Greatest Dad"

TROPHY STAND NOT AVAILABLE FOR PURCHASE. SEAGRAM DISTILLERS CO., N. Y., N. Y.