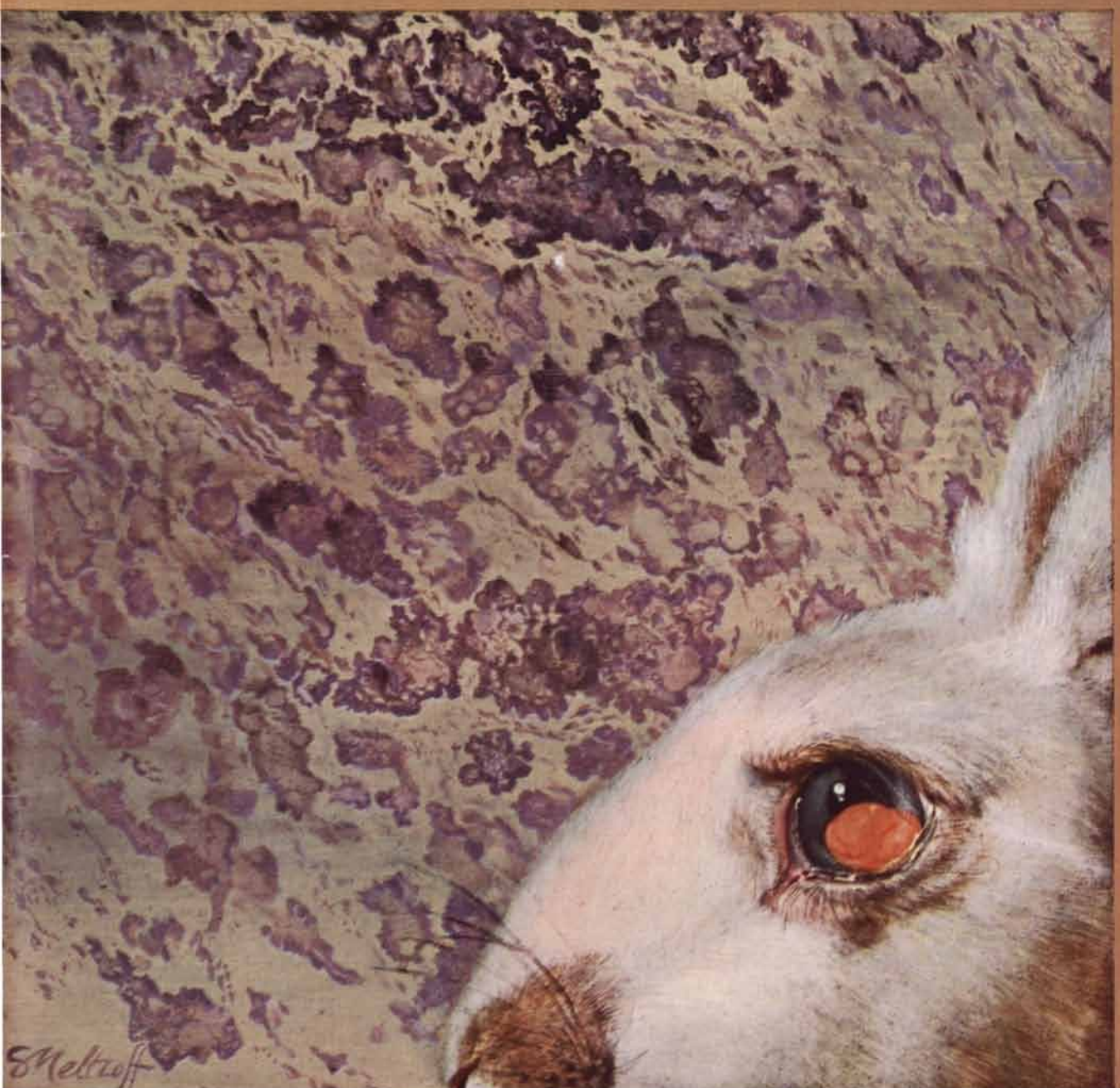
SCIENTIFIC AMERICAN



TRANSPLANTED CANCER TISSUE

FIFTY CENTS

December 1948

His chest was protected—but...

Drape-shape steel gave this well-dressed knight a certain amount of protection against stray missiles . . .

Yet he died, not in battle, but in bed . . . felled by a deadly dart 1/10,000th of an inch long—the *tubercle bacillus*.

He and millions of others through the ages never knew what hit them.

Today *we* know. But ignorance and indifference still account for most of the 50,000 people who are killed by tuberculosis each year.

The germ that steel couldn't stop certainly can't be thwarted by a business suit or a mink coat.

Modern science and medicine, however, *can* give you effective chest protection. A chest X-ray is a sure way to detect TB!

If you are harboring TB germs, an X-ray can "see" their destructive effects long before you feel sick. If proper treatment is started in the early stages, the cure is comparatively easy.

The later TB is found, the longer, harder, and costlier will be the cure.

Remember, too, that TB is contagious. A person who has TB can spread it to other members of his family.

You can find out whether or not you have TB by having your chest X-rayed.

SO PLAY SAFE...

CHECK YOUR CHEST... *GET AN X-RAY TODAY!*

See your Doctor, Tuberculosis Association or Health Department

A PUBLIC SERVICE PROJECT · THE ADVERTISING COUNCIL

LETTERS

Sirs:

Yesterday afternoon I had the pleasure of leading a discussion in a group of perhaps twenty-five members of the Natural Science Faculties of Williams College based on George Gamow's "Origin of the Ice," which appeared in the October *Scientific American*. I believe that I am reporting the conclusions accurately when I say that the group felt that Gamow's account of Milankovitch's computations gave a very satisfactory explanation of glaciation during the past 600,000 years. They felt, however, that this was a very short time scale at the end of a very long history of intermittent glaciation on this planet, and questioned whether the astronomical explanation alone was sufficient to account for the very long periods of unusually warm conditions which occurred during the geological ages preceding that covered by your article. They rather felt that the article implied that "here is the cause and the whole cause" though it may not actually have said that in so many words.

Why not another article soon by some competent glaciologist presenting the whole known history of glacial ages, together with other possible explanations such as changing elevation or carbon dioxide in the atmosphere which may well have combined with the planetary perturbations to produce the ancient glacial ages and also the very long interglacial ages?

THEODORE G. MEHLIN

Department of Astronomy
Williams College
Williamstown, Mass.

Sirs:

According to George Gamow's article "Origin of the Ice." which was published in your October issue, the ellipticity of the earth's orbit is an important factor in the relative severity of the seasons, and in the occurrence of terrestrial ice ages. Dr. Gamow says. "Winters in the Northern Hemisphere, coming when the earth is closest to the sun, are at present milder than those in the Southern Hemisphere, and the summers are somewhat cooler."

The astronomer F. R. Moulton has called attention to the interesting fact that because the earth obeys the law of areas in its motion around the sun, the total amount of radiation received during corresponding seasons at points in equal northern and southern latitudes are equal. "The deficiency in the amount received per day in the Northern Hemisphere during its summer, as compared with the amount received per day in the Southern Hemisphere during its summer, is exactly counterbalanced by the greater number of days of summer in the Northern Hemisphere." This being the case, only secular perturbations, the decrease of the solar mass by radiation, and the momentum effects of the radiation itself (all of which affect the mean distance of the earth from the sun) would be significant in connection with mean temperatures on the earth. Presumably these changes are too slow to account for ice ages as recent as 25,000 years ago.

No mention was made, in the article by Dr. Gamow, of the relatively well-known fact that the solar system, in its motion through the galaxy, may often pass through regions of obscuring matter. A small screening effect would easily cause the small temperature drop necessary to produce an ice age.

WILLIAM A. CALDER

Department of Physics and Astronomy
Agnes Scott College
Decatur, Ga.

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SCIENTIFIC AMERICAN

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER 1898. "The population of the globe, according to M. P. D'Amfreville, is about 1,480,000,000, distributed as follows: Asia, with 825,954,000; Europe, with 357,379,000; Africa, with 163,933,000; America, with 121,713,000; Oceanica, and the Polar regions, with 7,500,400; Australia, with 3,230,000; or a grand total of 1,479,729,000 souls. It is stated that of every 1,000 inhabitants of the globe, 558 live in Asia, 242 in Europe, 111 in Africa, 82 in America, 5 in Oceanica and the Polar regions, and only 2 in Australia. Asia thus contains more than one-half of the total population of the earth, and Europe nearly one-fourth."

"The question of the relative strength of the navies of the world, with particular reference to the standing of the United States, cannot fail just now to be of vital interest. In the three brief months of the Spanish war, the supreme importance of sea power was brought home to the American people in a series of events the significance of which they have not failed to perceive. Great Britain easily maintains the position which she has set for herself, of being equal in power to the next two strongest navies, those of France and Russia; and the fact that we have moved up to fourth place with a substantial lead over Germany and Italy, will be a pleasant surprise, and highly gratifying to all those who are interested (and who is not?) in the growth of our naval power."

"Although New York City did not undertake the construction of lofty office buildings until they had become a familiar feature in the architecture of some Western cities, it has run them up in such numbers and to such unprecedented height in the last ten years that they have now become the most characteristic and obtrusive feature of its architecture. Towering high above the tallest of these great structures is the vast bulk of the Park Row building, which lifts its twin towers 29 stories and 390 feet into mid-air. Omitting the Great Pyramid of Egypt, it is conspicuously the tallest inhabited building in the world."

"Dr. Koch has recently left Rome, after six weeks of study in the hospitals where are treated cases of Roman and Campagna fevers, and in which he has been aided by the foremost specialists of Italy. As a result of these studies, it is now declared that the malarial fevers of Italy are identical in cause and general character with those of East Africa, and it is believed that science is on the eve of a decisive victory over this whole group of maladies by means of liquid injection of quinine into the pulse vein. The importance of this discovery to Italy will be evident from the fact that of the 69 departments into which that kingdom is divided, only six are absolutely free from malaria, and 1,200 square miles, including some of the most fertile districts of Italy, are, like the whole southeastern coast of Corsica and much of Sardinia, practically uninhabitable on account of malarial disease."

DECEMBER 1848. "A short time ago, the most flattering accounts were received in this city from California about the mountains of gold and the valleys flowing with silver. Some believed it was a joke, while others believed it to be a 'hue and cry' for some speculative purpose, and to the latter implication we must plead guilty. We believed that the accounts received here a short time ago about vessels being deserted by their crews and houses by their inhabitants, who had proceeded to the El Dorado valley, was all a hoax or something worse. But it seems, after all, that Madam Rumor sometimes tells true tales. The President in his Message to Congress has confirmed the extraordinary fugitive accounts heretofore received. We hope that the gold and silver that is about to flow into the treasury of our nation will not be the means of corrupting or enervating our people. Rome was mistress of the world until her citizens drank their beverages from golden bowls. We therefore wish better fortune to our potato diggers than our gold diggers, as we consider that land to be the Golden Land, which presents the greatest number of fields waving with golden harvests."

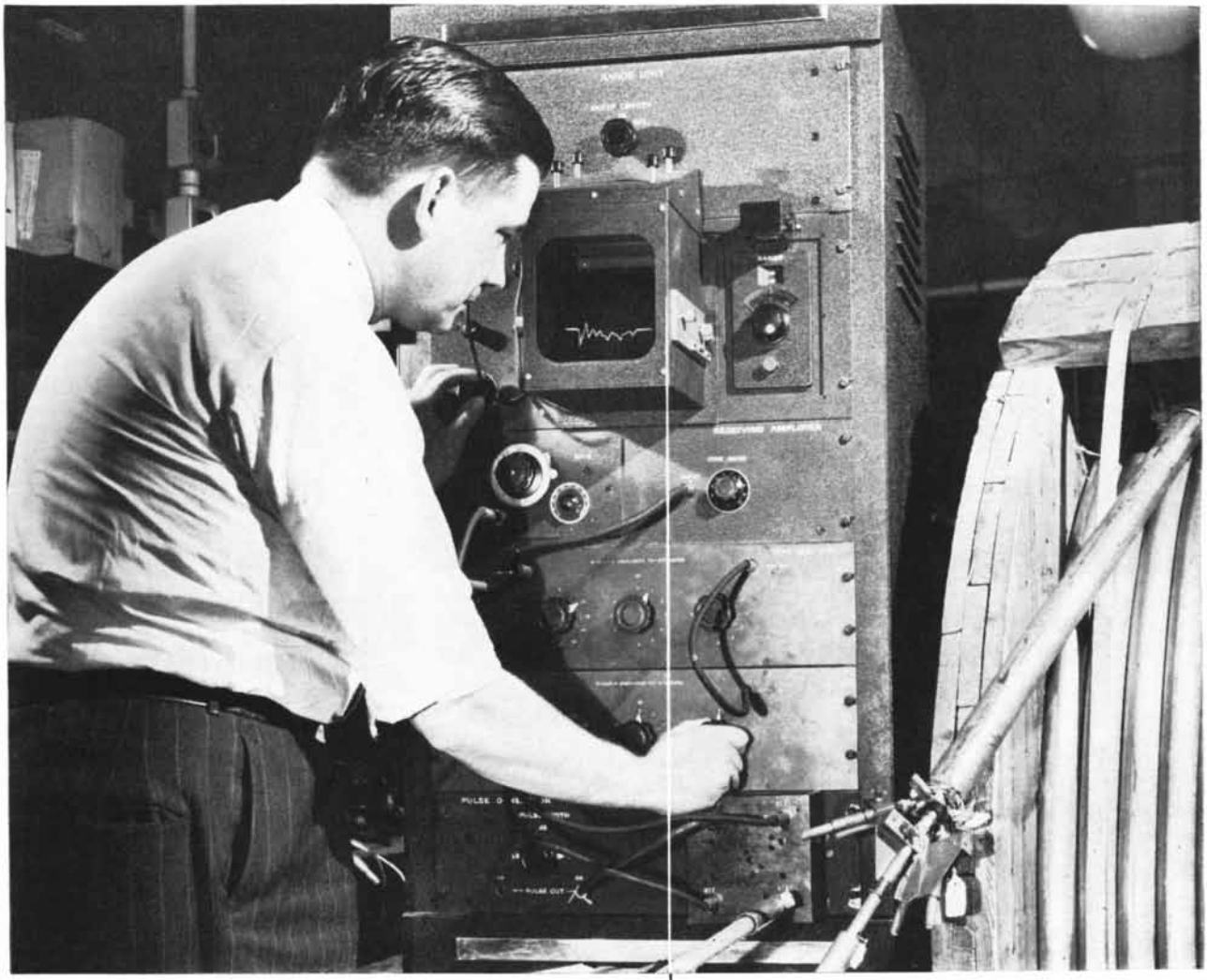
"Those of our subscribers who remember the description of Staite's Electric Light, and the first notice of this light published in America, will be pleased to know that the discoverer has secured an English patent for the same and introduced it in London. It was exhibited last month in Hanover Square Concert Room, and examined by the most eminent scientific men in that city. It possesses the remarkable property of being without heat, not combustible, and not hurtful to the eyes, and that it could be conveyed by wires like bell wires. These are indeed remarkable properties, and we are almost sceptical upon the subject.—Were it not for the authority we would be apt to disbelieve it, but there is no doubt regarding its beauty and purity. This new electric light, it seems, is not the result of combustion, for no air is admitted to the light. All that is seen is the light in a close vase, and the wire that conveys the fluid from the voltaic battery, the circuit of which can be broken and closed at pleasure. The light of one hundred wax candles, it is said, can be furnished for two cents per hour. This is rather too loose a statement we think, but it certainly is a most wonderful discovery."

"The entire President's Message was telegraphed from Baltimore to St. Louis, the task being completed on Wednesday afternoon, in just twenty-four hours from the commencement. The message was written out in full, following the copy verbatim, even to the punctuation and paragraphs, a thing not usually done in telegraphing. The number of words was 50,000. The idea of such a document appearing in print in a city nearly one thousand miles distant from Washington, twenty-four hours after delivery is almost beyond belief."

"Messrs. Howland and Aspinwall the great shipping merchants of this city have petitioned Congress for assistance to construct a Railroad across the isthmus of Panama. The petition has met with encouragement and at present all idea of Whitney's Railroad to Oregon seems to be out of the question. California and the Bay of San Francisco seem to be the climax of a railroad to the Pacific at present."

"The cause of the accident to the steamship Great Britain, according to late English papers, has been satisfactorily ascertained to have been the derangement of the compass by the iron of the vessel!"

"The Smithsonian Institute, at Washington, is progressing rapidly. The last wing is being finished interiorly with taste and beauty. The professors are making every arrangement for the consummation of their designs; and it is thought they will be ready for operation by the middle of this month.—The west wing is up and covered in, and the main building, whose heights will be the admiration of all, is advancing as fast as the skill and perseverance of the directors can impel it."



He asks an echo

Radar sends out pulses of electric waves which, reflected from a target, return to reveal the target's location.

Likewise, the apparatus pictured above sends electric waves over a coaxial telephone cable. Minute irregularities reflect the waves back to their origin; the echo makes a trace on an oscilloscope screen and so tells where to look for the trouble.

Telephone messages need smooth "highways" over which to travel across country: circuits able to transmit every talking frequency, without distortion. Television needs even smoother highways and at many more frequencies. So Bell Laboratories devised this method of spot-testing the cable over the entire frequency band needed for telephone or television. It is so delicate that any possible interference with transmission is detected at once. Its use makes sure that every inch of highway is clear.

This is another important example of how Bell Telephone Laboratories constantly develop finer communications for the nation.

BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for continued improvements and economies in telephone service.

THE COVER

The painting on the cover illustrates the unorthodox technique used in the study of cancer by Pathologist Harry S. N. Greene at the Yale University Medical School (*see page 40*). Human cancer tissue, shown in microscopic section in the background, has here been transplanted to the eye of a rabbit, where it develops as a growing pink tumor. Its ability to grow in the rabbit's eye is a test of its malignancy.

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Cover by Stanley Meltzoff

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SCIENTIFIC AMERICAN

Established 1845

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ARTICLES

●

DEPARTMENTS

Show Them You CARE

IN France . . . in Italy . . . all over Europe and Asia . . . there are people who need your help. Men, women, children who are poorly clothed and poorly fed. Hunger and disease are widespread. The Marshall Plan is slowly rebuilding foreign economies. But reconstruction takes time. Thousands need your aid right now!

•

YOU can help through CARE (Cooperative for American Remittances to Europe, Inc.), a non-profit, government-approved agency of 26 major American welfare groups. CARE assembles food and clothing textile packages, guarantees their delivery overseas, all at one flat fee—$10. Send CARE packages to relatives and friends. Send them to needy strangers —CARE's member agencies will select someone you will be glad to help.

•

CARE has a new 22½ pound standard food package, recently improved to contain more meats, more fats, more sweets. Other CARE packages are: British, Greek, Italian, Oriental, kosher food assortments; infant or baby food; baby layette; knitting wool; wool blankets; household linens; wool suiting, with the sewing accessories to turn it into warm clothes. Just mail your order—CARE does the rest!

•

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Belgium
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Italy
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Korea
Netherlands
Okinawa
Poland

New Food Package:

1 lb. Beef in Beef Broth
1 lb. Steak and Kidney
½ lb. Corned Beef Loaf
½ lb. Liver Loaf
½ lb. Bacon
¾ lb. Prem
2 lbs. Margarine
1 lb. Swift'ning
1 lb. Apricot Preserves
1 lb. Honey
1 lb. Raisins
1 lb. Chocolate
2 lbs. Sugar
½ lb. Egg Powder
2 lbs. Milk Powder
2 lbs. Coffee
2 lbs. Flour
2 lbs. Rice
12 oz. Soap

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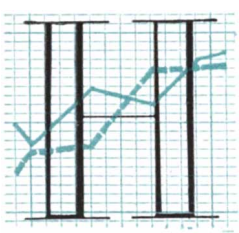
SCIENTIFIC AMERICAN

DECEMBER 1948 VOL. 179, NO. 6

PUBLIC OPINION POLLS

Why did they fail? A leading authority assays their weaknesses and suggests some tested new techniques that would improve their accuracy

by Rensis Likert



HOWEVER wrong George Gallup, Elmo Roper and other pollsters may have been in their forecasts of the recent election, no social scientist believes that public opinion polling itself was thereby discredited as a useful tool in social research. Actually it would be as foolish to abandon this field as it would be to give up any scientific inquiry which, because of faulty methods and analysis, produced inaccurate results. Science often learns more from mistakes than from successes. In this case, the polling fiasco of 1948 had at least two healthy results: 1) it demonstrated dramatically that polling as it is now conducted is far from being an exact science (which apparently needed public demonstration), and 2) it will force more rigorous standards upon the polling business.

It would take an exhaustive investigation to find out specifically where and how the election polls went wrong—if indeed that can ever be reliably determined. The poll results themselves were only partly responsible for the erroneous predictions; errors were also made in the analysis and interpretation of the results. Thus in the Gallup Poll, when the interviews were analyzed, a considerable block of voters was ignored. This was the group, constituting some eight per cent of all the voters interviewed, who said they were undecided and would give no indication of which presidential candidate they leaned toward. Gallup stated after the election that although four out of five of this group had voted Democratic in previous elections, these voters were disregarded in his predictions on the assumption that they would not go to the polls on election day. If his assumption was incorrect, this error might explain some of the discrepancy between Gallup's prediction of a 44.5 per cent vote for Truman and the 50 per cent the President actually received.

If the polls could be so inaccurate in predicting an election, what of their activities in sampling public opinion on complex social, economic and international issues? In that field there has been skepticism for some time. The skeptics have given many reasons for their doubts: the samples are too small or are otherwise inadequate; the problems are too complex to be dealt with in a few simple questions; the investigators are biased.

How valid are these criticisms? Just how sound are the present polling techniques, and how reliable are their results? The polls have had a great influence on political leaders, on the selection of candidates, and on the actions of legislators, government administrators and businessmen. This is an appropriate occasion for an analysis of the polls.

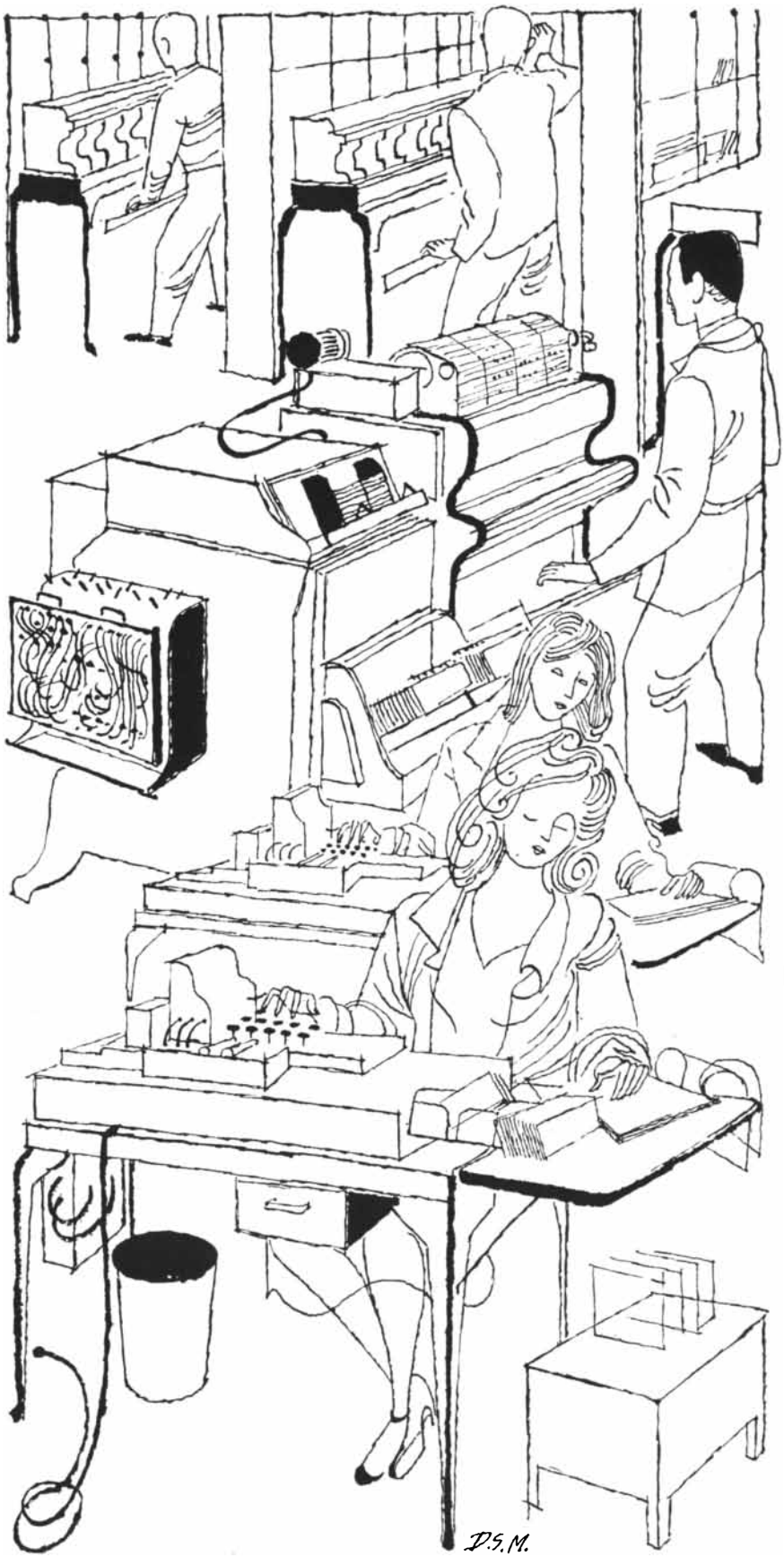
Polling Methods

The polling process divides conveniently for study into two major parts: 1) the population sample used; 2) the questionnaire, the method of interviewing and the analysis of the replies. The accuracy of any poll obviously depends upon the accuracy of each of these parts.

Let us consider first the sample. Its importance was made plain by the dramatic failure of the *Literary Digest* Poll in 1936. That poll focused attention on the fact that the design of a sample is as important as its size. With a sample of more than two million persons, the *Literary Digest* Poll still had an error of 20 percentage points. This error had two sources. First, the poll was restricted to *Literary Digest* and telephone subscribers. Second, it obtained a biased sample of those subscribers, *i.e.*, only those people who answer mailed questionnaires. The final sample therefore was not representative of the total population. So long as the voters who were not represented by the sample voted like those who were represented, the poll's predictions were borne out. But in 1936 this condition did not hold, and the poll accordingly went far astray.

The present public opinion polls use samples based on the so-called quota-controlled method. This method depends for its accuracy on finding those variables that have a high correlation with the behavior being studied. Thus to design a sample for predicting an election, the pollsters determine how voting correlates with party affiliation, age, economic status, and so on. They then attempt to find out how these variables are distributed in the whole population, and finally they assign to each interviewer quotas based on this distribution of variables: the interviewer must poll a certain number of persons in each age group, socio-economic group, etc.

For maximum accuracy, however, a pollster would need to know all of the variables correlated with voting behavior, such as previous voting behavior, education, income, occupation, religion, party affiliation of the voter's father, mother and close friends, and so forth. He would also need precise information on the distribution of all these variables in the population. Unfortunately for public opinion polling, these two conditions almost never exist. In the first place, many of the variables that affect voting or other be-



POLLING MACHINERY features the latest in business methods, such as punch tapes (*foreground*), tabulators (*center*) and mechanical sorters (*rear*), but sampling and interviewing techniques used are not so up to date.

havior are unknown. In the second place, no data are available on the distribution in the population of most of the variables that are known.

In spite of these difficulties, pollsters using the quota method have usually been able to make surprisingly accurate predictions. The methods generally employed are, briefly, as follows. Quotas are set, usually on the basis of geographical region, size of community, age, sex and socio-economic level. In some parts of the country, race also is included. In making election predictions, the results that these quota samples yield are generally tested by asking respondents how they voted in the previous presidential election and checking the percentages obtained with the actual election figures. Any discrepancy that exists is eliminated by weighting the results. For example, in a poll taken in Maine in 1944, 38 per cent of the persons interviewed said they planned to vote for Franklin D. Roosevelt. An analysis of the replies showed that the sample contained an under-representation of persons who had voted for Roosevelt in 1940. When a ratio correction was applied, a weighted estimate of 48 per cent for Roosevelt in 1944 was obtained.

This type of weighted correction has apparently sufficed to remedy the deficiencies in quota samples in most election polls in the past. There is always a possibility, however, that the high correlation between past and present voting behavior may change substantially for some important group not correctly represented in the sample, and in that case the error in the prediction may be large. It is conceivable, although there is no evidence on the point, that such a change may have occurred among some farm and labor groups in the 1948 elections.

Errors in the Samples

A major source of bias in quota samples is the fact that interviewers, in a perfectly human fashion, endeavor to fill their quotas in the easiest manner possible. They go to places where people are readily available and seek any who will fill the age, sex and socio-economic specifications of their quotas. They tend, therefore, to secure a sample which is biased in that it includes more people who are easily contacted than a truly representative sample should include. There is evidence also that some of the controls—for example, the socio-economic level—are vaguely defined.

An analysis of samples obtained with the quota-controlled method shows that this method tends to obtain data with biases which at times may be serious. For example, quota samples tend to include too few respondents from high income families. Thus analyses have shown that in typical quota samples in 1946 less than 10 per cent of the interviews were with persons in families with an income of

$5,000 or more. Census data for the same year show that actually about 15 per cent of the families had incomes of at least this amount. Quota samples also tend to have too few interviews with people of very low incomes. Another bias that often exists is the inclusion of too many persons who have at least completed high school and too few persons with grade-school education or less. Thus in typical quota samples about one third of the respondents have only a grade-school education or less, whereas census data indicate that the correct figure is about one-half.

The basic weakness of the quota-controlled method is that it does not employ a random sample. A general human failing among interviewers, or errors in the fixing of quotas, may produce a sample which is systematically biased in the same direction. In other words, when deliberate human choice enters into the final selection of respondents, the usual laws of probability governing the sampling phenomenon do not apply; the errors or deviations may not balance one another as they tend to do in a purely random sample, but at times may become cumulative and produce a bias of large and unpredictable dimensions.

A More Accurate Method

All this indicates that a method which rigorously follows random procedures will produce more accurate samples than the quota method can. Acting on this basis, a few Government and university groups have developed new methods of sampling which do indeed produce much more reliable results. These methods are called probability sampling. The fundamental requirement of probability sampling is that the final determination of just which persons are to be polled must be left to chance. Because this procedure is in conformity with statistical laws, it is possible to calculate precisely the probability that the margin of error in any sample will not exceed a given amount.

A method based on these principles is now being used by the U. S. Bureau of the Census, the Bureau of Agricultural Economics, Iowa State College Statistical Laboratory, the Survey Research Center of the University of Michigan, and other agencies. It is known as the area sample. The basic principle of this method is that each person in the population is given an equal, or known, chance to come into the sample. This is done by associating each person with one, and only one, very small geographic area and then selecting a random sample of the small geographic areas into which the country is thus divided.

The first step is to make a purely random selection of counties and metropolitan areas. Then within each of these areas a sub-sample of small geographic segments is selected, again by random methods. The final sample may include all the dwellings in each selected segment, or every k^{th} dwelling, depending on the size of sample desired. The selection of persons actually interviewed in each dwelling will then depend on the purpose of the survey; if its purpose is to predict an election, the sample will consist of all the eligible voters in the designated dwellings or certain voters selected at random.

When this method is used, the interviewer has no choice whatever. He goes to the specified dwelling and interviews the specified person or persons. If a respondent is not at home he calls again and again until he gets the interview; if he finds it impossible to do so, he reports that fact to headquarters.

Results

Area sampling eliminates the sources of bias present in quota-controlled samples. We do not need to know the variables affecting voters or their distribution in the population. We avoid human biases in selection of the persons to be interviewed. We can compute with confidence the limits or range of error for any result obtained—which is not possible in the case of quota samples.

The greater accuracy of the area sampling method has been amply proved in practice. The Survey Research Center at Michigan, using small nation-wide samples (500 to 3,500 persons) based on this method, has obtained results which check closely with census data and other reliable criteria. For example, a series of five sampling surveys was made between June, 1946, and October, 1948. The five samples were analyzed for certain characteristics—the percentage of white persons in the sample, the proportions in various age groups, the amount of schooling, and so on. To determine whether the samples were typical for the nation as a whole, the results obtained were then compared with U. S. Census figures. Comparing the survey of October, 1948, with the most nearly comparable census data, these were some of the results:

The data on racial distribution were close to the census figures. In the Survey Research Center sample, 91 per cent of the persons interviewed were white; the census figure for white persons in the whole population is 90.6 per cent.

With regard to age distribution, 23 per cent of the sample turned out to be in the group aged 21 to 29, and the census figure for the same group is 22.8 per cent; in the other age groups the correspondence was equally or almost equally close.

In the results on schooling, the proportion who had gone no farther than grade school was 44 per cent in this survey and 46.1 per cent in the census; those who had finished high school were 23 per cent of the sample, 22.9 per cent in the census; those who had finished college, 5 per cent of the sample, 5 per cent in the census.

These results were obtained with a random sample of only 1,151 persons widely distributed around the country. The four other surveys in this series, using even smaller samples (about 600 persons each), yielded approximately the same results; for example, the range in percentage of white persons in the four samples was from 89 to 91. Similarly consistent findings have been obtained in various area-sample surveys of family incomes and other variables in the population.

Another kind of check has been made by expanding the results from a sample to an estimate for the nation as a whole. Thus in an area-sample survey made for the Federal Reserve Board in January and February, 1948, the Survey Research Center asked 3,562 households the amount of their 1947 money income; as a check, the average family income in this sample was multiplied by the number of private households in the nation, as estimated by the Census Bureau. The estimate of national income obtained in this way proved to be 10 per cent less than an estimate by the Department of Commerce based on aggregate data. As is to be expected, expansions of this kind show somewhat greater errors than direct comparison of percentages and frequency distributions.

The chief disadvantage of the area sample method is that it is more expensive. It costs more to design the sample and it costs much more for interviewers to take time to locate each designated respondent. But the increased accuracy of this method outweighs its additional cost. Because of the greater cost, most pollsters have resisted using probability samples and have adhered to the quota-sample method. Until the best available methods of sampling are used by those making election predictions and publishing polling results, it will be well to keep in mind that the sampling methods now employed can have a substantially larger error than is claimed. The formula now used by pollsters to compute the probable error in their polls is not applicable to quota samples; the formula is actually based on the assumption that the sample is truly random.

Interviewing

Now let us consider the other part of the polling process—the questions that are asked, the quality of the interviewing and the competence shown in the analysis and interpretation. Since these problems are somewhat different in a poll for predicting elections than in a poll measuring opinion and knowledge on social and economic issues, it will be well to discuss these two uses of polling separately.

In asking people how they plan to vote, there is little problem about the wording of the questions. People know the parties involved and know the major candidates. The names of the parties and the candidates have substantially the same meaning for all. There is a very real problem, however, in obtaining frank, unrestrained answers. Several different procedures have

been used to encourage respondents to answer accurately.

One of these is publicity, intended to inform people about the poll so they will be prepared to be interviewed. Gallup at times has had his interviewers wear badges. This publicity has incidentally produced a problem for the polls. People expect to be interviewed, and many become convinced, because neither they nor their friends are ever approached, that the poll results are fictitious and not based on actual interviews. Polls, however, use a sample of cities and counties, as well as a sample of people within these communities. Obviously, people who do not live in these particular sample points will never be interviewed. Moreover, only a very small proportion of the total U. S. population falls into any of the samples. No one should be surprised if he or his friends are never polled.

The pollsters also try to win the cooperation of respondents by assuring them that their answers will be treated as confidential; the answers are not identified by name, but are used only to compile statistical totals. Sometimes the polls use a secret ballot. The interviewer carries a ballot box conspicuously locked with a padlock, and the respondent deposits his "ballot" in the box. The evidence varies on the usefulness of this method. In some tests it seems to have obtained more accurate answers, in others less satisfactory ones. Generally it appears to encourage voting by some of the persons who would otherwise answer "don't know."

One of the most useful devices is the indirect approach. Instead of asking the voter bluntly whether he is going to vote and, if so, for whom, the interviewer first asks a series of questions, such as how the voter feels about each of the major issues in the campaign, which of the candidates can best handle farm problems, high prices, the housing shortage, foreign policy, and so on. People who are reluctant to say whom they expect to vote for will almost always tell how they feel about the issues, how strongly they feel, and which candidate they believe will handle each of the different problems best. The answers to all these questions can then be analyzed to predict the probable proportion of each group who will vote and how they will vote.

The prediction of elections involves a particularly knotty problem which often is neglected. This is the "turnout problem"—predicting who will vote. To predict an election it is not sufficient to know what candidates are favored; it is necessary to know what candidates are favored by those persons who will actually go to the polls. This means that the pollster must know which voters are most likely to vote and which most likely to stay home. Unfortunately, the pollsters have made few attempts to develop questions to measure the intensity of the determination to vote, and the results consequently have a large possible error.

After the recent election, Gallup is reported to have stated that his polls indicated a relatively small turnout, but that he did not mention this large factor of uncertainty because his newspaper clients would have accused him of "hedging." As a rule, the larger the turnout, the greater the Democratic vote, but this rule may not have applied in this year's elections. In any case, it appears likely that the "undecided" vote and the size and character of the turnout played a large part in the miscalculations of the pollsters. Had they obtained more data on these factors and analyzed them adequately, their predictions might have been less positive and less wrong.

The Questions

The measurement of opinion on social, economic and international issues, and of

INTERVIEWER often biases sample by polling only people easy to reach.

public knowledge about these issues is more difficult, as a rule, than the prediction of elections. The problems in this field of polling are still so serious that opinion-poll results should be taken with even greater caution than predictions about elections.

Perhaps the greatest of these problems is that of meaning. Most of the issues of the day involve words and concepts that have different meanings for different people. On some issues large sections of the population may have no understanding of the major dimensions of the issue or the terms used. To understand the meaning of the percentages obtained in a poll, it is essential to know what respondents meant when they answered each question. Unfortunately, such data are not available. Yet polling results are often presented and discussed with the implicit assumption that each respondent understood the question and answered it from precisely the same point of view as that of the person conducting the poll.

An indication of the inadequacy of the usual polling questions can be obtained by asking a very small sample of respondents a question taken from any poll on a complex current problem and permitting these respondents to answer in their own words and to elaborate their answers. Several tests of polling questions have been made in this fashion. Quite consistently evidence has been obtained that questions on complex issues have different meanings for different people who are called upon to answer them.

Richard L. Crutchfield and Donald A. Gordon of Swarthmore College ran a test on the following Gallup Poll question which appeared in news releases of August 22, 1943:

"After the war, would you like to see many changes or reforms made in the United States, or would you rather have the country remain pretty much the way it was before the war?"

To test interpretations of this question, the investigators interviewed a cross-section sample of 114 New York City residents. After recording the respondent's initial reaction to the question, "the interviewer then encouraged the respondent to enlarge upon his answer in an informal conversational manner." The interviewers found that the initial response of their New York respondents gave substantially the same results as those obtained by Gallup for the country as a whole. But they also found that their respondents had seven different frames of reference in mind when answering the question. Some persons thought the question referred to "domestic changes or reforms"; others "technological changes"; others changes in the "basic political-economic structure of the U. S."; and still others thought it referred to changes in "foreign affairs of the U. S."

Respondents also had quite different meanings in mind when they answered "change" or "remain the same." For example, among those who answered in terms of "domestic changes and reforms" the word "change" for some persons meant shifts in a more liberal direction, such as "increases in social security," "higher pay levels," and "greater social equality for members of minority groups." Other persons meant a shift in the conservative direction, such as "change to a Republican administration," "less government control of business," and "more control of labor unions." Similarly, some of those who answered "remain the same" had in mind conservative aspects of our economy; others giving the same answer referred to liberal aspects, such as "maintaining high wages." It is obviously impossible to interpret percentages which

combine into single totals answers which have such widely different meanings.

This study of what the respondents really meant by their answers substantially altered the interpretation of the poll. Thus in their first answers, 49 per cent of the New York City respondents said they wanted the country to "remain the same." and 46 per cent voted for "changes or reforms." But further questioning of those who were thinking in terms of domestic changes showed that 60 per cent wanted "changes or reforms," and 40 per cent favored "remain the same"—a direct reversal of the results with respect to this phase of the question. Most of those who thought the question meant technological change favored such change, while those who thought it referred to the basic political-economic structure of the U. S. did not want change.

Many of the polls dealing with complex current issues use questions which are very likely to be as misunderstood as was the question tested by Crutchfield and Gordon. The importance of knowing what questions mean to respondents and what the latter mean by their answers is illustrated by the following two questions, which seemed similar in wording but produced substantially different results. The Gallup Poll asked: "Do you think the U. S. and all the Western European countries participating in the Marshall Plan should join together in a permanent alliance—that is, agree to come to each other's defense immediately if any one of them is attacked?" The answers: Yes, 65 per cent; No, 21 per cent; No Opinion, 14 per cent. At about the same time (the results of both polls were published in the same week—May 31 and June 2, 1948), the National Opinion Research Center asked: "As you may know, England, France and other countries of Western Europe recently signed an agreement to defend each other against attack. Do you think the U. S. should promise to back up these countries with our armed forces if they are attacked by some other country?" The answers: Yes, 51 per cent; No, 39 per cent; No Opinion, 10 per cent. Thus on what was essentially the same question—the formation of a military alliance—there was a difference of 14 percentage points in the Yes answers and 18 points in the No answers. Unless data are obtained showing what respondents in a poll actually mean by their replies, the percentages obtained are of limited significance and sometimes may be seriously misleading.

The problem becomes even more difficult when attempts are made to take polls on complex issues in several different countries at the same time. The language and cultural differences, added to all the other difficulties, are likely to make the results seriously inaccurate. In an international poll it is virtually impossible to have a complex question mean the same thing to all respondents.

There is no simple solution to this problem of the meaning of questions. One essential step is to analyze the problem in terms of psychological theories. This step works best when combined with a method of intensive interviewing using fixed questions and free answers. In using this technique, the polls would ask the respondent to select one of a number of alternative answers to a question, or would ask open questions, such as, "How do you feel about such and such a situation?" Interviewers would be trained to record the respondents' answers fully, and in the case of a question with alternative answers would encourage the respondent to elaborate his choice, using follow-up questions such as, "What do you have in mind?" The open-question method and the fixed question-free answer technique have demonstrated their usefulness in many tests. The major disadvantage of these methods, as with area sampling, is that they are somewhat more expensive than the more conventional polling techniques. Here again, this disadvantage is outweighed by greater accuracy.

STRATEGY BOARD in pollster's headquarters shows areas polled.

The Future of the Polls

Public opinion polling is a very young technique. None of the present polls was in existence 15 years ago. In less than 15 years the public opinion poll has become thoroughly established in this country, and it is gaining status rapidly in most of the rest of the world. The leaders of the polling business, particularly Gallup and Roper, are chiefly responsible for this achievement. The polls have been widely used by the public, by business and by government, and they affect many important decisions. Year by year their importance and use have increased. In spite of such failures as that in the recent election, their use is likely to continue to increase, because polls employing sound methods can obtain essential information which is obtainable otherwise only at a prohibitive cost—as by a referendum—or not obtainable at all.

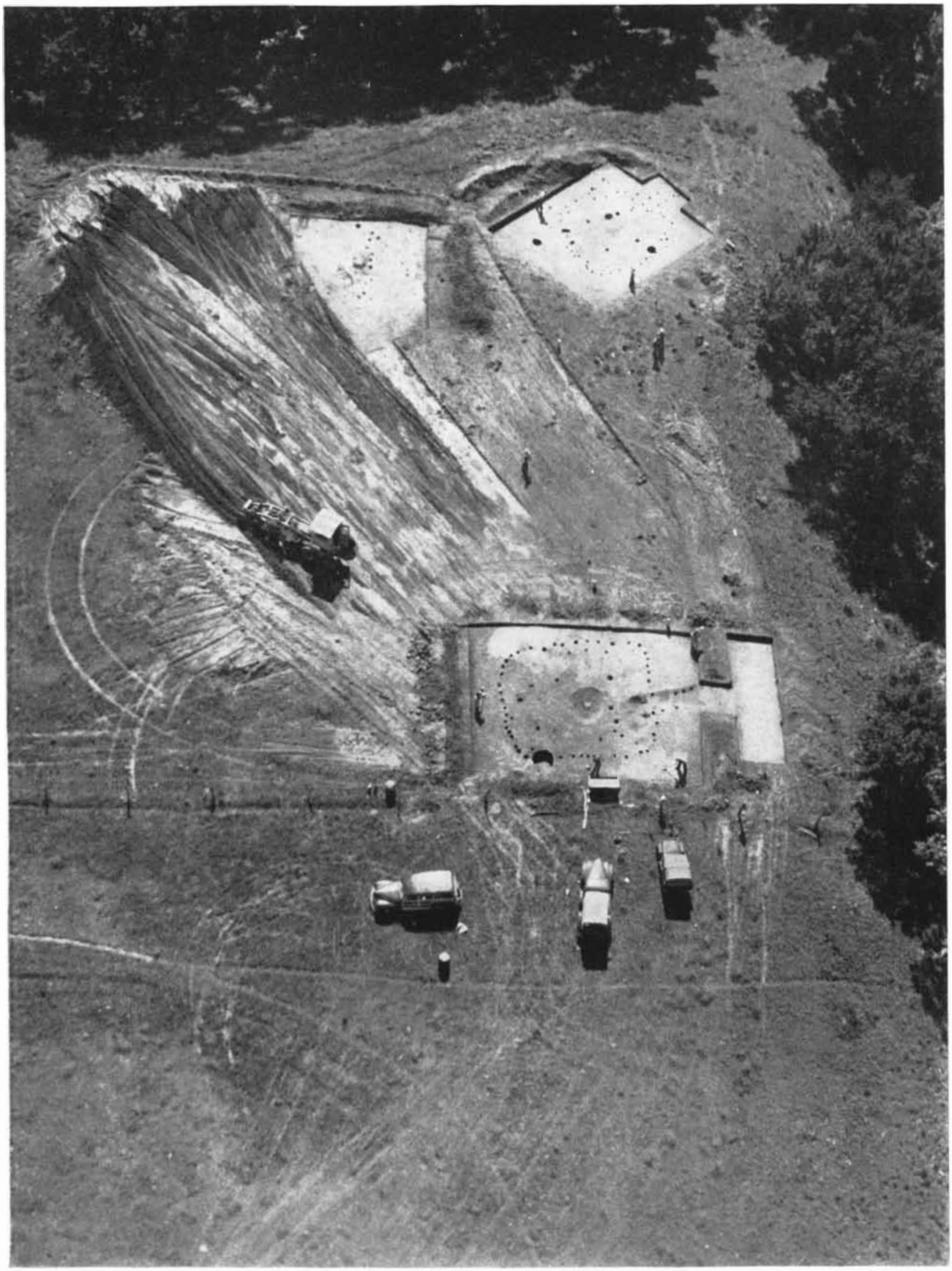
The public opinion polls therefore have a tremendous responsibility. Their readers, including all those persons who make important policy and administrative decisions on the basis of their results, rely on the polls for accurate information. The polls must use methods which will assure that their results are reasonably accurate on all issues and at all times. In terms of their own self-interest, the polls must assume this responsibility. Indeed, their ability to regain public confidence may now depend on their willingness to restudy and improve their methods.

Among the methods now available which would permit them to measure opinion more accurately are probability sampling, the fixed question-free answer method of interviewing, open questions, questions employing an indirect approach, and the use of a series of interrelated questions covering the same phase of a particular issue from several different approaches. By using the best methods available, the polls will discharge more adequately their responsibility to the public, government officials and businessmen.

The public opinion poll is only one area of application of a far more important instrument: the sample interview survey. The sample interview survey is one of the research tools of the social sciences. It is being used increasingly to study such widely different problems as the behavior of consumers, the distribution of income, principles of organization and management, religious behavior, the factors affecting political behavior, the production plans of farmers, and the processes of propaganda. Either alone or in combination with experimental methods, this tool enables the social sciences to deal with their problems in a quantitative manner. Consequently, social scientists have taken a keen interest in this technique.

A great deal of research on improvements in the technique is now going on. Some of this research is being done by the public opinion polling agencies. More, however, is being done by the Federal government and educational and research organizations. Important methodological advances are flowing and will continue to flow from this research on all phases of polling, such as sampling, interviewing and research design. Social science is making available to the polls improved methods. It is to be hoped that the polls will accept and utilize them.

Rensis Likert is the director of the Survey Research Center at the University of Michigan.



EARTH-MOVING MACHINE working on a slope at the Medicine Creek Reservoir in Nebraska is an indication of the archaeologists' haste. Here they have uncovered the sites of three dome-shaped houses built by Indians some 500 to 600 years ago. The original post holes made by the inhabitants have been dug out again by hand.

A CRISIS IN U.S. ARCHAEOLOGY

The damming of rivers will shortly flood the valleys where lived the aboriginal Americans. Archaeologists must work fast to save what they can of the remains

by Frank H. H. Roberts

DURING the past two years archaeologists have been scraping away at the river basins of the U. S. with an anxious haste that suggests Noah's preparations for the Flood. Their search parties have prospected thousands of miles of the North American watershed, searching for traces of its prehistoric inhabitants, and have staked out hundreds of sites for excavation. They are so pressed for time that in some places they are digging with bulldozers instead of with the customary archaeologist's spade. The objective of this activity—perhaps the most massive and most unleisurely excavation project in archaeological history—is to unearth as much as can be saved of North America's prehistoric remains before it is too late. For the archaeologists are actually working against the deadline of a series of impending floods that soon will bury the civilizations of the aboriginal Americans beyond recovery.

The reason for this state of affairs is the Federal government's nation-wide river development program. Its numerous projects for flood control, irrigation, hydroelectric power and navigation will inundate most of the archaeological sites in the U. S., many of which, unfortunately, are still completely unexplored. The American aborigines, like the inhabitants of other lands, generally lived along river banks, where there were fields for raising crops and good locations for camps and villages, where game, fowl and fish abounded and where easy transportation by water was at hand. For this reason, about 80 per cent of the archaeological remains in this country are located in places where the damming of rivers and the formation of reservoirs will obliterate them for all time.

The archaeologists of the U. S. have thus been suddenly presented with a problem of appalling dimensions. The construction of dams is going ahead so rapidly that they have only a few short years to carry out explorations which would ordinarily take several generations.

Early in 1945 they began to organize their forces. Within a year there was mobilized a large cooperative enterprise supported by the Army Corps of Engineers, the Bureau of Reclamation, the National Park Service (which is charged by law with responsibility for the preservation of archaeological sites) and the Smithsonian Institution. The National Research Council's Committee on Basic Needs in American Archaeology, the Society for American Archaeology, the American Anthropological Association and the American Council of Learned Societies formed an independent Committee for the Recovery of Archaeological Remains (including also paleontological remains) to serve in an advisory capacity and to assist in planning a nation-wide survey and digging program for all the river basins where dam projects were in prospect. As the program progressed the committee helped to enlist scientists from many universities, museums and state societies in the cooperative effort. The Smithsonian was given chief responsibility for the scientific work, and the National Park Service agreed to keep it informed of all dam and reservoir projects and to make arrangements for surveys of the areas involved.

PROJECTILE POINT is brushed by archaeologist working in Angostura Reservoir area of South Dakota.

The archaeologists went to work first in the Missouri River Basin, where 105 river development projects had already been authorized. From field headquarters at the University of Nebraska, survey parties reconnoitered more than 13,000 miles of the basin and covered 94 reservoir areas. Meanwhile other parties began explorations in the Columbia-Snake Basin in Oregon, on the Etowah River in Georgia, the Roanoke in Virginia, the Brazos and Neches rivers in Texas, and in the Central Valley of California and the Arkansas drainage basin in Oklahoma. And other surveys, sponsored by individual universities, have been started or planned in a score of states from Florida to Oregon.

Thus far the central survey staff alone has located some 1,800 archaeological sites and recommended digging operations at 250 of them. Because of limited funds, large-scale digging has actually been undertaken at only nine sites: the Addicks Reservoir in Texas, Medicine Creek Reservoir in Nebraska, Angostura Reservoir in South Dakota, Heart Butte Reservoir in North Dakota, Boysen Reservoir in Wyoming, McNary Reservoir in Oregon, O'Sullivan Reservoir in Washington, Fort Gibson Reservoir in Oklahoma and the Tucumcari project in New Mexico. The cooperating universities, however, have undertaken a number of other excavations, and at many additional sites there has been preliminary test digging.

Some of these excavations are being made, with great haste, in places where the destruction of the sites by the engineers is imminent or, indeed, already under way. An example is the Medicine Creek project on the Republican River in Nebraska. There, for the first time in archaeological history, power machinery has been used on a large scale. Time and man power were so short that the archaeologists decided to risk utilizing heavy equipment, provided by the Bureau of Reclamation, to scrape away the earth covering buried villages. The experiment

SKELETON of a 70-year-old man is carefully uncovered in the same Medicine Creek Reservoir area that is shown on page 12. This region has been the most thoroughly worked of all those that will be inundated.

FLOORS of Indian houses are exposed in the Medicine Creek Reservoir area. Posts placed in the holes supported an earth-covered structure. The entrance was at rear center. The larger holes were employed for storage.

surpassed expectations; it was found entirely feasible to remove the overburden from large areas with practically no damage to the underlying remains. In five months this group accomplished as much work as would normally have taken a much larger crew two full seasons. It was therefore decided to use machinery at other sites.

The diggings have already yielded important and interesting information about the little-known prehistoric peoples of North America. Among the most significant finds have been those in the Columbia River Basin of the Northwest. There the diggers have unearthed at successive levels the buried remains of villages ranging in time from 4,000 years ago to the time of the Lewis and Clark expedition in the early 1800s. The two seasons of preliminary exploration in this relatively unknown area have turned up many camp and village sites, rock shelters and burial grounds. From the great wealth of buried material archaeologists hope to reconstruct a continuous history of the aboriginal occupation covering several thousand years. The Columbia Basin was the most important prehistoric travel route in the West; there is evidence of aboriginal trading up and down the river from the West Coast to the upper Missouri Basin.

In the Missouri Basin there have been finds of cultures much older than those on the coast. Indeed, some of the deep strata which have been exposed by streams cutting through the terrain promise to yield material belonging to the so-called Paleo-Indian, who is believed to have migrated from Asia to North America in the late Pleistocene period. Most of the sites in the Wyoming-Montana area contain no pottery—an evidence of very primitive culture. Farther east, in the western Dakotas, pottery begins to appear. In both areas great numbers of stone circles or tipi rings, marking tent sites, have been unearthed. But to the south, in northwestern Nebraska and northern Kansas, the predominant dwellings were pit houses, and in the eastern Dakotas there are many mounds and remains of villages—all suggesting a more sedentary, agricultural type of civilization.

SOME of the largest, best preserved and most impressive fortified Indian sites in the U. S. have been found along the main stream of the Missouri in the Dakotas. In some of the sites there are records of prehistoric floods, of silting and soil erosion, of recurrent droughts and of fluctuations in climate. The excavation and interpretation of the data contained in such sites should not only contribute to the story of the growth and development of the Plains Indians but also add considerably to our understanding of how the aboriginal people met and overcame climatic and other environmental conditions not unlike those of the present day. Part of this study has already been made at the Medicine

Creek Reservoir in Nebraska and at the Angostura Reservoir in western South Dakota.

The Medicine Creek area, thanks to the help of earth-moving machinery, to date is the most thoroughly explored of all the projects. Its remains consist mostly of house pits, middens (dumps for debris and refuse), cache pits where crops were stored, and burial grounds. The material already uncovered indicates that archaeologists will have to revise some of their long-held theories about the Indians of that area and their relationship to their environment. The finds show that these Indians practiced community planning and varied their housing architecture. They also shed new light on early developments in horticulture.

The Medicine Creek villages which have been excavated probably were occupied about 500 to 600 years ago. They certainly were never visited by white explorers, and so far it has not been possible to connect them with the Indian tribes that have lived in the area in more recent times. Each village consisted of a half dozen or more earth-covered, dome-shaped houses. The floors were slightly below ground level. Near the center of the large chamber in each house was the fireplace, with the smoke passing out through a hole in the roof. The entrance to the house was a tunnel-like passage, placed on the side away from the prevailing winter winds.

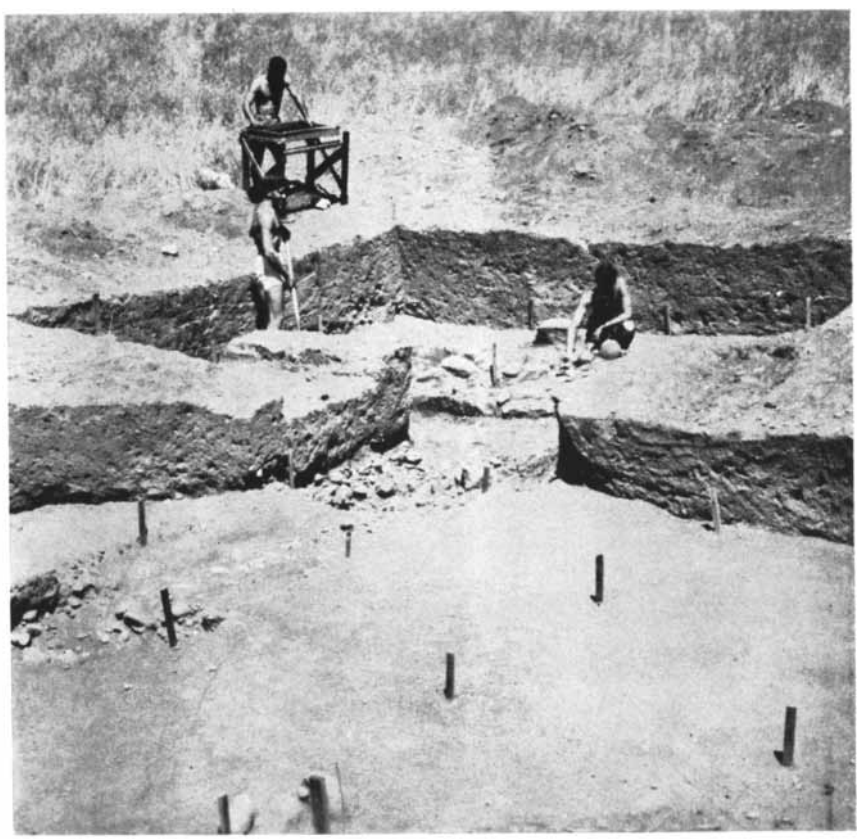
Each house probably was occupied by two or more families. Small underground pits inside and outside the houses were used for storage, and later as dumps for refuse. The remains show that these people raised corn, squash and beans, gathered wild fruits, berries and tubers, and hunted bison, deer, antelope and small game. They also depended a good deal on aquatic food; bone fishhooks have been found, and vast numbers of fresh-water mussel shells.

Just above these archaeological deposits is a thick layer of dust—evidence that the area suffered a period of severe droughts comparable to those which occurred in the Plains area a decade ago. During the drought period the Indians withdrew from the region. Later the weather improved and layers of good soil, now covered with sod, were deposited over the dust. This is just one of many proofs that cycles of good and bad times have been not uncommon in the area.

The fact that when white men first came to North America from Europe they found a virgin wilderness, apparently very sparsely populated, has fostered a wide impression that the continent had only a scanty human history. The current digging is amply demonstrating how wrong that impression is. It shows, as archaeologists have long suspected, that what is now the U. S. was peopled in ancient times by many diverse tribes occupying almost every region on the continent.

In California the present survey has un-

PIT DWELLING is dug out at the O'Sullivan Reservoir in Washington. This region was one of the most important prehistoric travel routes in U. S. Remains of villages dating from 4,000 years ago have been unearthed.



INTERIOR of pit house in the picture at the top of the page shows structural plan. Many such houses had a fireplace in the center, with a hole in the roof for a chimney. Man in rear sifts earth for small objects.

TIPI RINGS, circles of stones set on the ground to anchor Indian tipis, are plainly visible in the Tiber Reservoir area of Montana. These rings locate the sites of some comparatively recent settlements of the Indians.

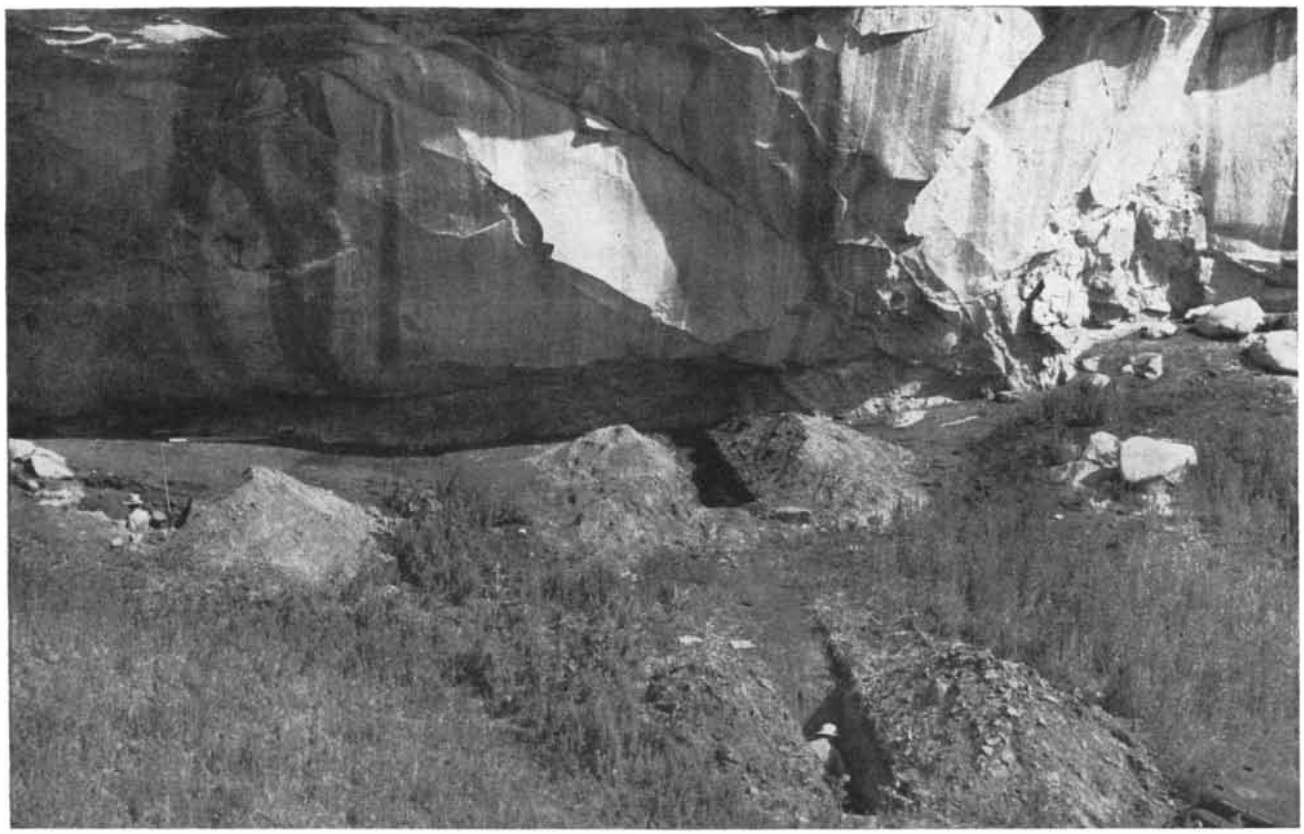
FORTIFIED VILLAGE built by the Indians is still a rough outline beside the muddy main stream of the Missouri River. This site, visible at bottom center of this aerial view, will be inundated by the Oahe Reservoir.

earthed village sites, soapstone quarries, pictographic writing and pottery of peoples previously unknown. In Texas, camp and village sites have been found in many new areas. In Virginia and North Carolina there are a number of signs of what seems to be an eastern phase of the famous Folsom culture which flourished in the Western Plains during the closing days of the last Ice Age. At the Fort Gibson Reservoir site in Oklahoma there are valuable remains which are attributed to the great mound-building era, the period of cultural efflorescence which swept across the southern U. S. in the late pre-Columbian and early historic period.

THE flooding of river basins will of course bury many deposits of fossils as well as those of aboriginal cultures. Thus far reconnaissance in this field has been confined mostly to the Missouri Basin, but it is now being extended to other areas. On the whole the loss to paleontology will not be so serious as that facing archaeology, for fossils similar to those that will be inundated can in most cases be found in other locations. A few unique quarries will be flooded, however, and there are many valuable fossil remains in the Indian sites themselves. Archaeologists frequently find fossil bones and leaves which the Indians apparently collected as curiosities. They used them as ornaments and sometimes carved implements from them.

The nation-wide effort to salvage archaeological and paleontological materials, the largest coordinated project of the kind ever undertaken in this country, has made a good start, but a staggering amount of work remains to be done, and time is running out. The great problem is lack of funds. So far the work has been financed mainly by funds transferred from appropriations of the Department of the Interior and the Army Corps of Engineers. The money available has been so limited that in many critical areas where sites are about to be destroyed the necessary surveys and excavations cannot even be attempted. As the Federal river development program proceeds, the emergency will become more and more acute. The Committee for the Recovery of Archaeological Remains is making a yeoman attempt to obtain the increased financial backing that is greatly needed. Unless more active support is provided, much of the archaeological story of North America will be lost. It will take a great combined effort by Federal, state and local institutions to achieve even a fair sampling of the nation's archaeological resources and to save a minimum of its prehistoric record.

Frank H. H. Roberts is Associate Director of the Smithsonian Institution's Bureau of American Ethnology and Director of the River Basin Surveys.



EXPLORATORY TRENCHES are dug in the lee of a cliff in the Oregon Basin Reservoir area. Indian villages were very likely established here for shelter. Layers of earth in village sites indicate that Indians lived under climatic conditions much the same as those of today. One layer indicates a long period of severe drought.

CAVE IS WORKED by a group of archaeologists in the Boysen Reservoir region of Wyoming. Deposits on the floor of the cave are carefully removed in layers. Each layer is separately sifted for artifacts. This process insures the segregation of characteristic artifacts left by the inhabitants of different periods and cultures.

The Navigation of Birds

How do they find their way in their vast migrations over land and water? Some new evidence on an old mystery

by Donald R. Griffin

FEW natural phenomena have so enchanted and puzzled men in all ages as the migrations of birds. The oracles of Homeric Greece and the augurs of the Roman Empire wove the seasonal appearance and disappearance of wild birds into their everyday religion and mythology. After the Romans, for many centuries birds received less sophisticated attention. Nevertheless their annual comings and goings have always intrigued all sorts of men from dilettantes to professional specialists. Perhaps there is a common denominator in the interest displayed by the augurs of ancient Rome and by the Audubon societies of today. No naturalistic conception of the universe seems really complete unless it deals with bird migration, and even in the most mechanistic modern climates of opinion this has been a phenomenon demanding special explanation. The attempted explanation may be a mechanistic one, but even so it is likely to be less mechanical than explanations of other phenomena. This is as true in these days of relativity, radar and mesons as it was in the time of James Clerk Maxwell and Charles Darwin. Bird migration is still something of a mystery even to those who deny the existence of mysteries.

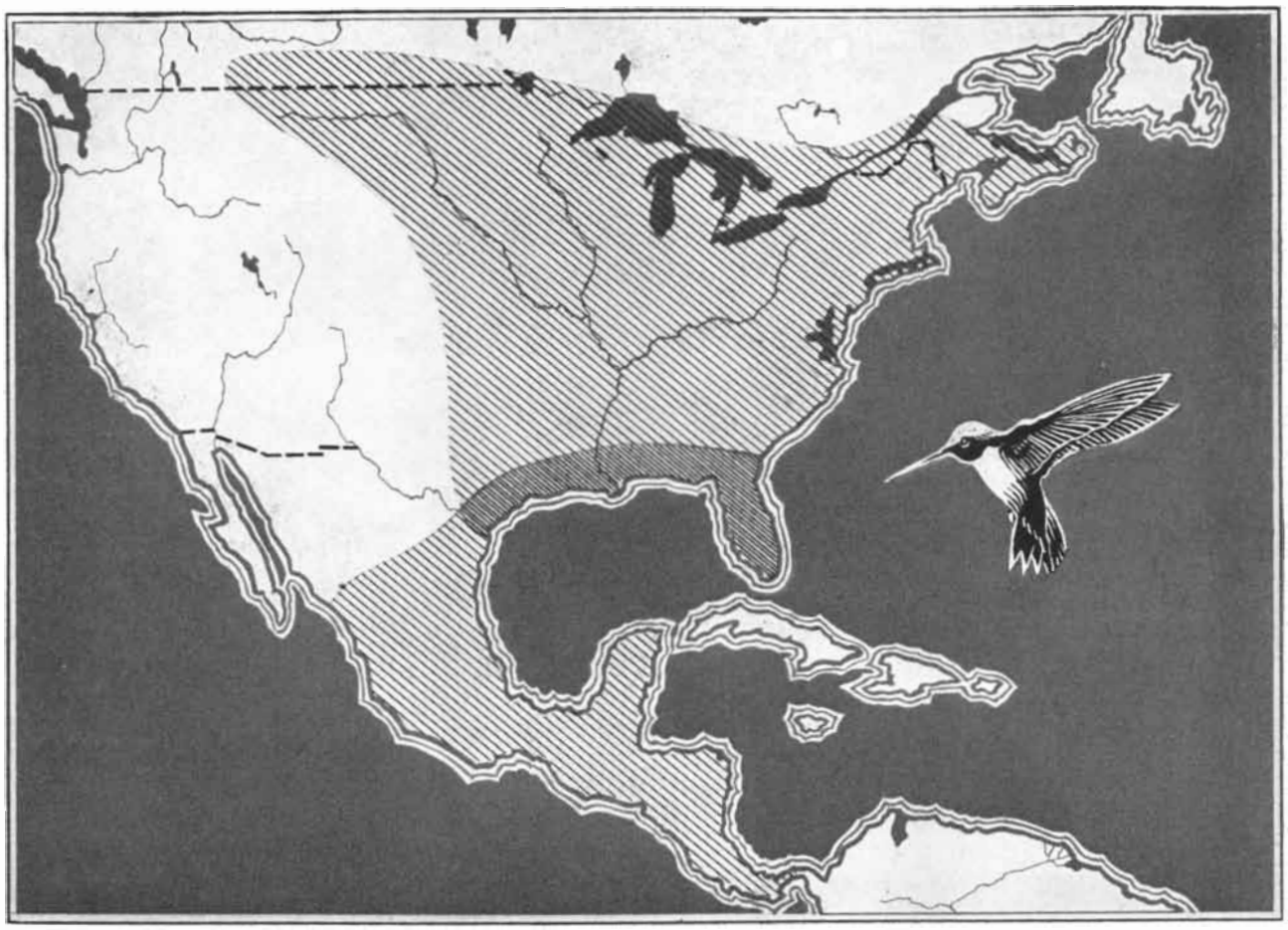
I must disclaim at once any attempt in this article to offer a solution of the mystery, but it does seem worth while to describe the progress that has recently been made toward an understanding of bird migration. During the past century the patient work of ornithologists has furnished a rather adequate description, if not an explanation, of the main features of bird migrations: their extent, the times of departure and arrival, the approximate routes followed by most species, the speed with which a whole population moves from winter to summer range, or *vice versa*. Repeated observations have established certain interesting facts, such as that some species migrate by night while others travel in the daytime; that in some species the young and old birds travel together, while in others they may migrate by entirely different routes or at different dates. The success of this description intensifies the urge to understand how the long journeys are accomplished. Of all the questions that have been asked about bird migrations, the most baffling and the most critical is the matter of orientation—how do the birds find their way?

To appreciate the dimensions of this problem one must consider the vast distances that birds often travel in their seasonal flights. While some birds are nonmigratory or travel only a few miles, as from a mountain-top to a neighboring valley, others span a major portion of the globe. One typical example is the tiny ruby-throated hummingbird (*Archilochus colubris*). This species, a familiar one in the eastern U. S., has wide summer and winter ranges, which are shown in the map on page 20. While the summer and winter ranges overlap somewhat, as they do with many birds, it is clear that individuals nesting along the Canadian boundary during the summer must migrate many hundreds of miles to reach even the northern edge of the winter range. The hummingbirds' summer and winter ranges are similar to those of many common songbirds, so that migrations of this length are the rule rather than the exception. A more extreme and spectacular case is that of the golden plover (*Pluvialis dominica*), a shore bird or wader slightly larger than a robin. Two closely related subspecies of this bird nest in the arctic latitudes of North America and Siberia and migrate to the Southern Hemisphere in winter. In addition to its great length, this migration route presents other features of interest. First, the adults seem to leave the breeding grounds before the young, so that many of the latter must make the entire journey without guidance from other golden plovers that have previously flown the course. Also, the golden plover does not swim on the water's surface, or at least has very seldom been observed to do so; it appears highly probable that the bird's extensive overwater flights, such as those to the Pacific islands or that from Nova Scotia to the Lesser Antilles, are made without stops for food or rest.

These migration routes are merely examples; many more are known to be just as extensive and to involve equally difficult feats of navigation. There are oceanic birds such as albatrosses, boobies, petrels, shearwaters and fulmars, which spend most of their lives at sea but must fly hundreds of miles to islands to lay their eggs and raise their young. The kingfisher or halcyon was believed in Aristotle's time to lay its eggs in a floating nest and to require a calm sea and fine weather for the safety of the eggs—hence the expression "halcyon days." Modern ornithology has found no birds which build nests floating on the open sea, but it has observed very remarkable habits among such birds as the petrels and shearwaters. Although highly adapted to a life at sea, these birds protect their nests from predators by digging burrows to shelter the eggs and young. Some species come ashore to enter these burrows only under cover of darkness. It is difficult even to guess how they find the islands on foggy nights. Petrels nesting on islands in the Bay of Fundy seem to prefer foggy nights, when they are safer from gulls, for their visits to the burrows, but tremendous problems of navigation must be posed by this searching for the nests.

ALL of these migrating birds must guide their flight by means of some aspect of their environment which is related in a reasonably reliable fashion to the direction of the goal. We must also take as certain, unless we are to fall back on extra-scientific theories, that this environmental cue must be perceived by the birds; it must stimulate some sense organ or receptor cells, for these are the only functional contacts between a bird's nerv-

MIGRATING BIRDS, here illustrated by a flight of swallows, often span a major portion of the globe in their journeys from summer to winter ranges. Their sense of direction has been variously ascribed to effects of the earth's magnetic field or its rotation, but these theories seem to be disproved by experimental evidence.



HUMMINGBIRD, the smallest of all the feathered species, flies huge distances in its seasonal migrations. Its summer and winter ranges are here shown by shaded areas. The summer range covers the central and eastern U. S. to the Canadian border; the winter range, which is mostly in Central America, overlaps the summer.

ous system and its outside environment. Our problem, then, is to find the environmental cue, and also to find the sensory mechanism by which this environmental cue is recognized and channeled into the central nervous system, where it can result in the appropriate actions to move the bird in the right direction.

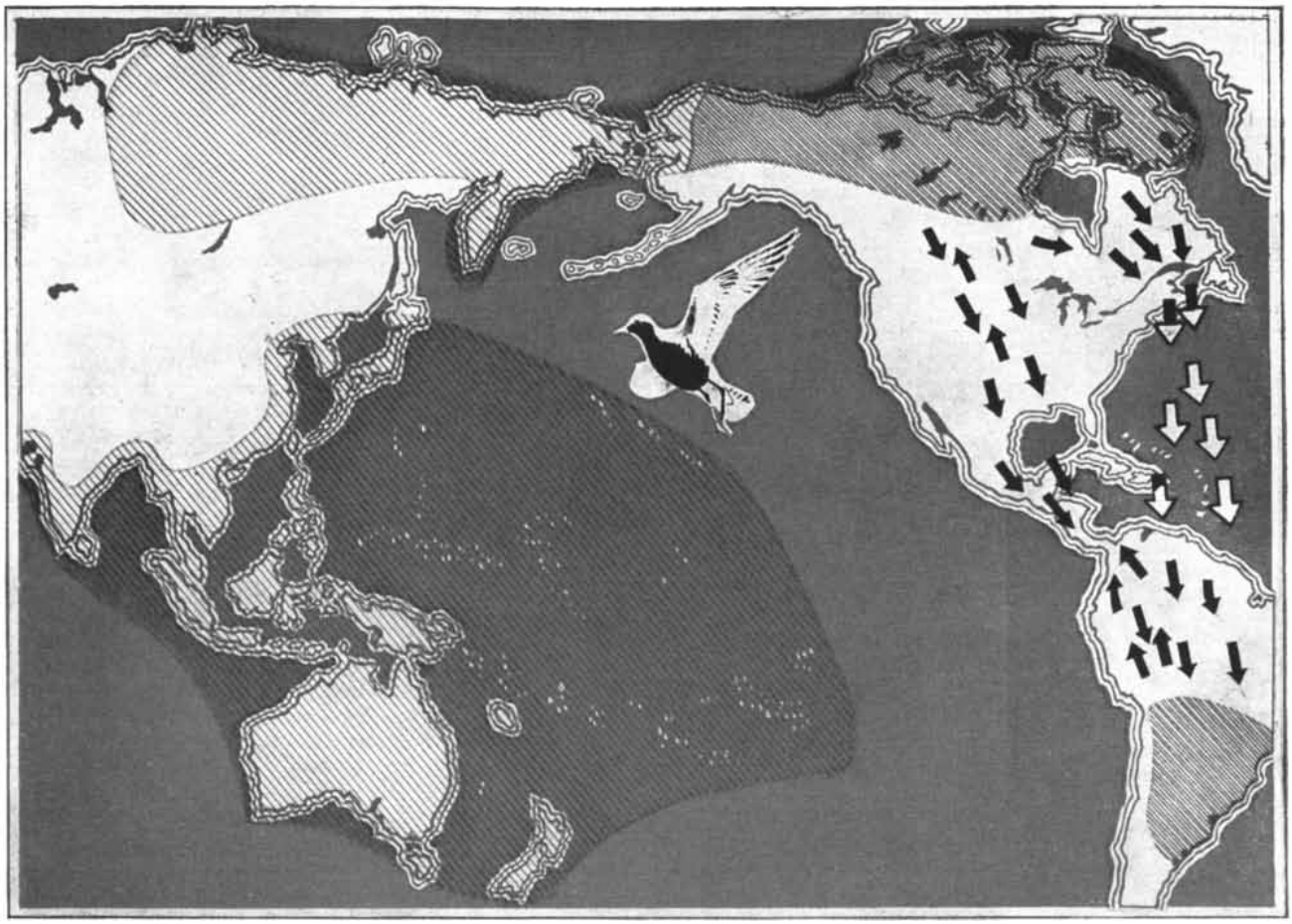
No one has yet succeeded in solving this problem, and all attempts to do so have been impaled on one or both horns of a dilemma: either the proposed environmental cue has seemed altogether too unreliable, or it has been impossible to demonstrate that the birds could perceive it.

On the first horn of this dilemma we find those who try to account for bird navigation in terms of the known sensory mechanisms, which are much the same in all higher vertebrates. Some have suggested that migrants are guided by visual landmarks. But the overwater routes such as those of the golden plover are devoid of topography for hundreds of miles, although some guidance might be obtained from the ocean swells, which tend to be rather constant in direction over any one part of the ocean. Others feel that wind direction may offer a guiding cue, but winds are notoriously changeable, and only if the bird knew the wind direction characteristic of each type of air mass and weather condition along its route could it guide itself from arctic to tropics.

The sun or other celestial points of reference might be guides, but a bird navigating by them would be obliged from hour to hour to change the angle between its flight path and the azimuth of the heavenly body upon which its attention might be fixed. Additional but smaller shifts would be made necessary by changes in longitude and latitude as the migration progressed. An even more obvious objection is that the birds migrate during overcast weather and even on cloudy nights. Answers are possible to these objections, such as the fact that even on heavily overcast days the sun's position is to some extent revealed by the pattern of sky brightness, the sky being slightly brighter in that half containing the sun. Yet it is difficult to be at all satisfied with any of the attempts to find environmental cues which would be adequate as a basis for the navigation of migrants and yet which lie within the sensitivity range of the known sensory mechanisms.

Turning then to the other horn of the dilemma, we find a variety of ingenious theories hung up on formidable objections from the point of view of the sensory physiologist. Best known, perhaps, is the idea that birds have the equivalent of a magnetic compass—that they can perceive the earth's magnetic field in some manner and guide their migrations accordingly. This theory has assumed many forms. Some postulate that birds can tell the direction of magnetic north, while others argue that they can judge the intensity of the earth's field, or the horizontal or vertical components in it. One of the most elaborate theories holds that birds can sense the angle of dip in the lines of force constituting the earth's magnetic field. The numerous but quite unconfirmed reports that birds' navigation is affected by the electromagnetic waves from radio transmitters are usually linked to the theories of magnetic sensitivity, though not in any precise manner.

The tendency of these theories is to postulate that the birds are aware of two effects, one of which informs them of their latitude and the other of their longitude. The migration is conceived of as a movement resulting from some type of simple reaction or "tropism" (automatic orientation) of which even one-celled protozoans are capable. By assuming sufficiently sensitive receptors, one can thus picture the



GOLDEN PLOVERS of America and of the Pacific migrate tremendous distances over water. In America, young plovers fly south to winter range by way of Mississippi Valley and Brazil; adults fly 2,000 miles over Atlantic by way of Lesser Antilles. Pacific plovers make even longer ocean flights from Siberia to New Zealand.

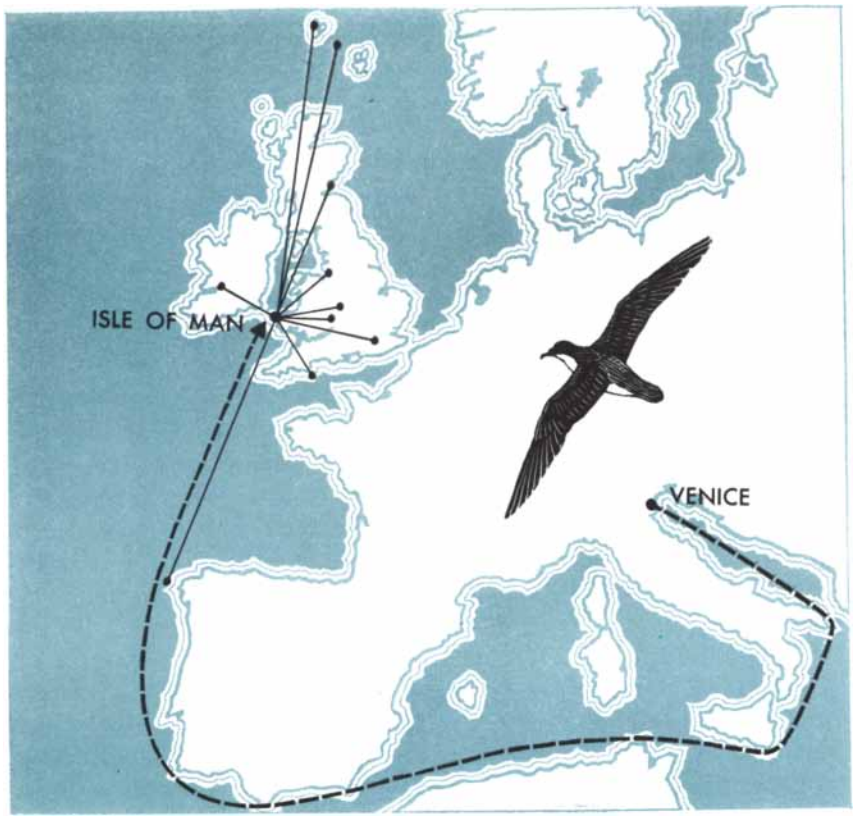
actual reactions of the birds in very simple terms. But these theories must face the fact that no one has shown that birds can sense a magnetic field as weak as the earth's, any more than we can ourselves. Birds have been subjected to very intense magnetic fields in the hope that they would exhibit some response—indicating that they felt the magnetism. But no such response has ever been demonstrated, and we must therefore discard the magnetic theories unless and until such a sensitivity can be shown.

A really new theory was advanced recently, namely that birds orient themselves by means of mechanical forces arising from the earth's rotation. These forces might take many forms, such as 1) an increase in the apparent weight of a flying bird depending on the direction of its flight, 2) a lateral force exerted on fluids flowing through its arteries, or 3) the so-called "Coriolis force," which causes a body traveling with uniform velocity through the air to trace a slightly curved path over the earth's surface, owing to the fact that while the flying object is in the air the earth rotates underneath it. These effects are of a type which might be within the range of a bird's sense organs, since they involve mechanical accelerations for which the bird has specialized receptors in the inner ear labyrinth. But the difficulties in the way of a bird's being able to make quantitative distinctions in such effects are enormous. The variation in weight is only one part in several thousand, and it could easily be masked by the much larger accelerations resulting from flight itself, to say nothing of the slightest turbulence of the air, or even the bird's own breathing and heartbeat. Similarly, the lateral forces on arteries are infinitesimal compared with the effects of turbulence within the blood and the waves of pulse pressure traveling from the heart. Thus this hypothesis seems scarcely more plausible than the magnetic theories.

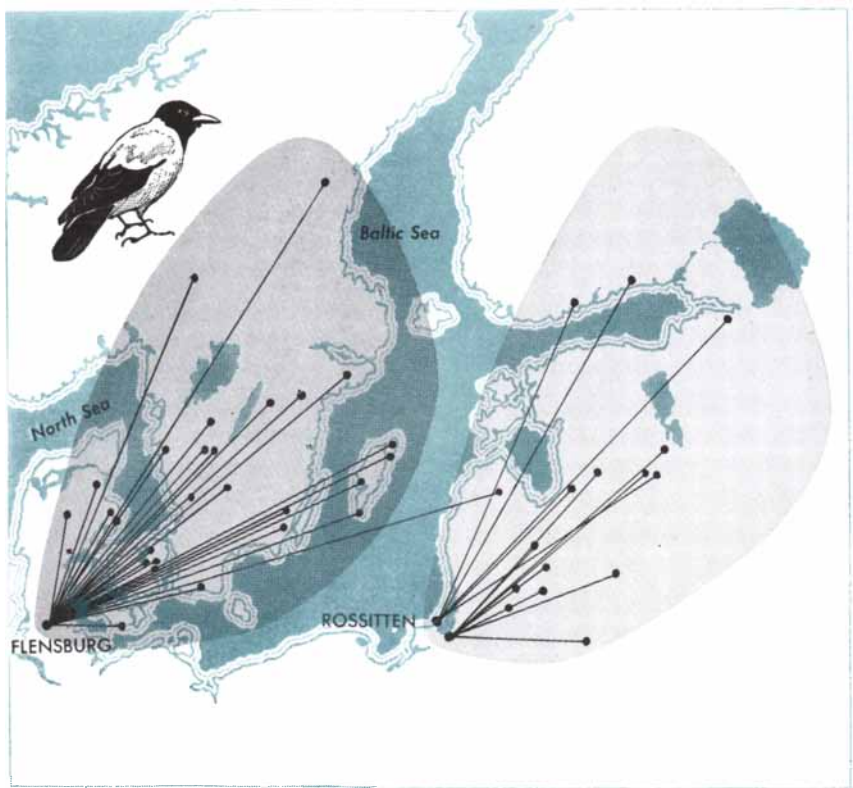
ONE reason for our persisting ignorance concerning the sensory basis of bird navigation is the difficulty of making detailed observations of an individual bird while it is actually setting its course. One can watch wild birds leave their breeding grounds; one can observe them passing various points on their way south; one can note the time of arrival and departure of a species in any region; and by observing where the birds are concentrated during migration one can map with fair accuracy the chief routes traveled. But birds can seldom be followed from the ground for more than a mile or two, and such observations disclose birds flying in all directions even during the height of a migration. Thus one can very seldom be sure that at a given moment any particular bird is actually starting a migratory flight in the correct direction. Birdbanding—the fixing of numbered metal bands about the legs of birds—has demonstrated the extent of many individual journeys, but for our purposes this method suffers from several limitations: the percentage of recoveries at significant distances from the point of banding is extremely small, and almost invariably several weeks or months elapse before the birds are recovered at a distance, so that one has little assurance from the results of banding alone that a bird traveled directly from the point of banding to the point of recovery. Nor can one tell anything of the route followed, or the conditions under which the migration was performed, much less the sensory mechanism employed.

Direct experiments with migrating birds are extremely difficult, but some have been performed, notably by William Rowan in Canada and Werner Rüppell in Germany.

Rowan kept young crows in captivity in Alberta until November, when all wild



HOMING EXPERIMENTS show wild birds' remarkable ability to find way back to nests. Here Manx shearwaters were released at various distances from home in Wales. One bird returned from Venice by sea route in 14 days.



DIRECTIONAL SENSE of birds is illustrated in famed crow experiment. Crows which normally summer northeast of Rossitten were trapped during migration and released at Flensburg. Their summer range was displaced.

crows had left the area for their winter range 1,000 miles or so to the southeast. Then the young crows were banded and released with a widely publicized reward for their recovery, dead or alive. Several were shot and reported within the next few weeks. All of those that had traveled any distance were recovered within 30 degrees of the normal migration route. This showed that young crows could take the correct direction without adults to guide them.

Rüppell's experiments involved a European species of crow which could be captured in large numbers during spring migration on the Baltic coast of East Prussia. In his most clear-cut experiment some 500 crows were captured at Rossitten on the Baltic and released 465 miles to the west at Flensburg, a locality which this population of crows had never visited previously. The normal summer range of these crows, as revealed by the recovery of many birds banded over a period of years, was an area northeast of Rossitten. When the crows displaced to Flensburg were retaken during the following spring and summer, all recoveries came from the area to the northeast of Flensburg; in other words, the crows had shifted their summer range westward. Evidently these crows continued their spring migration in roughly the normal direction even though they were displaced into different territory.

SUCH experiments with migrating birds are valuable, but they are also very laborious. One still does not know much about the actual routes flown by individual birds, nor is there much opportunity for direct experimentation. Another procedure has therefore been widely used to study bird navigation. It is a sort of artificial migration which can be arranged experimentally in many species by catching adult birds at their nests, while they are incubating eggs or caring for young, and transporting them to a distance before release. Birds treated in this way often return hundreds of miles, behaving somewhat like homing pigeons. These artificial homing experiments, as they are called, bring one a step closer to the direct observation of the individual navigating bird. Here one knows at least the beginning and end points of the journey; by watching the nest, one can observe the bird's return and accurately measure the total elapsed time for the homing flight.

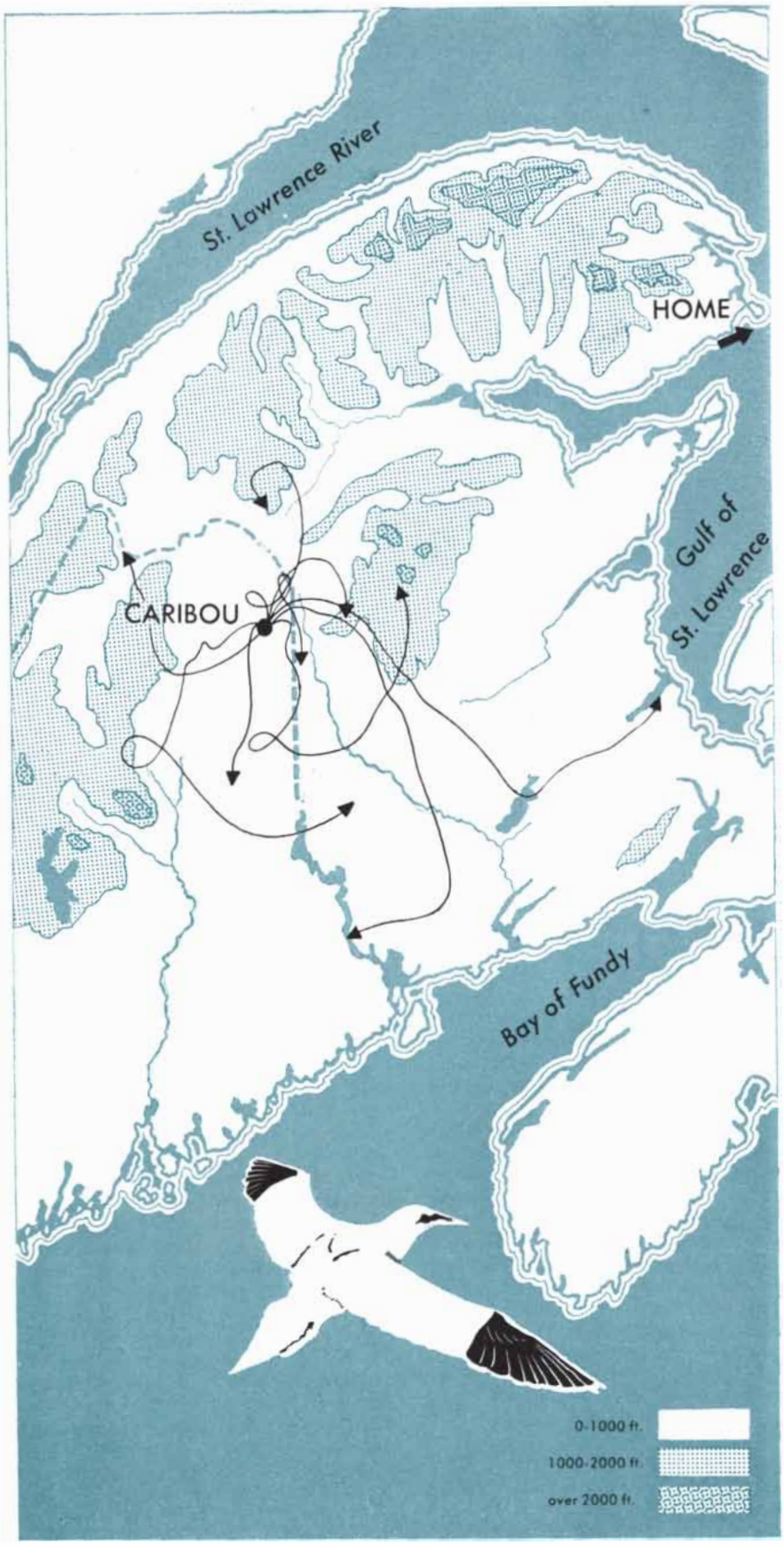
The homing performances of various wild birds in these experiments seem almost as spectacular as their natural migrations. The first experiments of this type were those of John Watson and Karl Lashley with noddy and sooty terns (*Anoüs stolidus* and *Sterna fuscata*) nesting near Key West, Florida. Some of these birds returned even when carried 855 miles northwest to waters where these two species are seldom seen. More recent experiments have involved swallows (*Hirundo*

rustica) which returned 1,200 miles from Greece and Spain to nests near Berlin. In another series of experiments, four out of six herring gulls (*Larus argentatus*) nesting on the Massachusetts coast returned from Chicago, 870 miles inland. The most startling case is that of a strictly marine species—the Manx shearwater (*Puffinus puffinus*)—which returned in 14 days from Venice to its nest on an island near Wales. Presumably it flew all the way over water (since shearwaters are almost never seen inland), using a roundabout route of at least 3,700 miles by way of the Mediterranean, the Straits of Gibraltar and the Atlantic.

So striking are these homing performances of wild birds that they have been widely cited as experimental evidence for the theories of special sensory mechanisms —evidence which to many has seemed fully as important as the natural migrations. Thus the magnetic theorists describe the behavior of a homing bird as a return towards the latitude and longitude of the home area by the simple following of gradients in the magnetic sensations. This theory does not appear to be supported by experimental test, however, for when small magnets are attached to a homing bird or when it is exposed to a strong magnetic field its performance does not seem to be affected.

Certain other studies of homing birds have led to an unexpected conclusion: that when released in really strange territory birds are not able to head directly home but explore wide areas, often flying in quite the wrong direction until they reach territory which they have visited before and where they can presumably find familiar landmarks to guide them home. Birds do not return as quickly or in as high percentages from unfamiliar territory as from equally distant areas which they have visited before. Moreover, the average speed of return in homing experiments is far below the birds' known velocities of flight. Even allowing considerable time for resting and feeding along the route, there remains time for wide deviations from the straight line connecting the release point and home. Occasional spectacular cases like that of the shearwater released at Venice would be expected as a result of chance; significantly, a second shearwater carried to Venice did not return until a year later.

TO test the hypothesis that birds find their way home by exploration, it was necessary to learn something about the actual routes they flew. By learning to fly light airplanes, Raymond J. Hock and I were able to achieve this objective. We managed to follow a group of gannets (*Morus bassanus*) in the air for a considerable part of their homing flight. Gannets are sea birds, feeding on fish. A large number nest on Bonaventure Island in the Gulf of St. Lawrence. Their large size and white color render them easily visible from the



ACTUAL FLIGHT PATHS of homing gannets released at Caribou and followed in airplane show that birds explored in all directions before finding correct direction to their island nests, where they eventually arrived safely.

air. Several were transported about 215 miles west southwest from the island and released on fresh water near Caribou, Me. They were surrounded by completely unknown territory; to reach their nests they had to fly for at least 100 miles over land. Yet they displayed a homing ability quite comparable to that of other wild birds. Those released at Caribou averaged almost 100 miles per day during the return flight. The significant advance over previous homing experiments was our ability to follow the return routes of eight of the seventeen birds released at Caribou for periods as long as nine and a half hours and distances as great as 230 miles. The map on page 23 shows the initial portions of these eight return routes, and I think that the exploratory nature of the flight paths is clear.

One naturally asks whether the presence of the airplane did not cause the birds to behave abnormally. The gannets showed no fear of the plane even when it was within 500 feet; at least they did not turn away from their previous course at our approach, as many birds do when an airplane comes near. Nevertheless we kept 1,500 to 2,000 feet above the gannets during these obesrvations in order to minimize the chances of influencing their choice of route. But the best indication that the airplane did not disturb the gannets was that the homing performance of a control group which was not followed was almost exactly the same with respect to average speed and percentage of returns as the performance of the eight birds we observed from the air. If the airplane influenced or frightened the gannets, it did not prevent them from returning to their nests at the normal speed.

These observations seem to confirm several lines of indirect evidence that the homing ability of both wild birds and domestic homing pigeons is based largely on visual landmarks, or on exploration when the birds are released in unfamiliar territory. Such a conclusion leaves us in something of a quandary. The homing experiments argue strongly that birds do not possess any special sensory mechanism that can guide them home or inform them of their latitude and longitude. Yet in the case of natural migrations it is preposterous to suggest that the birds are merely exploring. Even young birds without guidance begin their first migration in roughly the correct direction, as shown by the experiments of Rowan and others. Individual young birds may deviate 20, 30 or even 40 degrees from the average direction for the species, but virtually none go north in the fall.

There remains the possibility that migratory birds can determine the direction appropriate for a particular migration. But this is of no help when they are artificially transported into unknown territory, for then they cannot know whether home lies north, east, south or west. If this be true, then clearly the homing experiment would not reveal the basis of navigation by migrants. For this reason, among others, the best hope for future progress seems to be offered by experiments with actual migrations, particularly if the routes flown by individual birds can be traced as we were able to trace the routes of homing gannets.

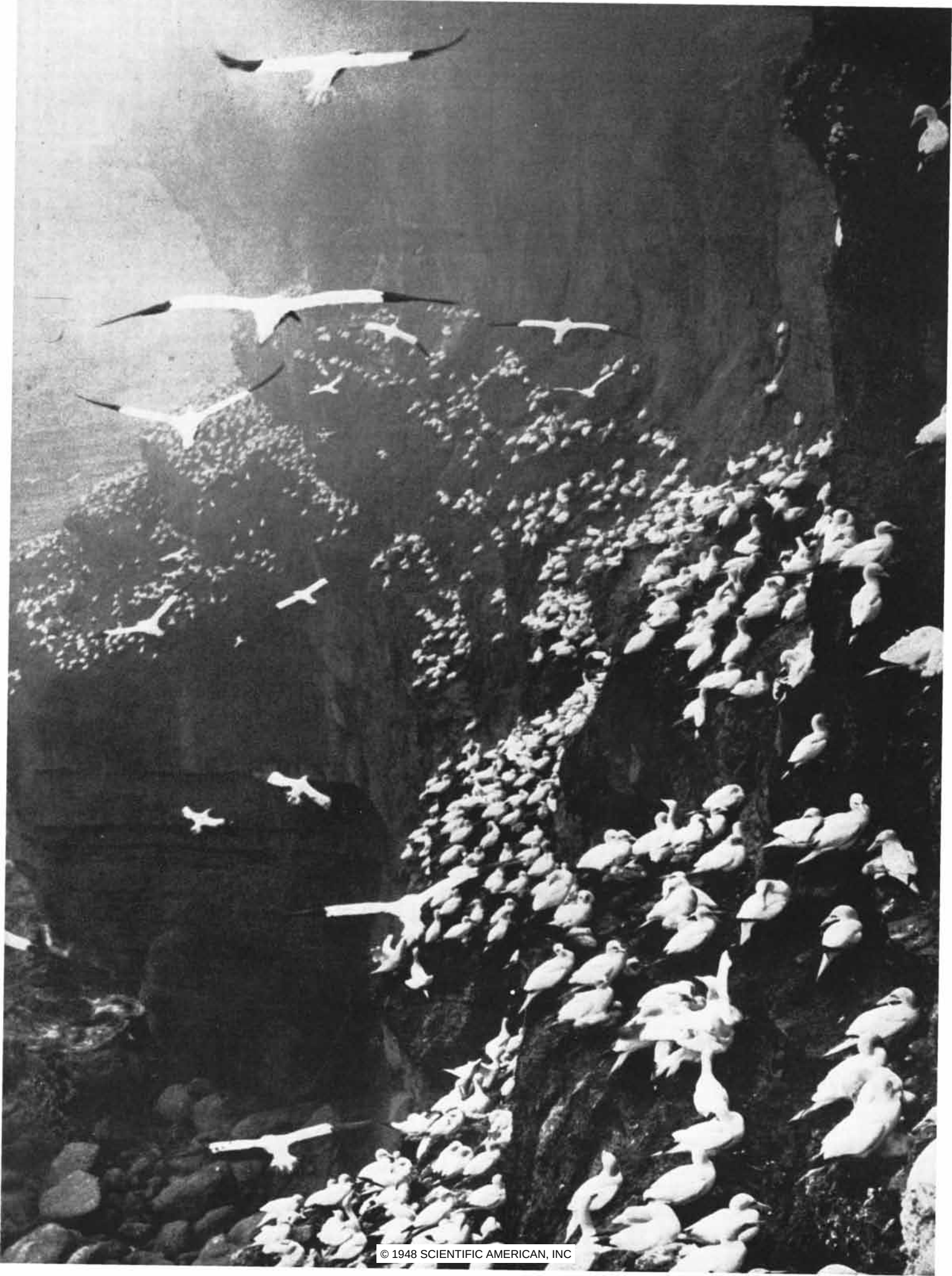
The late Werner Rüppell, who was the leading European investigator of these phenomena until his death during the war, originally postulated that the homing of wild birds depended upon a mysterious and unidentified "sense of direction." But in his last paper. describing the experiments with migrating crows which I have cited previously, Rüppell suggested that the position of the sun might be the guiding cue. Such a theory is certainly rendered more plausible by the recent demonstration of the Austrian zoologist Karl von Frisch that bees locate sources of food with reference to the position of the sun in the sky [SCIENTIFIC AMERICAN, August].

These questions cannot be settled without specially devised experiments. which should include prolonged following of individual birds from the air and a close correlation of the birds' behavior with meteorological data. For instance, it would be most valuable to learn whether birds begin a migratory flight in the correct direction under heavily overcast skies when no celestial objects are visible. The fact that birds are observed migrating under such conditions is not conclusive evidence, for the overcast may be a local one and the birds might have started their flight 50 or 100 miles away under clear skies, holding their course in thick weather by means of local cues such as topography or wind direction.

The novelty and the expense of airplane observations of individual birds have prevented such work from being undertaken on any extensive scale, but I hope that the increasing practicability of light airplanes (and eventually helicopters) will serve as a stimulus for such work in the future. Perhaps we can look forward in the next few years to the emergence of a group of air-minded ornithologists who will trace significant portions of the migration routes of individual birds with a simultaneous understanding of the ocean of air in which they move. Such research, wisely conducted and on an adequate scale, might well provide the key to these ancient and baffling questions.

Donald R. Griffin is associate professor of zoology at Cornell University.

GANNETS NEST on Bonaventure Island in the Gulf of St. Lawrence. Taken to unfamiliar territory in Maine, birds flew hundreds of miles over land to return to their home.



SCIENCE AND

"Atomic Storage Battery"

A NOVEL idea for an "atomic storage battery" which conceivably could be used to drive automobiles was suggested in a recent speech by Lewis L. Strauss of the Atomic Energy Commission. Atomic power has been considered out of the question for small vehicles because it has been assumed that the power would have to be provided by a chain-reacting pile, requiring bulky shielding. But Commissioner Strauss suggested that radioactive isotopes might be used as a portable source of power. They would be produced in a central-station pile and put up in containers to generate heat wherever desired.

A similar idea was advanced two years ago by George Gamow, the George Washington University physicist, in his book, *Atomic Energy in Cosmic and Human Life*. He proposed using for this purpose radioisotopes which give off only nonpenetrating alpha or beta radiation. They would need no other shielding than their own container and thus would provide a compact heat source.

Atomic storage batteries would be a wasteful utilization of atomic energy, however. Radioisotopes cannot be turned on or off at will, but decay continuously; the storage battery, therefore, would run on whether or not it was in use. Moreover, isotopes are produced in a pile only at the expense of other pile reactions. Each neutron used in forming a radioisotope means one neutron less for forming fissionable material or for the fission reaction itself. And the energy yield of the alpha- and beta-decay processes is at most a hundredth (usually much less) of the yield of the fission process.

Another Meson

AS the investigation of mesons proceeds, the picture seems to become more complicated instead of clearer. At least five of these atomic particles have already been generally accepted by nuclear physicists. They are the positive and negative mesons of mass 200 times that of the electron, positive and negative mesons of mass 300 and a neutral meson of mass 88. Some physicists think there is also evidence for the existence of three other varieties—positive, negative and neutral mesons of mass 800 to 1,000. Now the discovery of still another meson is reported. E. G. Cowan of the California Institute of Technology has announced evidence for a particle with a mass of about 10—by far the lightest meson yet found.

In a Wilson cloud chamber photograph of the results of cosmic-ray collisions with atoms, made in a plane at an altitude of 27,500 feet, Dr. Cowan noticed a highly unusual track. The amount of ionization indicated that it was that of a meson, yet the particle had been markedly deflected in collisions with two electrons, indicating that it was extraordinarily light in weight. Dr. Cowan's calculations from its angle of deflection give 11.5 as the upper limit of its mass. Its charge is unknown; the photograph yielded no information on that point.

Chemical Trends

TWICE a month the American Chemical Society publishes a compact journal, *Chemical Abstracts*, which might be considered the Domesday Book of chemistry. Sooner or later practically everything in scientific literature of interest to chemists is summarized in its pages.

E. J. Crane of Ohio State University, its editor, surveys his journal every few years to analyze trends in chemical research. His latest canvass has yielded these interesting facts:

Germany has dropped precipitously from a position of leadership in chemical research (which is no great surprise); its output of scientific papers is only one sixth of what it was before the war. The leading nation is the U.S., which accounted for 40 per cent of all chemical research reported last year. Next were the British Empire and the U.S.S.R., each producing roughly an eighth of the world total of published papers. India is in eighth place; its chemists are making as many contributions as the chemists of all of South America.

During 1947 some 30,000 papers were abstracted, as compared with 46,000 in 1938. This drop represents not a decrease in research, but a change in its character. The single researcher is being replaced by the team, which prepares fewer but more comprehensive papers. The individual abstracts are now one third longer on the average than they were 10 years ago.

Major changes have also taken place in the relative importance of different branches of chemistry. Papers on organic chemistry now outnumber inorganic papers by four to one. Within organic chemistry, the greatest relative increase has come in research on cellulose.

Nobel Awards

THE Nobel prizes for 1948 in medicine, chemistry and physics have been awarded to:

Medicine: Paul Mueller, research chemist for the Swiss pharmaceutical firm of J. R. Geigy Co., for discovery of the insecticidal powers of DDT.

Chemistry: Arne Tiselius of the Institute of Physical Chemistry, Upsala University, Sweden, for his invention of an apparatus to separate complex mixtures of proteins, such as blood, and for other discoveries in biochemistry.

Physics: Patrick Maynard Stewart Blackett of the University of Manchester, England, for improvement on the Wilson cloud chamber and for cosmic ray research.

Geological Institute

AN American Geological Institute is being formed by 11 scientific societies in the field of geology. It will represent the earth sciences in the same way that the recently formed American Biological Institute represents the biological sciences.

The Geological Institute will maintain an information center and serve as a point of contact between the geological professions and the government. It will be affiliated with the National Research Council. Among the 11 founding societies are the Geological Society of America, the Mineralogical Society of America, the American Association of Petroleum Geologists, and the American Institute of Mining and Metallurgical Engineers.

Television for Farm Areas

TELEVISION is growing much more rapidly than radio at a comparable stage 25 years ago. By next summer there will be transmitting stations in most large cities and receiving sets in nearly two million homes. But the short range of television transmitters, which currently have an effective radius of only about 25 miles, remains a serious limitation.

The publicized attempts to extend the radius of transmitters by rebroadcasting from high-flying planes have not been particularly successful so far. A recent effort to telecast a football game from a plane flying over Cleveland, for example, was a failure.

Another approach has been suggested to the Federal Communications Commis-

sion by Kenneth A. Norton of the Bureau of Standards' Central Radio Propagation Laboratory. Norton said that interference could be reduced and coverage greatly increased by systematic spacing of stations and by requiring all stations on a given channel to use the same amount of power and antennas of the same height.

Norton suggested that each station use 100 kilowatts of power and a 1,000-foot antenna, and that stations on the same channel be located 280 miles apart in an equilateral triangle. According to studies by the Central Radio Propagation Laboratory, such an arrangement, with the triangles properly overlapped, would make it possible to cover the principal rural areas and most metropolitan centers without interference.

Fertilizer for Fish

IN response to the twin pressures of world food needs and severe overfishing in many areas, fishery experts are now advocating the wide use of fertilizer to speed up the growth of fish. About two years ago a Scotch biologist fertilized a closed-off arm of the North Sea with superphosphate and sodium nitrate. The fertilizer greatly increased the plant food supply and the number of fish.

Similar experiments have been conducted with fresh-water fish by Earl F. Kennamer of the Alabama Polytechnic Institute. Kennamer seeded two one-acre Alabama ponds with bluegill bream. One pond was fertilized at two- to four-week intervals with 20 pounds of a nitrogen-phosphorus-potassium mixture. The other pond, not fertilized, was used as a control. At the end of the season, the treated pond yielded 200 pounds of fish averaging four to six ounces apiece—a good size for this species of pan fish. The control pond, on the other hand, yielded only 40 pounds of fish averaging one ounce each. Thus at a cost of roughly $20 for fertilizer the yield of fish was increased fivefold.

X Disease

A NEW disease about which so little is known that it is called X Disease by Department of Agriculture veterinarians is killing many cattle. It was first recognized in a dairy herd in upstate New York in 1939 and now has been found in 32 states. About one third of the animals in diseased herds become sick; 60 per cent of these die.

The first recognizable symptom is a thickening and hardening of the skin, whence the disease was first called hyperkeratosis. The mouth, tongue, throat and stomach soon become badly inflamed, with the result that the animals cannot eat. Death usually occurs in a few weeks. Only the Pacific coast states are free of the disease. Beef cattle are affected more often than dairy animals. No cure is known. The cause is suspected to be a nutritional imbalance or a poison in commercial fertilizers.

X Disease does not compare in economic destructiveness with brucellosis or mastitis. Its cost to farmers is probably no more than $4 million a year. But its rapid spread during the past decade makes it a serious threat for the future. The Department of Agriculture has started an emergency research program to identify the cause and find a cure.

Technology and Cancer

BRITISH researchers in cancer have long believed that the rise of this disease is not due simply to improved diagnosis or the aging of the population, but is in part a result of industrialization. They place the blame on new materials used in modern technology and industry which can produce cancer. This view is now gaining acceptance in the U.S., partly as a result of a U.S. Public Health Service study two years ago which proved that lung cancer was a specific hazard of the chromate industry.

Last month, accordingly, the National Cancer Institute initiated a comprehensive new program of research on this problem. It established an Environmental Cancer Research Laboratory at the Georgetown University Medical School. Other studies in the program are under way in Ohio, New Jersey and New York, where a joint Occupational Cancer Committee has been set up by industry and the state government.

The list of suspected carcinogens among modern materials is long. In addition to chromates and petroleum hydrocarbons, it includes nickel carbonyl (a widely used catalyst), arsenicals, asbestos, benzol, amines, creosote and other wood-tar products, and dye intermediates. Many other materials may also be carcinogenic. Charles S. Cameron, medical director of the American Cancer Society, told a meeting of the Society last month that it "cannot be categorically denied that pollution of the air by smoke, chemically treated water supplies and other artificial impediments of modern living may increase the incidence of cancer."

Mission to Liberia

DURING the late war the President of Liberia, William S. Tubman, asked President Franklin D. Roosevelt for American help in improving the health of the Liberians. At the time large numbers of American troops were stationed in or passing through Liberia en route to the North African front. Roosevelt responded to the appeal by sending a U.S. Public Health Service mission. Senior Surgeon John B. West, the mission chief, has now reported on the results of the mission. The report is a demonstration of what can be accomplished by even a small group of experts in a so-called backward tropical country.

In three years, the mission effected a virtual revolution in Liberia's health. At the time of the mission's arrival, Liberia, with a population of two million, had a total of about 200 hospital beds, six doctors and four nurses with first-class training. Some of the hospitals were without a physician. Only two rubber company hospitals were reasonably well equipped. The annual government appropriation for public health was only $40,000. Malaria, venereal disease and helminthiasis (an intestinal worm disease) were widespread.

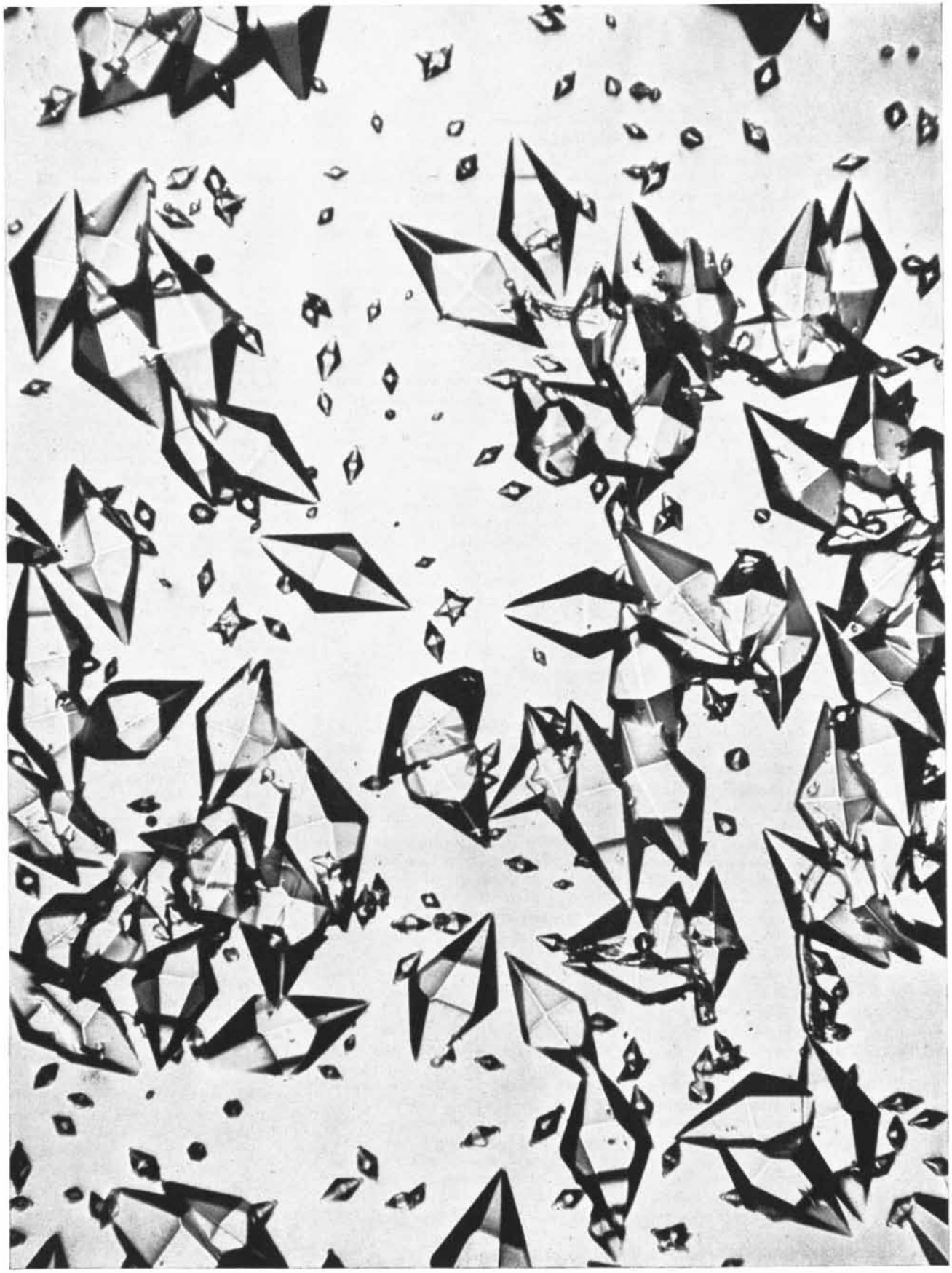
The mission concentrated its first efforts on Monrovia, the capital, near which was located the major American air base. An intensive DDT-and-drainage program reduced the incidence of malaria by nearly 95 per cent. By cutting the fly population in half, it also lowered the incidence of intestinal disease. A simple chemical treatment all but wiped out helminthiasis. The success of the attack on veneral disease so impressed the Liberian Government that it appropriated funds for compulsory periodic examinations and free treatment for the entire population.

The mission organized the first clinical laboratory Liberia had ever had. It launched a program to train Liberians in mosquito control. The U.S. State Department sent a mission to start nursing education. These educational activities grew into the Tubman National Institute of Medical and Allied Sciences. Because there are few college graduates in Liberia, the courses are geared to the needs of high-school graduates. Although the program is far below European or American standards, it has proved an effective stepping-stone between jungle witchcraft and modern medicine. Meanwhile, the mission has sent back to American laboratories for study a steady stream of specimens of tropical disease.

Meetings in January

SOCIETY of Automotive Engineers. Annual meeting. Detroit, January 10-14.

American Physical Society. New York City. January 27-29.



A PURE ENZYME is isolated as crystals. The crystals shown here are pepsin, the enzyme that breaks down proteins in the stomach. The laborious process of isolating a few such crystals was first accomplished in 1930 by J. H. Northrop of the Rockefeller Institute at Princeton, N. J. Here they are enlarged 180 diameters.

ENZYMES

They are the catalysts of life. Long known for their ability to turn sugar into alcohol, they engineer a host of other biochemical reactions

by John E. Pfeiffer

SOME three million of your red blood cells die every second. Or, to look at it another way, three million red cells are born every second, because the body continuously calls up reserves to keep the total count the same. The entire red-cell population is replaced in about three months, and cycles of birth and death turn even faster among the molecules in the plasma of the blood. Cell-free plasma contains countless protein molecules; every four weeks all of them have disappeared. They have been broken down and new molecules have been rebuilt at the precise rate needed to keep the body functioning efficiently.

This rapid molecular turnover goes on in relatively solid tissues as well as in the circulating blood. Deposits of fat, which were once believed to serve as warehouses for the storage of food reserves, are more like department stores during the Christmas rush. They seethe with biochemical activity, decomposition and synthesis neatly balancing each other so that within a few months entirely new fat deposits are created. The same goes for connective tissue, tendons and ligaments, blood-vessel walls, muscles. Swift changes occur even in the bones as the links of molecular chains are split and welded again in the ceaseless round of metabolism.

These facts, many of them determined by the modern technique of labeling molecules with isotopic tracers, were not known to earlier biologists. They conceived of the body as a machine. Food was the fuel, and the energy of combustion kept the machine going. All of this took place within tissues that had to be repaired from time to time as they wore out. Otherwise they were relatively firm and unchanging structures. When the body was active, of course, it needed extra resources of energy, but during rest metabolism idled until the next spurt of activity. Biologists now know that the actual situation is far different: living things must work ceaselessly merely to exist.

So life is more like a whirlpool than a machine. There is nothing machinelike about the vortex formed when water spirals downward. In one sense, an entirely new whirlpool comes into being every few seconds as the rotating center replenishes itself from the surrounding waters. But through it all the form does not change. The position of the vortex, the space it occupies, the shape of the spinning funnel, preserve their integrity over long periods of time; the system has an identity and structure of its own. Similarly the human body and every other organism known to be is a vortex of continual change.

Yet the cycles of breakdown and synthesis proceed in the face of an apparent paradox. The great majority of biochemical reactions do not take place spontaneously. When they are tried in laboratory glassware, most chemical constituents of life combine or decompose at a rate far too slow for the pace of metabolism. The average protein must be boiled for 24 hours in a solution of 20 per cent hydrochloric acid to be thoroughly broken down. The body does the same thing in four hours or less, and without high temperatures and strong acids.

The phenomenon that makes life possible is catalysis—the action of certain substances that speed up chemical reactions thousands of times without themselves being changed. Industrial chemistry uses catalysts in the cracking of petroleum, in the synthesis of ammonia, and in many other processes; organisms use them to help build tissues and to degrade foodstuffs to simpler materials, as in the case of the four-hour breakdown of proteins. The catalysts of life are called biocatalysts, or enzymes, and the rise of biology has come with an increased understanding of what they are, what they accomplish, and how they work.

Enzymes are unaffected by the reactions that they work; they are destroyed only by wear and tear or poisoning. They operate in amazingly small concentrations. A single cell has been estimated to contain about 100,000 enzyme molecules to accelerate its 1,000 to 2,000 chemical reactions—an average of only about 50 to 100 molecules for each process. A single molecule of the enzyme that splits hydrogen peroxide into water and oxygen (and creates the white foam when the antiseptic is placed on a wound), can transform more than 5 million peroxide molecules a minute. Other enzymes transform from 1,000 to more than 500,000 molecules in the same time.

Investigation has shown that these biochemical middlemen play a significant role in every vital process. They are key substances in the photosynthetic reactions that build plant tissues from water, carbon dioxide and sunlight. Enzymes turn leaves red and yellow in the fall, make the freshly cut surface of an apple or potato brown, convert grape juice into wine, and grain mash into whiskey. But the chemical processes in which they participate are so obscure that it has taken centuries to elucidate a few fundamental principles, and every month new facts are published which promise to alter many currently accepted ideas. Although perhaps as much as three quarters of our knowledge has come within the last 40 years, some of the first scientific studies of enzymes were made in the 18th century in connection with the study of digestion.

Early Advances

Until early in the 18th century men believed that the digestive system was a kind of meat grinder that accomplished digestion by contracting vigorously and rubbing food particles together. This was disproved when the French scientist René de Réaumur made a falcon swallow pieces of meat enclosed in a perforated metal tube to protect them from stomach friction. When Réaumur pulled the tube up a few hours later, he found that the tube was intact but that the meat had been digested. Lazaro Spallanzani, an Italian physiologist, performed roughly similar experiments on hawks—and later on himself!—using wire cages instead of tubes. In a treatise published in 1780, he suggested

that food is decomposed by substances in the gastric juices. One of the substances was found to be hydrochloric acid. In 1835, the German physiologist Theodor Schwann discovered a non-acid substance in gastric juice which he called "pepsin." But although it had been named, pepsin was still a chemical mystery.

The next advance in enzyme research came 25 years later, when the French Government commissioned the great Louis Pasteur to investigate a national catastrophe: the mysterious souring of entire batches of fine wine. Pasteur showed that the souring never took place under sterile

DE RÉAUMUR (1683-1757) **fed falcons meat in tubes to show friction was not the only agency of digestion.**

conditions; he proved that it was a "disease" caused by bacteria that produced lactic acid. This work led him to a thorough investigation of the entire process of alcoholic fermentation, first in wine and later, after France had been defeated in the war of 1870, in beer, to benefit "a branch of industry wherein we are undoubtedly surpassed by Germany." Pasteur discovered that fermentation was "life without oxygen": the work of yeast cells digesting sugars for their own nourishment.

Pasteur was a vitalist, believing that biological phenomena were the result of non-physical forces, and he went beyond the evidence of his experiments. The experiments informed him that living cells were capable of producing fermentation; from this he jumped to the incorrect conclusion that *only* living cells could accomplish it. On the basis of this theory Pasteur established two categories: 1) "organized ferments," the live organisms whose metabolic processes yielded alcohol, and 2) "unorganized ferments," lifeless substances like pepsin that could be isolated from living cells.

This terminology, plus a lack of exact knowledge as to the chemical nature and action of ferments, led to much confusion. Some biologists argued that substances like pepsin should not be called ferments because the name properly belonged to yeast cells and other microorganisms. Others twisted the argument another way. Yeast cells were not ferments, because all organisms, including man, harbor intricate chemical processes, and surely a man was not a ferment!

In 1878, to provide at least a semantic solution to the controversy, the German physiologist Willy Kühne suggested the new name "enzyme." Literally translated, the word means "in yeast," but Kühne suggested it for unorganized ferments, the substances that had already been known to exist apart from yeast. Thus until 1897 biologists had two words—"enzymes" for substances such as pepsin, and "ferments" for the processes in the living organism.

Then the distinction, and many of the vitalists' arguments, were broken down by a lucky accident in the laboratory of Eduard Buchner, another German scientist. Buchner wanted to determine whether cell-free yeast extracts had any medical value, and to obtain such extracts he had to kill the yeast organisms. First he ground yeast cells to a pulp in a mixture of quartz sand and fine abrasive. Then he put the material in a canvas bag and subjected it in a special hydraulic press to pressures up to 7,500 pounds per square inch. Finally he collected the juice that trickled out.

At this stage of the work Buchner was not concerned with ferments, enzymes or scientific debates. His problem was to preserve the extract for lengthy experiments with laboratory animals. One of the methods he attempted was adding large amounts of sugar to the extracts. This failed to produce the result he wanted. In fact, the mixture soon reacted to form alcohol; fermentation occurred in the absence of living yeast cells. This accidental finding ultimately won Buchner a Nobel prize. It demonstrated that there was no longer a need for the two words ferment and enzyme. They were the same.

But Buchner's experiment did not satisfy the vitalists. For 30 years some of them continued to dispute Buchner's findings. The vitalists also found new arguments in other experiments; enzymes are often entangled with philosophy. Ironically, one of the most ingenious and painstaking biochemical experimenters, Richard Willstätter of Munich, did as much to obscure as to clarify the nature of biocatalysts. Again it was chiefly a matter of concluding too much from too little.

The German investigator set out to determine the chemical structure of enzymes. Colloidal particles such as enzymes adhere to finely divided powders of China clay and other substances. By patiently filtering and centrifuging such powders and their attached particles, Willstätter succeeded in obtaining relatively pure enzymes. But his method was wasteful; to isolate one enzyme he began with about 20 pounds of brewer's yeast and lost 91 per cent of the enzyme it contained in the process. His final solutions were so dilute that experiments to reveal the nature of the purified enzyme yielded only negative results. Yet, sadly, the negative findings were used to draw positive conclusions.

Willstätter did not know—and apparently he did not consider the possibility—that certain substances are biologically active at concentrations of one part in a thousand million million. Their identification lay far beyond the sensitivity of his chemical tests. So Willstätter announced that enzymes were substances of a composition unknown to chemists. In 1925 one of the leading enzyme texts took up the theme in a section called "Enzymes Not Proteins" and, citing the German findings, went on to indicate that they were not carbohydrates or fats either. Conclusions of this kind were pleasing to the vitalists, but they were of little help in the further understanding of enzymes.

"The First Enzyme"

Yet the year after the textbook was published the first enzyme was obtained in pure form and identified chemically. For nine years James B. Sumner of Cornell University had worked to isolate an enzyme from the jack bean. The enzyme was urease, which decomposes the metabolic

SPALLANZANI (1729-1799) **swallowed meat in tiny cages to prove that it was digested by gastric juice.**

waste product, urea. Urease, like many other enzymes, is named after the substance on which it acts. Willstätter's results had often been cited to persuade Sumner that he should choose a more promising project, but the work went on despite occasional financial pinches and inadequate equipment. (In those early days Sumner used an old-fashioned coffee mill to grind the beans, and a window

ledge as a refrigerator.) The problem was to find a solvent that would dissolve urease and not other chemicals, and a substance that would then precipitate the enzyme.

The final process was, in Sumner's words, "absurdly simple." One day in April of 1926 he mixed jack-bean meal with acetone, a solvent that had been suggested by his former biochemistry professor at Harvard, and allowed the solution to filter overnight. Next morning he examined a drop of the filtrate under the microscope and saw something he had not seen before—tiny octahedral crystals.

PASTEUR (1822-1895) found that yeast cells were responsible for fermenting batches of fine French wine.

Then he centrifuged the crystals out of solution, concentrated them and found that the new solution possessed very strong urease activity. That afternoon Sumner telephoned his wife with the news that was to win him a Nobel prize 21 years later: "I have crystallized the first enzyme."

Urease turned out to be a protein with a molecular weight of 483,000. (One unit of molecular weight equals the weight of one hydrogen atom.) Despite Willstätter's bitter disagreement, the fact was confirmed. Researchers finally had positive evidence that the elusive substances they were attempting to purify were proteins.

But there is no single process for the crystallization of all enzymes. Aside from the useful guide that the experimenter should work with large amounts of material, at least several grams and several hundred grams if possible, each enzyme calls for special chemical techniques. Urease, once the correct procedure had been found, was easy to isolate. But to purify pepsin John H. Northrop of the Rockefeller Institute for Medical Research in Princeton, who with Wendell M. Stanley of the same institution shared the 1947 Nobel prize with Sumner, needed a far more complex process. He announced the method in 1930, nearly a century after pepsin had been named by Schwann.

The process began with a dilute preparation of crude pepsin, and involved five exceedingly sensitive precipitations. The delicacy of the technique was dictated by the very nature of proteins. Each protein is built up of amino acids, which come in 20-odd varieties and are relatively simple in structure. The proteins they form, however, are the most complex molecules known to chemistry. Amino acids can be hooked to one another in millions of different ways. They may form long structures called peptide chains, but biochemists have not yet learned the exact arrangement of the links in the chains or of the chains in the protein molecule. The magnitude of the problem is indicated by the fact that a single molecule of the pancreatic hormone insulin contains more than 400 amino-acid units, while other proteins contain as many as 125,000.

One of Northrop's chief problems was to precipitate proteins without destroying them. Protein molecules may exist as tiny spheres wrapped around by peptide chains, as amino acids strung out in delicate branches, or as a latticework of criss-cross strands. Since protein structures are maintained by a balance of electrical forces between atoms, a slight chemical shift in their environment may distort them into tangled masses which cannot be restored to the original patterns—which happens when an egg is boiled and the white coagulates.

This "denaturing" is one of the pitfalls in the crystallization of pepsin. Northrop's successful precipitation technique was used at the Rockefeller Institute in Princeton by Wendell M. Stanley to isolate the tobacco-mosaic virus, and by M. Kunitz to crystallize several enzymes. Of the 40-odd enzymes isolated to date, all are proteins.

The Work of Enzymes

The fermentation of sugar, yielding alcohol, is an admirable illustration of the detailed chemical processes engineered by enzymes. In the days when Buchner thought his cell-free yeast juice contained the single enzyme zymase, the glucose-to-alcohol reaction was represented by the following uncomplicated formula:

$$C_6H_{12}O_6 \xrightarrow{\text{zymase}} 2\ CO_2 + 2\ CH_3CH_2OH$$

This is a chemical statement to the effect that one molecule of glucose, catalyzed by zymase, yields two molecules of carbon dioxide and two of ethyl alcohol. But if fermentation were such a single-step process, it has been calculated, most of the resulting energy would appear as useless heat. Actually fermentation directly involves at least 12 enzymes—and it took hundreds of research workers from more than a dozen countries to unravel nature's scheme for altering glucose.

The molecule of glucose is built around a chain of six carbon atoms, the splitting of which is a crucial step in the fermentation process. Before this step can be taken, however, glucose must be suitably prepared for its destruction. Three enzymes transform glucose for the splitting, and nine more are involved in the remaining steps which lead to ethyl alcohol. This outline of the process is a poor reflection of the detailed chemical processes that propel it. These are presented in greater detail by the drawing on page 34.

This splitting of the carbon chain of glucose involves one of the most significant of all biochemical cycles. It requires a large amount of chemical energy, and the source is adenosine triphosphate, or ATP. The energy is obtained from one of ATP's potent phosphate groups, indicated by the two right-hand Ps in the following simplified formula:

Adenosine—Ⓟ ~ Ⓟ ~ Ⓟ

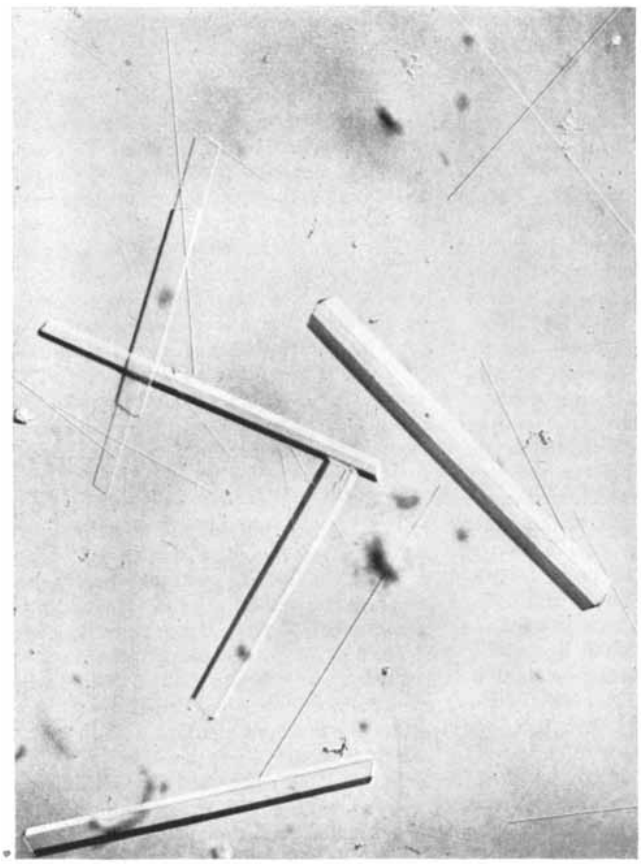
The two right-hand phosphate groups are attached by chemical bonds which yield 12,000 calories of energy when they break. (The left-hand group yields only 2,000 calories.) The bonds may be considered a sort of "cement" of electrons holding the phosphate groups. Oscillating back and forth at high speed, the electrons endow the phosphate groups with an extra reactivity. The specific usefulness of ATP is that enzymes can transfer its phosphate groups to other substances—along with the energy of their oscillating bonds.

The energy that drives the cycles of fermentation is first obtained by splitting off the right-hand phosphate group and

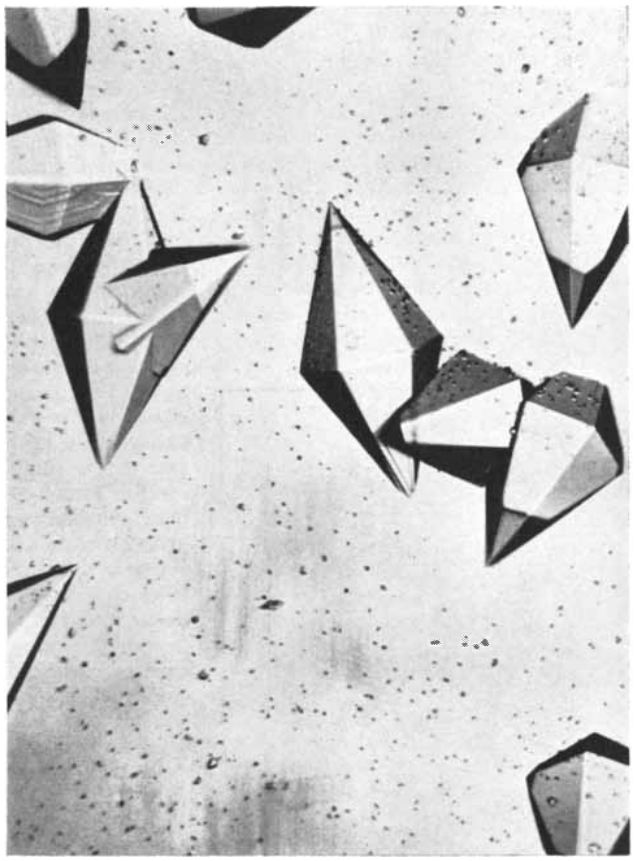
BUCHNER discovered in 1897 that lifeless juice of yeast cells had power to ferment sugar to ethyl alcohol.

attaching it to glucose; this step, catalyzed by the enzyme hexokinase, leaves adenosine diphosphate (ADP) and a glucose phosphate which is catalyzed to a fructose monophosphate. Transforming this latter substance to fructose diphosphate means splitting another section from another ATP molecule.

At this stage the process leaves two ADP molecules wandering about with



HEXOKINASE, an enzyme involved in the fermentation of sugar, was crystallized in 1946 by M. Kunitz and M. R. McDonald of Rockefeller Institute in Princeton.



ACETYL PEPSIN is a modified form used in the study of pepsin activity. It was crystallized in 1934 by R. M. Herriott and J. H. Northrop of Rockefeller Institute.

missing groups. Unless they are rebuilt as ATP, the entire cycle will grind to a stop. The deficit is made up during the next steps of fermentation when the six-carbon chain is finally split and two inorganic (non-ATP) phosphates are taken up into an intermediate compound. These inorganic phosphates, however, are low in energy content, and ATP will only accept the high-energy variety. The cell therefore uses an enzyme called triosephosphate dehydrogenase to remove two hydrogen atoms, which transform low-energy phosphates into high-energy phosphates.

The potent phosphate groups are then split off by another enzyme and attached to the two dismembered ADP molecules, forming ATP. The energy supply is thus sustained—but the cell does better than that. During the next stages two extra high-energy phosphate groups are created and passed back to other ADP molecules. This bonus may be used to accelerate fermentation or to provide the energy needed for the growth and reproduction of yeast cells.

There is still one biochemical loose end. During the manufacture of high-energy phosphate bonds, two hydrogen atoms have been lost. These are picked up by a special hydrogen carrier called coenzyme I. This substance now cannot participate in later reactions and, again, the entire cycle would break down unless it included a mechanism for freeing coenzyme I of its hydrogen. The opportunity comes at the very last step of fermentation, after pyruvic acid has been converted to acetaldehyde and carbon dioxide. Carbon dioxide goes off as a gas. Acetaldehyde, which remains, is just two hydrogen atoms short of being ethyl alcohol, the final product of the fermentation. The missing atoms are naturally presented by the hydrogen-bearing coenzyme I, and the latter is restored to perform its function.

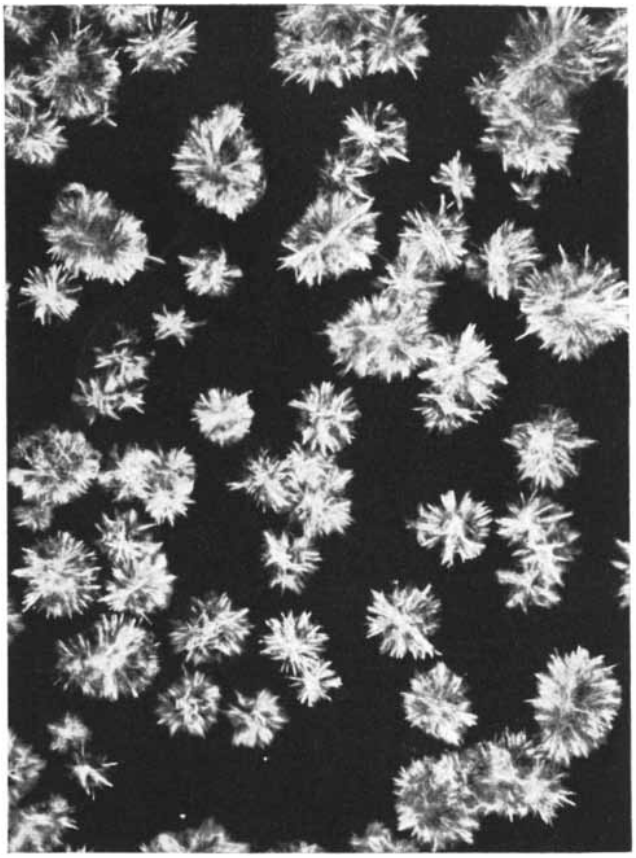
Enzymes and Muscles

This completes the fermentation process and some of its interrelated systems. Ethyl alcohol can then be taken internally and used to interfere with human enzyme systems. Incidentally, for every 99 parts of ethyl alcohol, yeast produces one part of fusel oil, a mixture of various higher alcohols which is not only responsible for most of the flavor of liquor but also for hangovers.

While some biologists traced the intricate cycles of fermentation, others studied the mechanism of muscle. Gradually, first from fragments of evidence and finally from an imposing structure of knowledge, both groups began to realize that the workings of yeast and muscle cells were very much alike. In fact, the processes that change malt and hops to beer, and those that provide the energy for an Olympic sprinter have 14 steps—and 11 of the 14 are exactly the same for the two types of process. The workings of the great ATP cycle and the wheel-within-a-wheel coenzyme I cycle are the same in both cases. One important difference is that in muscle contraction pyruvic acid is broken down to lactic acid instead of ethyl alcohol. The lactic acid is then carried by the bloodstream to the liver, where the reverse of the 14-step process builds it into animal starch, or glycogen. (Muscles cannot utilize glucose.) Another important difference is that the breakdown of glycogen yields three instead of two "bonus" ATP molecules. Muscles attain an efficiency of 60 per cent or better, as compared with the 50 per cent efficiency reached in modern steam turbines.

ATP not only supplies energy in muscle contraction, but also plays an important role in the workings of the nervous system. Nerve cells build up one of their essential chemicals, acetylcholine, with the aid of the enzyme choline acetylase, and the synthesis requires energy from ATP. Recent studies at Johns Hopkins University suggest that ATP is also the energy source for the reaction that enables fireflies and other organisms to produce light. That it may also be associated with the enzyme systems necessary for the movement of single-celled organisms is indicated in at

GAMMA CHYMO-TRYPSIN is one of several enzymes produced in the pancreas that have function of breaking down proteins. It was crystallized in 1938 by M. Kunitz.



RIBONUCLEASE is another pancreatic enzyme that has the specific function of breaking down a protein in yeast. It was crystallized in 1940, also by M. Kunitz.

least one case. the wriggling of sperm towards the unfertilized egg.

How They Function

Water is the medium for the majority of biochemical processes. In water the molecules of life are in ceaseless thermal motion, occasionally reacting when they collide with one another. Essentially the function of an enzyme is to increase the rate of reaction. In a solution without enzymes the chance that a molecular collision will result in a reaction may be a trillion to one. If the appropriate enzyme is present, the probability will be much increased. To use the gambling term, enzymes lower the odds. The question is how they perform this mathematical feat by chemical means.

Any explanation of the phenomenon must account for certain experimental facts. One of the most obvious is that a given enzyme does not speed reactions among all the molecules of protoplasm. If this were the case, the result would be biochemical chaos. Actually enzymes are highly specific, producing reactive collisions only among the molecules of selected compounds. These compounds are generally known as substrates.

A spectacular example of enzyme specificity involves molecules that are made up of exactly the same atoms in different structural arrangements. Such close chemical relatives are known as isomers. In 1860 Pasteur discovered that tartaric acid, a by-product of wine fermentation, exists in two forms. When a beam of polarized light was transmitted through crystals of tartaric acid, some crystals turned the plane of polarization to the right, while others turned it to the left by exactly the same amount. Since both types of tartaric acid are identical in chemical composition, the difference must be in the arrangement of their atoms.

It has been shown that such pairs of crystals—called dextrorotary and levorotary—are found among many compounds, and are related to one another as an object to its mirror image or as a right-hand to a left-hand glove. Enzymes can make the subtle distinction between isomers. The muscle enzyme lactic dehydrogenase, for example, acts on levorotary lactic acid but has absolutely no effect on its mirror image, dextrorotary lactic acid.

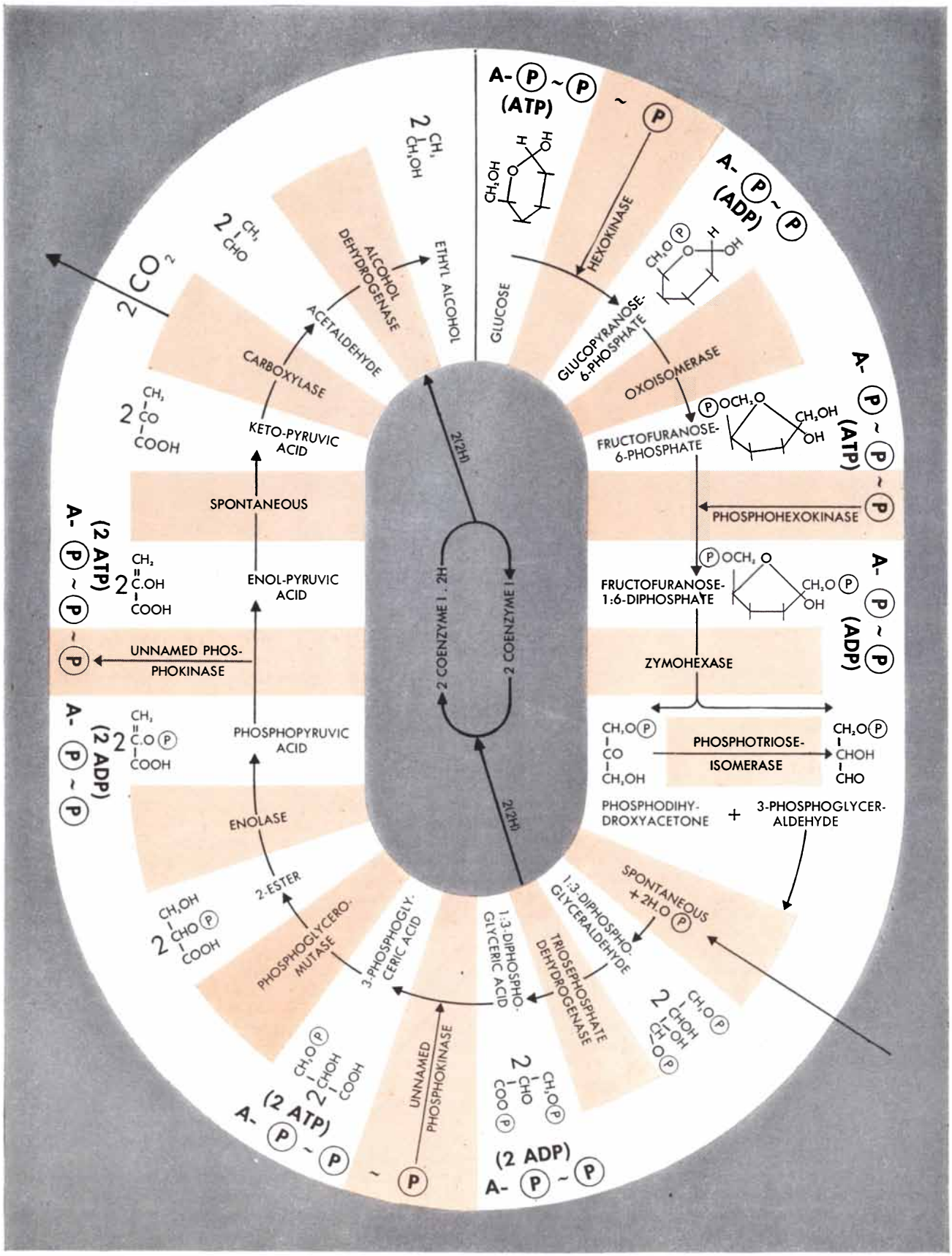
Some enzymes are even more selective. The so-called hydrolytic enzymes, as an example, are involved in the following general type of reaction:

$$A—B + H_2O \longrightarrow AOH + BH$$

Here A—B represents a molecule consisting of two parts connected by a chemical linkage. Some enzymes will break down any molecule with a particular linkage regardless of the nature of the linked structures; others demand not only the right linkage but also the right part, say the B structure. Still other enzymes, the most specific of all, operate only on molecules that satisfy the three-way requirement that both the A and B parts and their linkage must be of a particular kind.

A more detailed explanation of what specificity means is furnished by the phenomenon of competitive inhibition. The enzyme succinic dehydrogenase catalyzes the breakdown of succinic acid and nothing else. Its effectiveness is considerably reduced, however, if malonic acid, the structure of which closely resembles that of succinic acid, is added to the solution. Experiments show that malonic acid, while not being changed itself, apparently attaches itself to the enzyme and takes it out of circulation by occupying a position on its molecule that would normally be filled by succinic acid. In other words, malonic acid seems to compete with succinic for an active region of the enzyme molecule.

These and other experiments suggest an attractive analogy to explain specificity. It is a theory which some protein chemists label "philosophy," although they concede that philosophy can be useful. The enzyme molecule can be visualized as a "lock" with notches and indentations of a particular pattern; the substrate molecule, in this case succinic acid, is the



GLUCOSE-TO-ALCOHOL cycle involves 14 known steps and 12 enzymes. Latter are indicated in brown. Opening steps attach phosphate groups of adenosine triphosphate (ATP) to glucose, leaving adenosine diphosphate (ADP). Cycle also takes in other phosphates (*arrow at lower right*), finally surrenders all of them to rebuild two extra ATPs from ADP. Cycle in center carries hydrogen atoms until they are needed in last step.

"key," and its configurations mesh into the enzyme pattern. Malonic acid, a very similar key, will fit the lock, but not perfectly. The fit is good enough to keep out succinic acid, but not good enough to unlock the door—hence the door stays closed. Perhaps the most brilliant experimental evidence for such a concept, adduced by E. S. G. Barron and his associates at the University of Chicago, involves three closely similar substances: acetic acid, monofluoroacetate and monochloroacetate. The only difference among them is that one hydrogen of acetic acid is replaced by a fluorine atom in monofluoroacetate, and by a chlorine atom in monochloroacetate. The effect of this substitution is shown in the drawing at the bottom of page 37. The links between each of the three atoms and the rest of the molecule to which they are attached are of different length. For hydrogen the link is 1.09 Angstrom units (one Angstrom unit equals one hundred millionth centimeter); for fluorine it is 1.41 A.; for chlorine it is 1.76 A.

An enzyme catalyzes the oxidation of acetic acid (a process involved in fat metabolism) and presumably its molecule contains "notches" into which the acid fits. The addition of monofluoroacetate to the solution completely inhibits the oxidation, meaning that this compound also fits the enzyme molecule. Monochloroacetate, however, appears not to fit, for it has no effect on the enzyme's ability to oxidize acetic acid. In other words, the tiny difference in length between the link of the fluorine-containing inhibitor and that of the ineffective chlorine compound (.35 A., or about 1/762,000,000 inch) is enough to prevent a sufficiently close lock-key fit.

Fitted Molecules

The lock-key theory implies that there is some sort of fleeting union between enzyme and substrate, an implication which has been backed by many experiments. As a matter of fact, the spectroscope has permitted biologists to "see" the union taking place. This was attempted for the first time 12 years ago by Kurt G. Stern, then at Yale University. Using the enzyme catalase and a hydrogen peroxide derivative as substrate, he observed first the spectral light pattern characteristic of catalase and then a new pattern, presumably that of the enzyme-substrate union. A short while afterward, however, the original catalase spectrum appeared again, indicating that the enzyme had performed its duty and was ready for more work.

What is the purpose of the brief combination of an enzyme with its substrate? The answer to the question hinges on a fact mentioned earlier: that not all collisions between molecules produce chemical reactions. In a 100-cubic-centimeter solution of ethyl bromide and diethyl sulfide, for instance, there are 1.6×10^{34} (16 million billion billion billion) collisions a second, but fewer than one out of every billion billion collisions results in a chemical reaction. The reason for this low proportion of successful hits is that molecules are relatively stable structures, and most of them bounce off each other a bit jarred but essentially unscathed.

Now enzymes do not increase the speed of molecules in solution, nor do they increase the frequency of collisions. Instead they increase the number of fruitful collisions by weakening the structure of substrate molecules so that they react more readily. In combining briefly with its substrate (in the case of catalase the combination lasts less than one 85,000th of a second), an enzyme somehow distorts the architecture of the substrate molecule, converting it from a relatively stable to a highly reactive state. There is evidence that in some cases this effect is achieved by removing electrons and transforming the substrate molecule into a charged ion.

Chemical changes, however, do not necessarily take place simply because a substrate molecule has fitted itself into its enzyme mold and has been activated. With certain enzymes like pepsin, to be sure, this two-molecule union seems to be sufficient for completion of the substrate-converting process. But more often than not a third substance that is not a protein is an added requirement. Catalase, peroxidase and other enzymes seem to have such accessory substances more or less permanently attached to their proteins. These substances are therefore called "prosthetic groups." Many enzymes, however, apparently require only that the accessory substances be available in solution as so-called coenzymes. This field of inquiry is one of the most active and controversial in enzyme research, and the entire question of enzyme auxiliaries needs considerable clarifying. This much is known: in most enzyme processes the protein alone is not enough to speed chemical reactions. Unless coenzyme I is present in the alcohol fermentation system previously described, the process breaks down, and many other coenzymes have been discovered.

Taking a three-way, enzyme-coenzyme-substrate reaction as a case in point leads to the following rough sketch. The enzyme and its substrate combine in such a way that the molecular structure of the substrate is distorted sufficiently to increase its susceptibility to change. Almost simultaneously the enzyme may attract a coenzyme molecule to one of its unoccupied parts. A reaction between coenzyme and substrate may then occur, forming new compounds. Finally the temporary union breaks up, and the enzyme molecule is free for further action. Something of this sort happens during the first step of alcoholic fermentation, when the enzyme hexokinase synthesizes glucose phosphate from glucose and ATP. Both of these molecules are attached to a hexokinase molecule in such a position that one of the high-energy phosphate groups is transferred from ATP to glucose. Then the three-cornered union flies apart, leaving ADP, glucose phosphate and an unchanged enzyme.

Enzymes and Hormones

Even more obscure than the mechanism of enzyme action are the factors that control enzyme reactions. What is it that determines when and how quickly enzyme activities shall take place in nerve cells, muscle cells and all of the other specialized units that make up the higher plant and animal organisms?

There is reason to believe that hormones play an important part in controlling and coordinating the workings of enzyme systems. The most significant finding along these lines was made about two years ago by W. H. Price, Carl Cori and S. P. Colowick at Washington University in St. Louis. They discovered that hormones play an essential part in the enzyme system that maintains the balance between sugar in the blood and glycogen in the liver. There is a delicate equilibrium between the hormone insulin, which tends to lower the amount of sugar in the blood by promoting the storage of glycogen in the liver, and a presumed diabetogenic hormone secreted by the pituitary gland, which promotes the metabolism of glycogen and hence tends to raise the concentration of sugar. Diabetes may be the result either of too little insulin or too much of the pituitary hormone. The Washington University group suggested that this upset in hormone balance was directly connected with hexokinase, the same enzyme that initiates alcoholic fermentation.

Hexokinase is utilized in the liver to add a phosphate group to glucose, a preliminary step essential to the storage of sugar. The pituitary hormone, however, inhibits hexokinase activity. Whether it is overproduced or insulin is underproduced, the effect is the same: a relative excess of the diabetogenic hormone, subnormal storage of glycogen in the liver, and rising sugar levels in the blood. The discovery of this process is one of the first connections established between hormones and enzymes. Other hormones, including those that produce dwarfs and giants, probably influence growth and metabolism in a similar manner.

Such speculation brings us again to the notion of enzymes that can be inhibited and activated. Does the diabetogenic hormone inhibit hexokinase by providing substances that occupy strategic parts of the enzyme molecule and thus prevent it from working on its normal substrate? And does insulin counteract the inhibiting effect by removing these substances and "unmasking" the enzyme? Only further investigation can answer these questions, but it is known that the unmasking effect plays a significant role in the control of enzyme action during many biological processes. For example, pepsin, the func-

tion of which is to digest proteins, does not enter the stomach ready to act; it is secreted by the stomach walls as the inert substance pepsinogen, which is promptly converted to pepsin by the hydrochloric acid of the gastric juices. The conversion is accompanied by a drop in molecular weight from 42,000 to 38,000, and this may be interpreted as the removal of a protein fragment that masks pepsin action.

An example of mass unmasking is familiar to embryologists. An unfertilized egg cell is fully prepared for the most spectacular burst of biological energy known. It contains structural materials, ATP as a source of energy, and hundreds of enzymes that will engineer the building of a tree or a man from a tiny blob of protoplasm. The enzymes, however, are blocked, probably by specialized coatings, until fertilization takes place. Then, by an unidentified mechanism, the blocking substances are dissolved, hundreds of reactions are set off at once, and the cell begins to grow and divide.

Enzymes in Health and Disease

The patient investigation of enzyme action and enzyme control has brought added insight to a whole constellation of biological and medical problems. Enzymes not only speed the vital processes of the developing egg, but play a fascinating part in the act of fertilization. An unfertilized egg is protected by a tough coating of cells cemented with a substance called hyaluronic acid. The sperm carries the enzyme hyaluronidase specifically to break up the barrier and penetrate within.

There is evidence that the single sperm which accomplishes fertilization does not contain enough of the enzyme to break down the barrier by itself, and that the unsuccessful sperm cells must contribute their hyaluronidase. This explanation accounts for the fact that perhaps millions of sperm are necessary for fertilization, although only one penetrates the egg. Working on the theory that some cases of human sterility may be due to a lack of hyaluronidase, some physicians have recently administered extra amounts to a few selected patients and, according to preliminary announcements, normal pregnancy has resulted. Whether or not this simple treatment proves effective in a significant number of cases, any successful treatment for sterility will require an intimate understanding of the enzymes concerned.

Enzymes have also been identified with the toxins of infectious diseases. Thus *Clostridium welchii*, the rod-shaped organism most commonly found in gas gangrene, releases an enzyme called lecithinase. This destroys red blood cells by disintegrating the substance lecithin in their walls. (The same lecithinase is one of the poisons in cobra and rattlesnake venom.) The germ also liberates an enzyme that dissolves the protein connective tissue of muscle, and the "gas" of gas gangrene is produced by a group of enzymes that accelerate a pathological form of fermentation. The effects of many drugs and poisons are similarly tied up with enzyme reactions. Prostigmine, which is used in treating several diseases that paralyze muscles, strongly inhibits the enzyme cholinesterase. Strychnine also acts on cholinesterase. Cyanide affects cytochrome oxidase.

The chemical study of certain coenzymes has had unexpected medical consequences. In 1932 it was found that an essential part of the coenzyme I molecule was nicotinic acid, and three years later C. A. Elvehjem and his associates at the University of Wisconsin identified the substance as the anti-pellagra vitamin. Other vitamins definitely known to be part of coenzyme molecules include B-1, B-2 and B-6. Whether all vitamins are parts of coenzymes remains to be seen, but the possibility is particularly strong for those factors of nutrition that are needed in "trace" quantities. In amounts of less than one ten millionth of an ounce the new B-12 factor is sufficient to produce measurable rises in the blood counts of anemia patients.

Vitamins are as necessary to some harmful bacteria as they are to human life. This fact has opened the way for putting the competitive inhibition of enzymes to medical use. The possibility was discovered by accident after the introduction of sulfa drugs, though for a long while their effectiveness in curbing germs was a mystery. Then it was observed that the ability of the drugs to inhibit the growth of bacteria was considerably reduced in the presence of para-aminobenzoic acid (PAB), a member of the vitamin B complex and an essential factor in the growth of many organisms. A comparison of the molecular structures of sulfanilamide and the acid soon indicated the reason for the phenomenon.

Germs that need the vitamin presumably incorporate it into their metabolic processes as part of a coenzyme, and things go beautifully until sulfanilamide comes upon the biochemical scene. This sulfa drug is a very close chemical relative of PAB, which is the secret of its medical effectiveness. The resemblance is so close that the bacterium cannot tell the difference and takes up sulfanilamide as if it were a real food factor. By the time the mistake is discovered, the false "vitamin" has been drawn into the enzyme system and jammed the works.

Antivitamins

Sulfanilamide, the first "antivitamin," was discovered accidentally, but new drugs may be discovered by a planned offensive against this Achilles heel of bacterial metabolism. There is already quite a list of antivitamins (*see drawing on page 39*). There is also some evidence that the polio virus needs vitamin B-1, and the discovery of a B-1 antivitamin that would inhibit the virus without irreparably damaging cells is another possibility that awaits further research.

The part played by vitamins and other accessories in enzyme action also throws new light on the importance of trace elements in plant and animal life. In 1895 thousands of sheep on Australian ranches were dying of "bush sickness." Since the disease closely resembled anemia, ranchers tried feeding the animals large doses of iron. The treatment worked in some cases and not in others, the difference depending on the source of the iron.

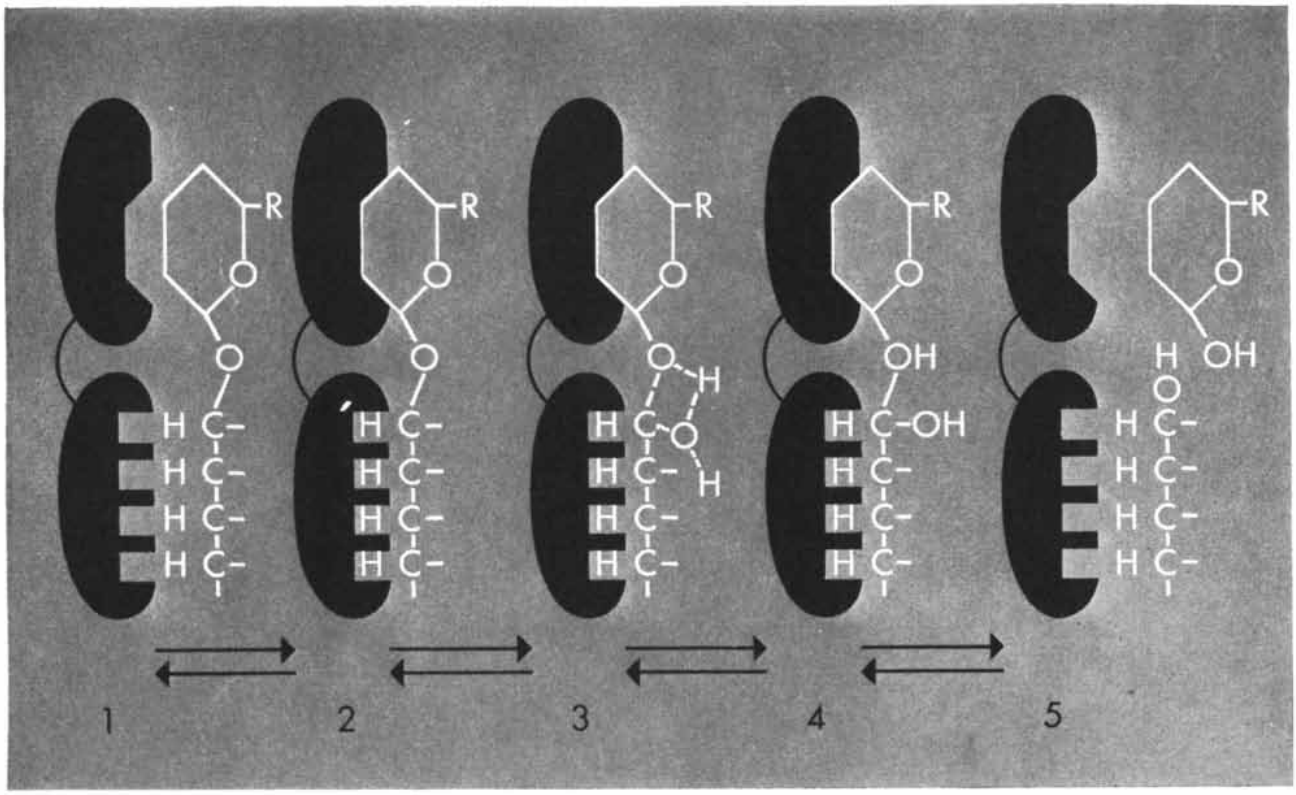
So the Australian Government imported iron ores from all over the world and compared the samples. After a series of elaborate analyses, it was found that the iron which helped to cure bush sickness contained tiny amounts of cobalt. A sheep's daily requirements were calculated, and it was found that about a millionth of an ounce of cobalt was enough to prevent the malady.

The need for such elements may be connected with the efficient working of enzyme systems, for many enzymes are known to contain or to require the presence of metallic elements in small amounts. One of the key steps in alcoholic fermentation involves an enzyme called enolase, which requires the presence of magnesium ions before it can take effect. Hexokinase, similarly, cannot work without magnesium.

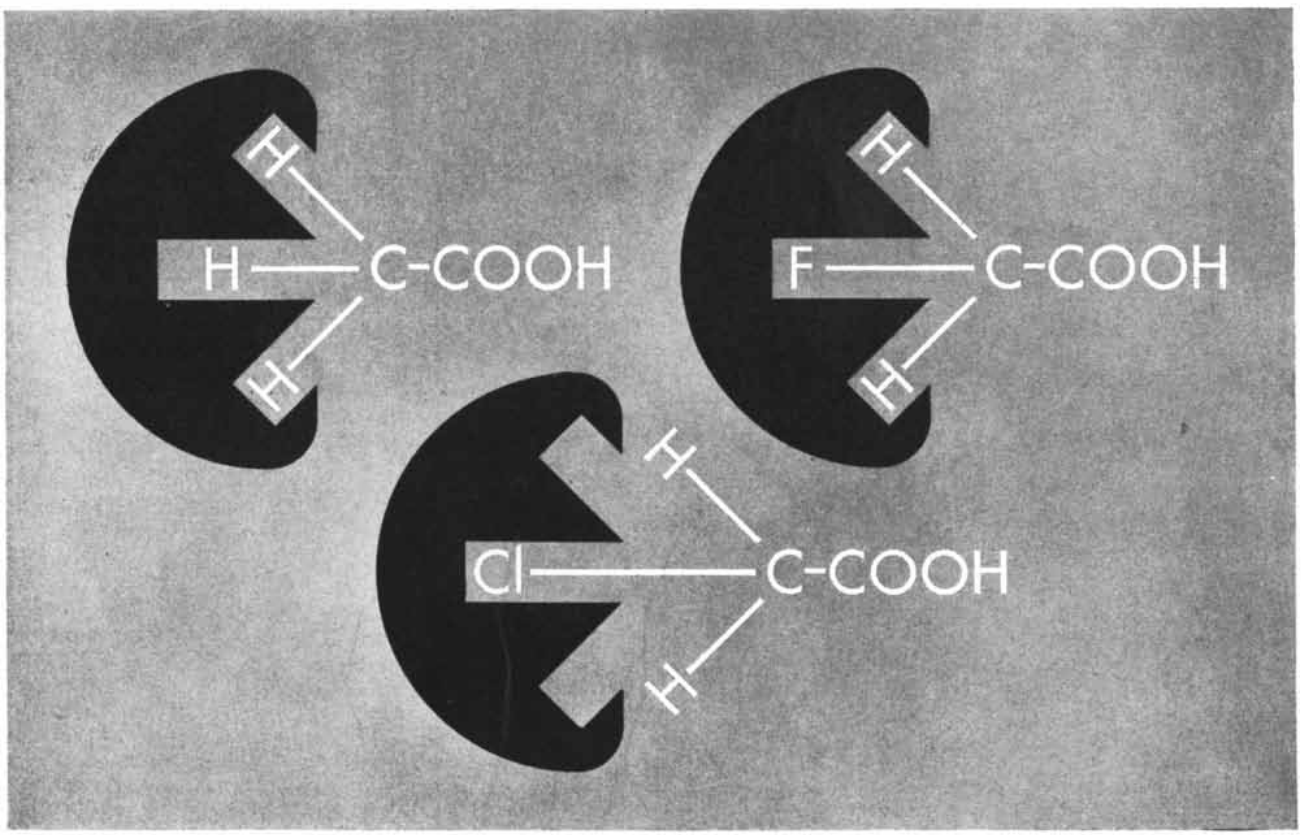
Industrial Uses

Enzymes have still other practical applications. By breeding improved strains of microorganisms and investigating their enzymes, research workers have increased the efficiency of alcoholic fermentation in the beer, wine and liquor industries. The fermentation process can also be redirected to produce industrial chemicals. Liquor chemists developed various biological methods to help relieve the severe fat shortage in Germany during the war. The Germans found that the addition of sodium bisulfite prevented yeast from transforming glucose into alcohol and detoured the process to yield glycerin. This they used in the manufacture of soap and explosives. The current potato surplus may provide extra work for bacterial enzyme systems which can break starches down to simpler compounds. An example of the latter is butyl alcohol, an industrial solvent and one of the chemicals utilized in producing synthetic rubber.

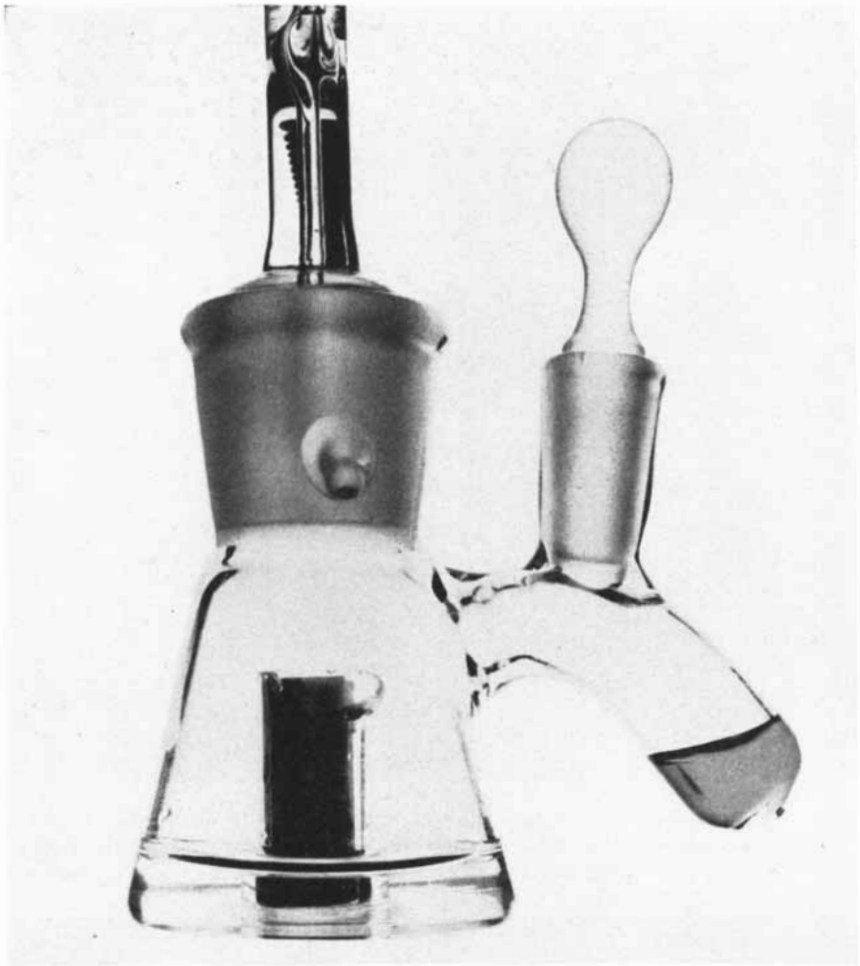
Enzymes are also used to obtain heating gas, fertilizer and many other valuable materials from sewage and industrial waste. They tenderize meat, tan leather, turn cornstarch into syrups and sugars, and help in the making of dozens of products in the cosmetic, textile and baking industries. There is even an enzyme-containing spot remover, based on the theory that protein-destroying enzymes might be effective in dissolving stubborn egg stains.



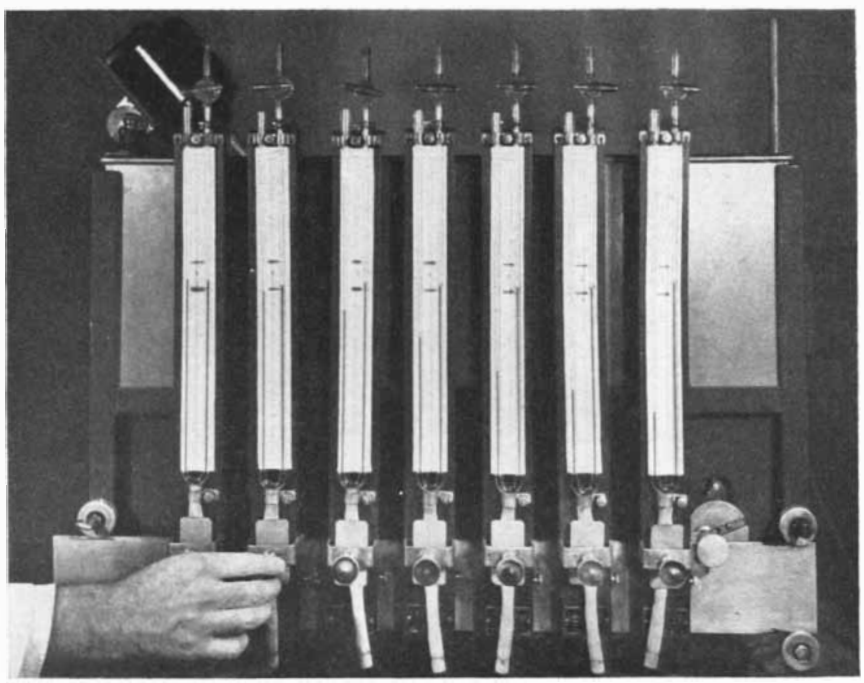
HOW ENZYME MAY WORK is illustrated by theoretical example. Here the enzyme, drawn in black, has two active parts. These fit the molecule on which they act (1). When they combine with the molecule (2), they deform it in such a way (3, 4) that it is broken down into two molecules (5), in this case a sugar and alcohol.



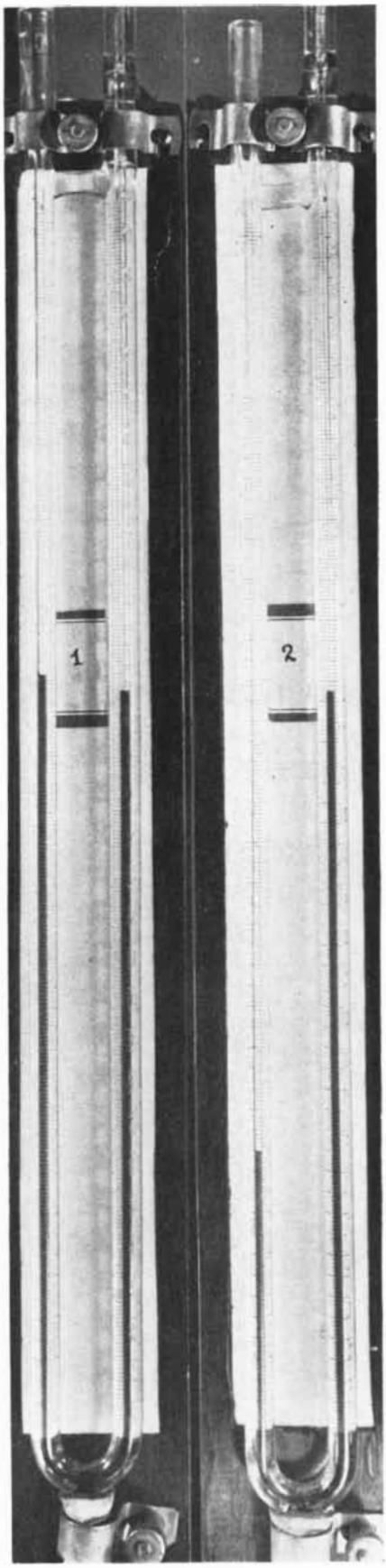
LOCK AND KEY THEORY is supported by experiment involving three similar compounds. An enzyme works on acetic acid (*left*). When one hydrogen atom of acid is replaced with fluorine (*right*), chemical bond is lengthened but enzyme still works. When enzyme is replaced with chlorine (*bottom*), the enzyme no longer works.



WARBURG APPARATUS is an important tool of enzyme research. The cup above, which is part of the apparatus, contains substrate at the bottom and enzyme at right. The two are mixed after warming in bath (*below*).



ROW OF MANOMETERS, each attached to a cup of the type shown above, moves from side to side as cups are shaken in warm bath. Manometers then measure the amounts of gas taken up by the enzyme reactions in the cups.



TWO MANOMETERS show amount of gas taken up by reaction in short time. Note drop in right manometer.

From the lofty perspective of science the fundamental problem is not industrial utility or even the artful crystallization of pure enzymes. The most challenging question is how the human body, or any organism, manufactures enzymes. An enzyme is a protein built up by the body from amino acids and peptide chains. If we assume that an enzyme may be synthesized as simply as possible, it is created when two protein fragments are pieced together by a single enzyme. If that is the process, how is the ultimate enzyme itself synthesized?

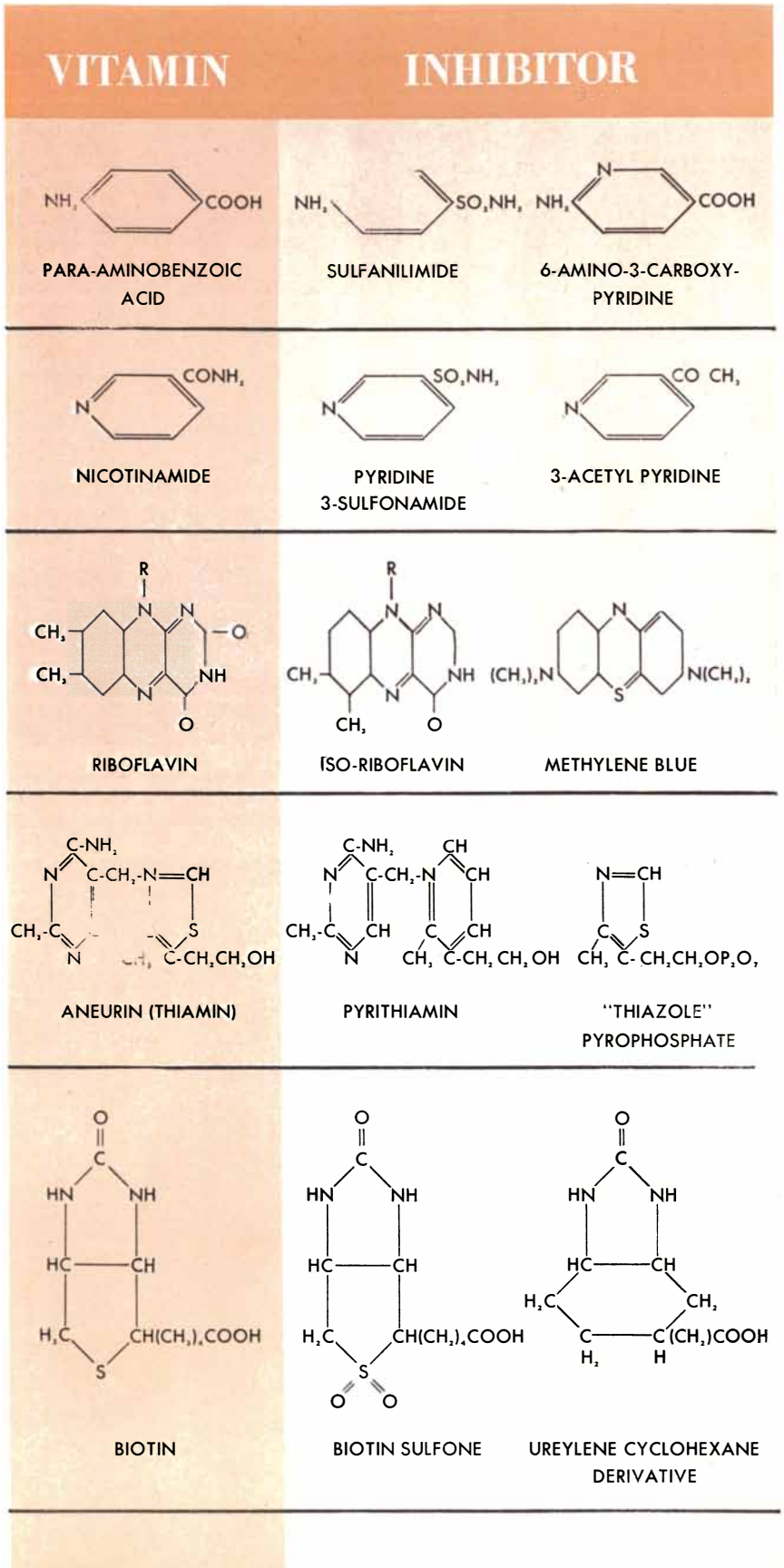
The only way of surmounting the difficulty is to assume that certain molecules are capable of forming exact replicas of themselves. This is to say that they act as enzymes for their own synthesis. This is reproduction at the molecular level. Genes, the units of heredity, have been assumed to be such substances. Viruses likewise are autocatalytic. There is some speculation that genes are the ultimate enzyme-makers.

The red bread mold Neurospora [SCIENTIFIC AMERICAN, September] is an experimental organism used in the study of this problem. In a whole series of experiments in which mutated Neurospora strains were created by ultraviolet radiation that knocked out a single gene in each case, each missing gene resulted in the organism's inability to synthesize a specific foodstuff, indicating that the heredity-transmitting molecules are directly connected with the production of enzymes. In fact, it has recently been indicated that a strain of Neurospora lacking a particular gene actually lacks an enzyme which can be extracted from strains having a full complement of genes.

To proceed from Neurospora to man, there are certain human diseases that are due to the deficiency of single enzymes. Significantly, these diseases also are inherited according to strict Mendelian laws. The lack of a single enzyme in the metabolism of the amino-acid phenylalanine is sufficient to cause a form of mental defectiveness, while another missing link in the same system is responsible for albinism. Since each of these diseases can ultimately be traced to the hereditary defect of a single gene, and the agency in each case is a missing enzyme, circumstantial evidence argues strongly for the theory that each gene is associated with the making of a single enzyme.

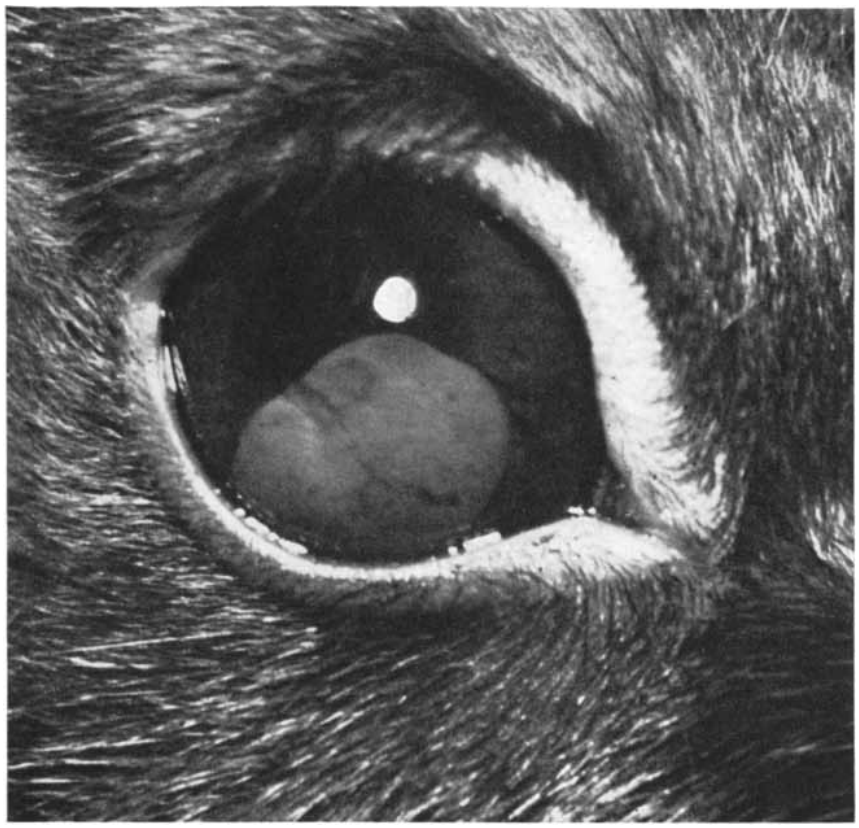
So enzymes bring us finally to the very core of the cell, and to the core of all biological problems. The solution of these problems depends more and more on our understanding of proteins, and particularly of enzymes, self-duplicating and otherwise.

John E. Pfeiffer was formerly science editor of Newsweek *and science director of the Columbia Broadcasting System.*

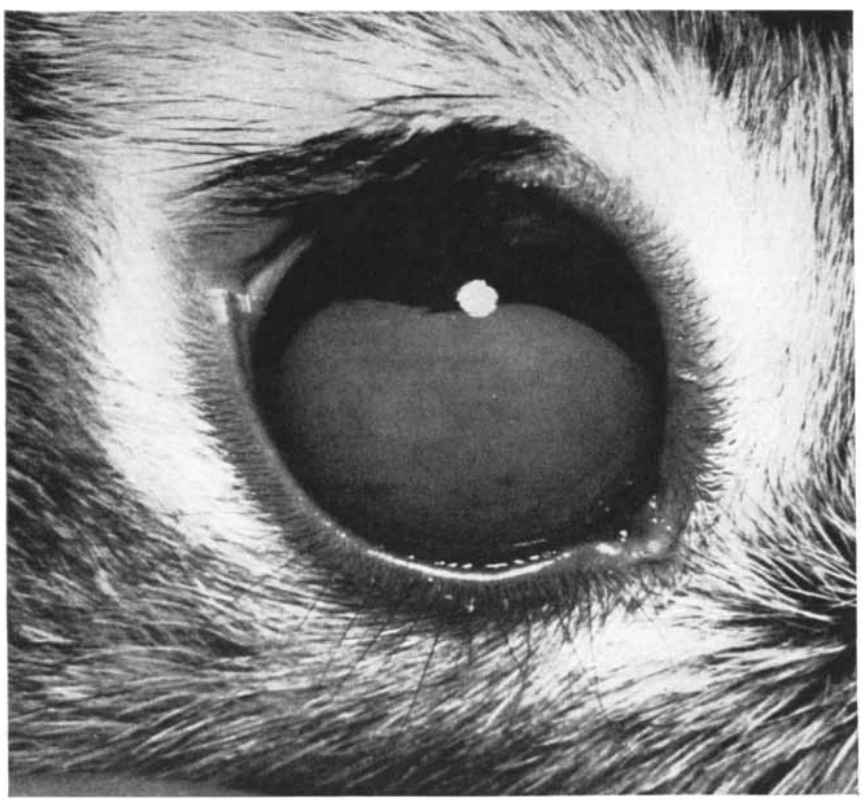


THEORY OF DRUGS that inhibit enzyme action is illustrated by the structural similarity of vitamins and the corresponding inhibitors. At top, for example, sulfanilimide is structurally similar to para-aminobenzoic acid.

ON THE



HUMAN LUNG TISSUE grows under the cornea of a rabbit's eye. The tissue was originally transplanted from a human embryo. Cells became specialized later. Transplantability of embryonic tissue may relate it to cancer.



HUMAN BRAIN TISSUE is also transplanted from an embryo into the eye of a rabbit. Cells now have characteristic organization of brain tissue. They even exhibit some nerve activity when tested with electroencephalograph.

THE problem of cancer is primarily a problem of behavior. A pathologist who examines tumor tissue under the microscope may observe significant details of form and structure, but he can never determine its malignancy from its appearance alone; only by its behavior in the living body can malignant tissue be unmistakably identified. Of two tumors with cells that look exactly alike, one may remain static or even disappear while the other inexorably spreads and kills the patient. Unfortunately many kinds and conditions of tissue which are not malignant bear a remarkable resemblance to cancer, and the pathologist often cannot distinguish between them. The diagnosis of cancer today does depend mainly on the analysis of cell morphology or appearance, but it is an imperfect guide. A judgment of the character of tissues from their appearance may indeed be as fallacious as an assessment of a man's qualities from his facial features.

We have been studying the behavior of living tissue in our laboratory by the device of transplanting it from one animal to another. The discovery many years ago that malignant tissue could be transplanted from its host to normal animals of the same species gave strong support to the idea that cancer is an independent, autonomous growth which can continue to grow even when it is removed from the conditions that originally produced and developed it. This concept in turn suggested the exciting possibility that a tumor might be transplanted from one species of animal to another; thus human cancer might be transferred to lower animals and experiments could be performed that would not be permissible in a human patient.

Many attempts at such transplantations were made; all failed. A study of these attempts suggested that it was not the concept but the methods used that were at fault. In our laboratory we had for some time been using the chamber of the eye behind the cornea in animals as a transplanting site, and the physiological conditions in this organ suggested that it might be a peculiarly favorable site for human cancer transplants. Our experiments proved successful; we found that we could grow many types of human can-

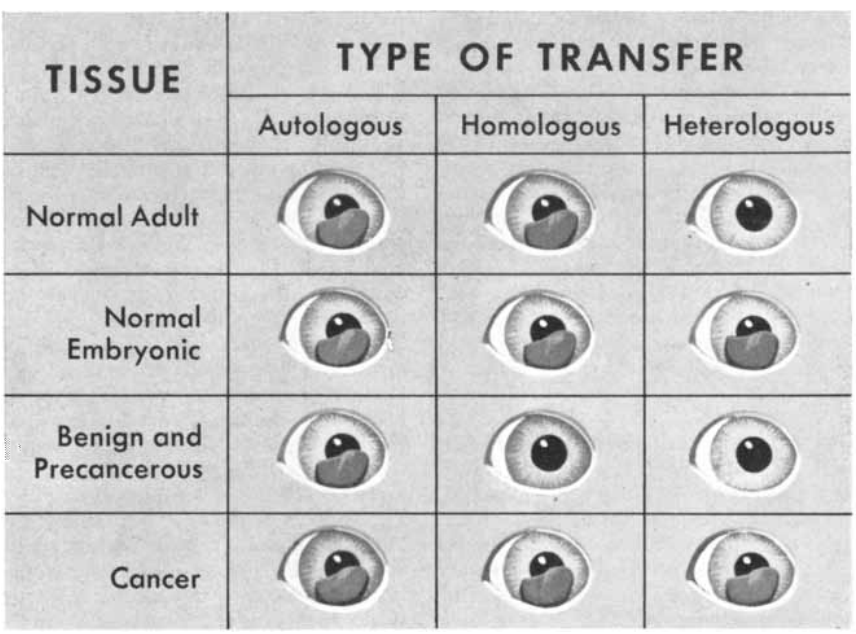
DEVELOPMENT OF CANCER

Transplanting tissue from one species to the eye of another yields a new insight into the nature of the malignant process

by Harry S. N. Greene

cer in the eyes of guinea pigs and rabbits.

Was cancer tissue unique in this property, or could other types of tissue also be transplanted from one species to another? Here was a means of comparing the behavior of cancer tissue with that of other kinds. We tested and compared four different types: normal adult tissue, normal embryonic tissue, benign and precancerous tumor tissue, and full-fledged cancer tissue. For each tissue three kinds of transplantation were tried: autologous (from one site to another in the same individual); homologous (from one animal to another of the same species); and heterologous (to an animal of a different species). The results are shown in the chart above.



SUCCESS OF TRANSPLANTING tissue in the eye of an experimental animal depends on source of tissue and type of transfer. Here eyes containing tissue show successful transfer; eyes without tissue, unsuccessful transfer.

Thus it was found that all four types of tissue could be transplanted back in the same animal; all but benign tumor and precancerous tissue could be transplanted to normal, unrelated animals of the same species; only embryonic and cancer tissue could successfully be transferred to an alien species. This finding at once suggested a biological test for human cancer: If a specimen of the suspected tissue can be transplanted to the eye of a guinea pig, it is either embryonic tissue or cancer, and even surgeons can easily distinguish between the two.

When this test was made, the significant fact developed that results of our biological test often disagreed with the diagnosis of the same tissue based on its microscopic examination. An illustrative case follows: A middle-aged man entered the hospital with a large tumor in his chest. X-ray examination showed no evidence that the tumor had metastasized (spread to other sites) and the growth was removed by surgery. On the basis of morphological examination of the tissue, it was diagnosed as a fibrosarcoma (cancer of the connective tissue). But transplants of the tissue in guinea pigs' eyes failed to grow, which indicated that by our biological definition the lesion was not full-fledged cancer. Six months later the patient returned with a recurrence of the tumor at the same site. There was still no evidence of metastasis; the appearance of the tissue had not changed; transplants still failed. An attempt was again made to remove all the tumor tissue, but again the operation was apparently inadequate, for eight months later the patient had another recurrence of the tumor. This time X-ray studies showed that the growth had metastasized to the lungs. The morphological appearance of the tissue had not changed, but the biological test of its behavior produced sharply different results: transplants of the tissue now grew in all of the guinea pigs used.

This is not an isolated case; similar tests of tissue specimens from other cancer patients show an identical course of development. It is significant that all tumors which possess the ability to invade and metastasize to other tissues in the body can be transplanted to animals of alien species, while many lesions judged to be cancerous on purely morphological grounds cannot be transplanted. Moreover, patients with disorders diagnosed as cancer by morphologists not infrequently make a complete recovery, whereas a diagnosis of cancer based on the behavior of the tissue is invariably followed, in spite of all attempts at treatment, by the death of the patient.

THESE disagreements in diagnosis have led to considerable controversy among pathologists. The bone of contention is, of course, the definition of cancer. The morphologist defines cancer as a group of cells with certain specific characteristics of structure and arrangement; the biologist, on the other hand, considers that the distinguishing feature of cancer is its ability to invade and metastasize.

The biological view suggests a fundamentally new concept of the entire cancer process. It has long been supposed that cancer is the result of a sudden transformation of normal cells into malignant ones. Some unknown factor or set of factors, according to this view, changes the character of previously healthy tissue so that it grows rapidly and malignantly. The new evidence on the behavior of various types of tissue, however, strongly indicates that cancer is not the result of a sudden transformation, but is the final product of a developmental process. The tumor goes

through evolutionary stages during which it does not change in appearance, but does change profoundly in its biological behavior. In the case which I have described, the tumor tissue, although it had the morphological appearance of cancer, did not at first behave like cancer tissue in the patient. Moreover, it was not transplantable to another species of animal. As the tumor developed, however, it acquired the ability to invade and metastasize and the attainment of these properties was associated with the ability to grow in an alien species. This change was demonstrated only in its behavior; it could not be detected by any alteration in the appearance of the cells.

What caused the change in behavior? Some light on this question may be obtained from a study of the reactions of tissues to homologous transplants from one animal to an unrelated animal of the same species. As we have seen, precancerous tumor tissue, *i.e.*, tissue in the process of development to cancer, cannot be transplanted to a normal animal of the same species, although all other types of tissue can be. If, however, the second animal is not normal, but itself has a spontaneous tumor of the same nature as the first animal's, homologous transplants of tumor tissue can easily be made to it. Evidently, then, tumor growth and development are dependent on certain specific biological factors which are present in the original animal and in other tumor-bearing animals. but which are not supplied by normal animals. In its developing stages, the tumor requires these factors to survive and mature. When its development is completed, however, the tumor becomes an independent growth that can thrive in the absence of such factors. and transplants will grow in normal animals.

In the case of the patient with a chest tumor, the tumor appears to have been in a dependent phase during the period when the first two operations were performed. If the tumor tissue had been completely removed at that stage, the patient would have survived and the case would have been recorded as a "cancer cure," despite the fact that from a biological point of view the tumor was not a cancer at all. It is not improbable that all instances of so-called cancer cures are of this kind. Actually small fragments of tumor were missed in both operations, and they eventually became autonomous, metastasized, and killed the patient.

The conception of a dependent phase in the development of cancer suggests several fields of inquiry. The most obvious question is: What are the factors on which the biological development of a tumor depends? A detailed search for constitutional differences between the normal animal and the tumor-bearing animal is a logical approach to the problem. Such an investigation has been undertaken in cancers of the uterus and mammary glands in rabbits. Here the problem is relatively simple, for the affected animals show obvious evidence of an endocrine disorder involving the estrogenic hormone. To test the influence of this factor, an endocrine disturbance was artificially produced in normal animals, and dependent (precancerous) tumor tissue was then transplanted into their eyes. The transplants were successful; transplants attempted in untreated control animals, on the other hand, did not succeed. The experiment demonstrated that the endocrine disorder was an essential factor in development of this type of tumor.

Tumors of the breast and uterus are special cases, for endocrine disorders are not associated with all tumors. Yet constitutional disturbances of a different order do accompany other tumors. It seems highly probable that, in a similar fashion, they constitute the factors essential for the tumor's growth and development. An investigation of these factors is of the utmost importance for the rational treatment of tumor patients; if the factors can be discovered and eliminated, the development of tumors to cancer may be stopped. This does not apply, of course. to the fully evolved cancer, for in such cases the growth has attained autonomy and is completely independent of the factors concerned in development.

For the present, heterologous transplantation provides a reliable test for cancer. If the specimen of tumor tissue can be transplanted successfully to a normal animal which contributes none of the factors known to be involved in tumor development, it means that the tissue has attained independence and is a true, autonomous cancer. This test gives information that cannot be obtained through the microscope, and, further, is a considerable aid to the microscope in the classification of cancer.

NOT infrequently the first sign of cancer in an individual is the appearance of a metastasis. This may occur as an enlarged lymph node in the immediate vicinity of the primary growth, or it may be far distant from the involved organ. In such cases, the surgeon removes a portion of the metastatic growth and sends it to a surgical pathologist. who attempts by a microscopic study of its appearance to determine in what organ or tissue the growth originated. If the metastasis retains the characteristic architecture of the differentiated or specialized cells in the original organ, the task is relatively simple. But if, as frequently happens. the cells are poorly differentiated and disorganized, and the picture is complicated by the death of cells or obscured by reactive processes. microscopic study is of little help in locating the primary site. Fortunately when such cancers are transplanted to normal lower animals they develop a higher degree of cellular differentiation and structural organization than they possessed in the patient; thus it becomes possible to classify the cancer and identify its place of origin more precisely than from a study of the original specimen.

The following cases illustrate this use of heterologous transplantation:

A 45-year-old woman appeared for examination with a greatly enlarged lymph node in the groin. The node was removed and on microscopic examination showed a preponderance of dead cells, with scattered cancer cells of nondescript appearance. There was nothing to indicate the proper classification or the site of the primary tumor. Fragments of the tissue were transplanted to guinea pigs; after 20 days the animals were killed and specimens of the growing transplants were examined under the microscope. The cells now showed such well-marked characteristics of structure and organization that the growth was readily diagnosed as malignant melanoma (cancer arising in a nevus, or birthmark). When questioned. the patient then recalled that she had had a birthmark removed from her foot several years before; the tissue had not been examined, however, and both the doctor and the patient had assumed that it was entirely benign.

The second case is that of a young woman of 24 who had a growth removed from her upper backbone. The growth was diagnosed as hemangioblastoma (tumor of blood vessels); the microscopic picture showed the classical signs of such a tumor. The growth was not completely removed by the operation; three years later the patient re-entered the hospital with a recurrence of the tumor. A second operation was performed. The tumor tissue had become more disorganized in structure, but its appearance was still consistent with hemangioblastoma and it was again so diagnosed. When grafts of the tissue were made to guinea pigs' eyes, however, the transplants in 12 days developed a well-organized growth of cells which showed the characteristic signs not of a tumor of blood vessels but of a cancer of cartilage. The surgeon in the case was understandably very skeptical of this new diagnosis. But when the patient died, about a year later, microscopic examination of the patient's metastasis at autopsy confirmed the guinea pigs' veracity.

The use of heterologous transplantation as an aid in cancer diagnosis is a simple procedure. The technique requires only an elementary knowledge of surgery. Interpretation of the results is almost foolproof. Although the grafting test itself fails to distinguish between cancer and embryonic tissue, which, as was noted at the beginning of this article, can be transplanted to an alien species just as cancer can, this fact does not invalidate the test, for the differences between an embryo and a cancer are fully apparent on gross examination.

On the other hand, the similarity in the reactions of cancer and embryonic tissue is itself of great theoretical interest. The

resemblance between the two types of tissue is not limited to transplantation reactions, but is also observed in biochemistry, immunology and morphology. Indeed, the only major difference between the two tissues is that, in the primary host and in experimental animals, embryonic tissue progresses to differentiation or specialization of function, while cancer does not. Embryonic tissue may be transplanted from any organ of the fetus. And all transplants of this tissue, whether homologous or heterologous, undergo differentiation into the organs that would have evolved had the tissue remained in its original site. Thus mammary tissue, when transplanted from any animal to a guinea pig's eye, develops into small mammary glands and can actually be seen to produce milk. The cells of cancer tissue, in contrast, simply reproduce themselves and show no changes indicating specialization.

These facts suggest that the step from embryonic tissue to cancer is relatively short, and that this step is probably concerned with the process of differentiation. Accordingly, one of our endeavors has been to inhibit or modify the differentiation of embryonic tissue transplants with the hope of thus producing a cancer. Various methods have been tried; to date, success has been attained only through use of the well-known cancer-producing chemical, methylcholanthrene.

The technique is easily explained. A minute crystal of methylcholanthrene is added to a specimen of embryonic tissue and the tissue is then transplanted to an adult animal. In from 30 to 40 days, a cancer develops in the transplant. This is a significantly short period, for ordinarily it takes from four to six months to produce cancer in the same tissue of an adult animal. Moreover, all attempts to produce cancer in certain adult organs by means of this chemical have proved unsuccessful, whereas cancer is readily induced in their embryonic counterparts. Any organ—the eye, the abdominal cavity, the kidney, a lung, the deeper layers of the skin—can be used as a transplantation site for treated embryonic tissue without changing the result.

The close relationship between cancer and embryonic tissue opens a promising field for further investigation, and many additional experiments are under way or planned. The experiments already performed appear to establish pretty definitely that cancer is not a sudden transformation of normal cells, but on the contrary represents the final step in a developmental process. And the constitutional abnormalities present in tumor-bearing animals suggest that cancer is not simply a local tissue disease, but rather a local manifestation of a generalized disorder.

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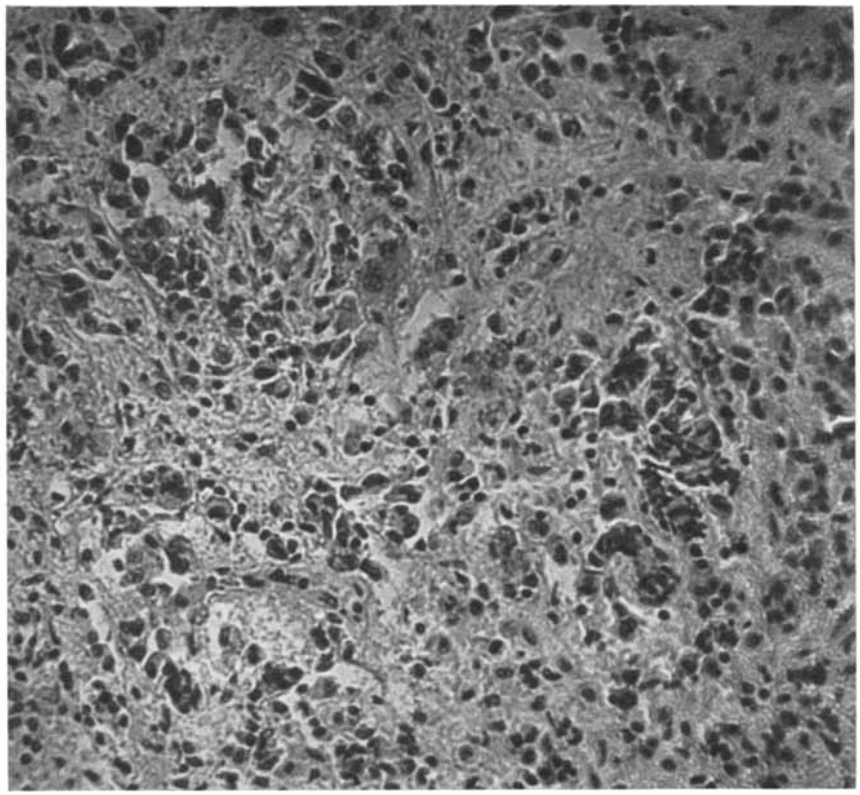
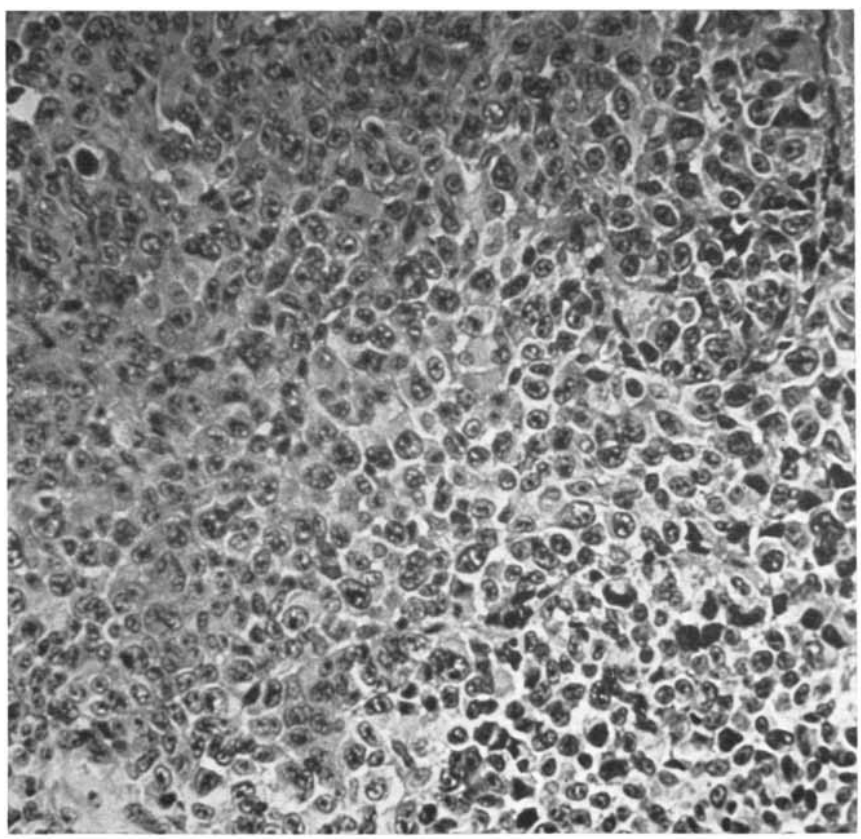


CANCER TISSUE mounted on a microscope slide is from a lymph node of 45-year-old woman mentioned in text of this article. Nondescript organization of cells made it impossible for pathologists to identify original tumor.



SAME TISSUE, after transplantation in the eye of a guinea pig, developed recognizable cell organization. From this slide pathologists were able to identify original tumor as a melanoma, or a cancer arising from a birthmark.

STONE AGE MATHEMATICS

The earliest comprehension of number and geometry appears to go back farther than the time of the Egyptians and Babylonians

by Dirk J. Struik

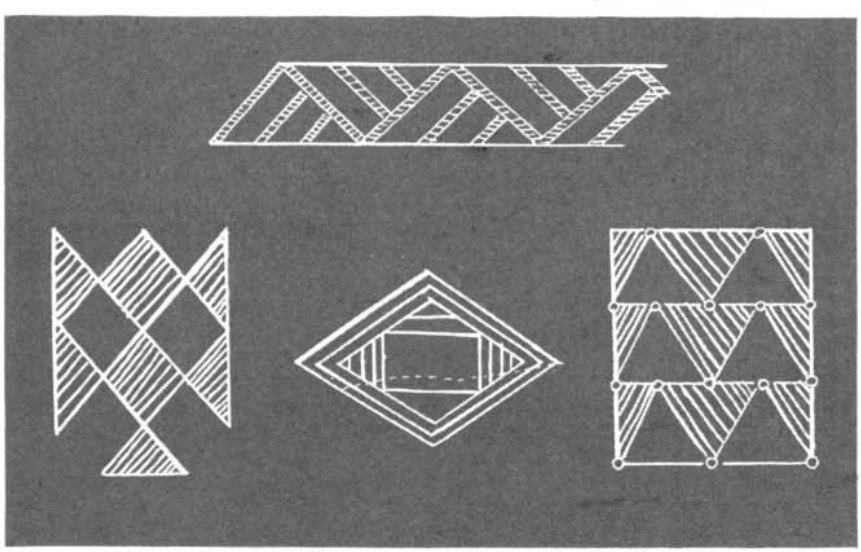
WHEN did mankind begin to use mathematics? It has long been customary to attribute the invention of this science to the Egyptians and Babylonians of the fourth or perhaps fifth millennium B.C. But if we assume that mathematics was born when men began to have some understanding of numerical and geometrical relations, then mathematics is much older than those ancient peoples. Its history goes back to the primitive races of neolithic times, and even the Old Stone Age. Indeed, there is some question whether we should stop there. Charles Darwin in his *Descent of Man* was sure that some of the prerequisites for mathematical reasoning, such as memory and imagination, exist among the higher animals. We may take it that man in his early stages borrowed some mathematical notions from his animal ancestors.

Even in his primitive stages, however, this man is already a mathematical prodigy compared to the higher apes. He begins to develop an articulated language, in which hardly any generalizations or abstractions occur, each expression being associated with some object or set of objects. He can express at least the difference between a single specific object and many such objects. Some conscious knowledge of order, size and form begins to appear. And above all, he introduces a new element into the evolution of living beings, an element which endows him with the potentiality for further development.

This new element can be defined as the process of labor. By means of labor man enters into a new form of active and conscious contest with nature; he begins to change nature and thereby changes himself. He invents tools. His labor slowly develops into a social activity. Very early in this process, certainly by the Old Stone Age some hundreds of thousands of years ago, he begins to acquire his first conscious understanding of numerical and spatial relations.

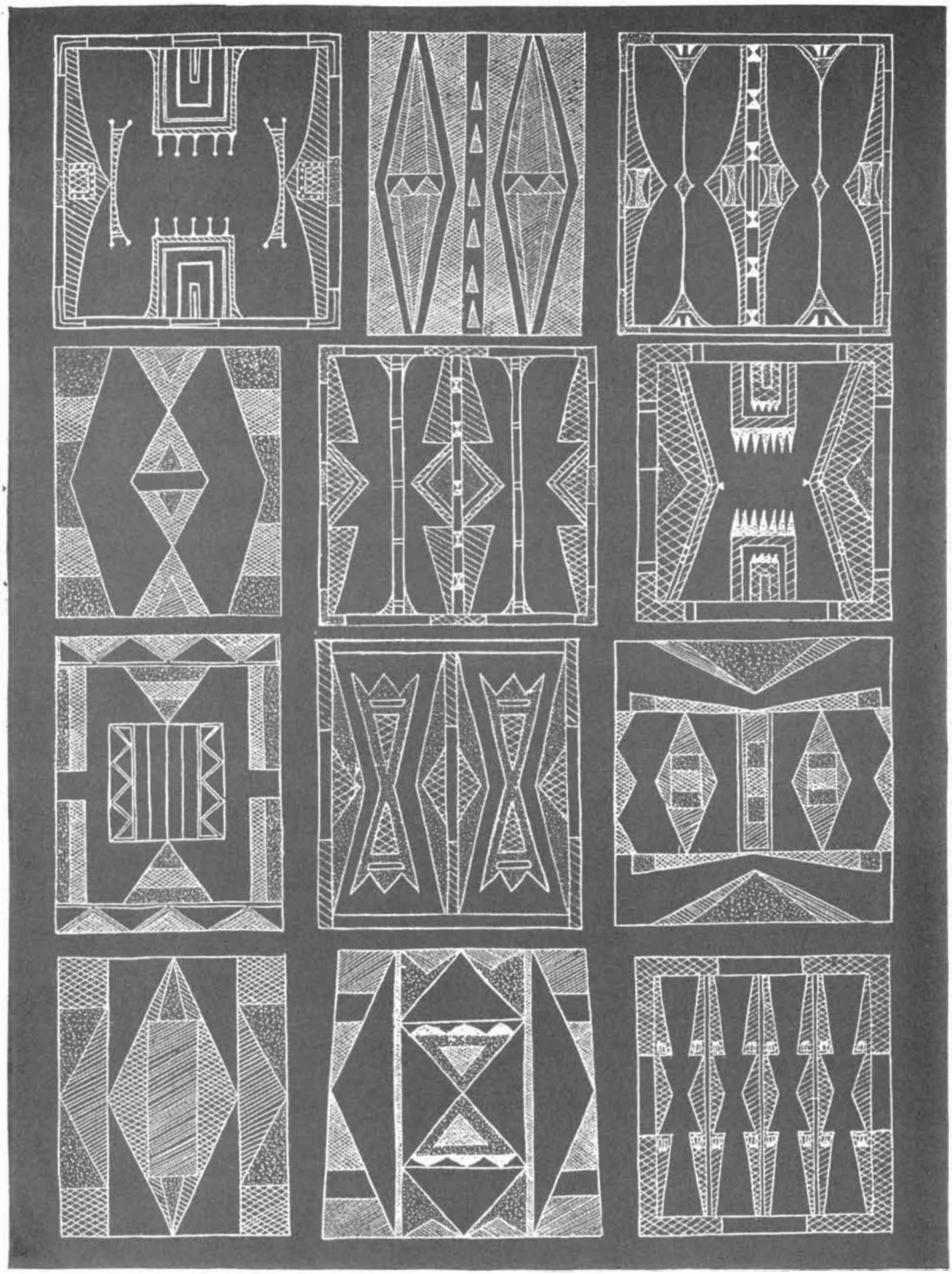
We can get some idea of the nature of this early paleolithic culture from studies by modern anthropologists of primitive tribes in Australia and Polynesia. These tribes were primitive hunters and fishermen; they had no agriculture and only the simplest tools; they lacked even the bow and arrow, which some tribes of the Old Stone Age are known to have possessed. But the Australian and Polynesian tribes already had the beginnings of a number system. Their languages had words for "one" and "two"; many of them counted up to 3 or 4, expressed as the sum of 1 plus 2 and 2 plus 2. Their language rarely went beyond the number 4. A few, however, had a special term for 3, and this step apparently represents a considerable advance beyond the primitive method of pairing. The early development of numbers is illustrated by the language of the Kamilaroi tribes in Australia: their word for 1 is *mal*; for 2, *bulan*; for 3, *guliba*; for 4, *bulan bulan* (2 plus 2); for 5, *bula guliba* (2 plus 3); for 6, *guliba guliba* (3 plus 3).

The earliest number concepts among primitive tribes are qualitative rather than quantitative. Just as we speak of one book as "a" book, primitive peoples think in descriptive terms rather than in numerical abstractions in designating two or even more objects. This frame of reference, which is reflected in their grammar, has come down in some modern languages; for example, in Greek and Celtic there are special terms for two objects, and German still uses *ein* both for "one" and for the article "a" (*ein Baum*) and declines the word as if it were an adjective (*eines Baumes*).

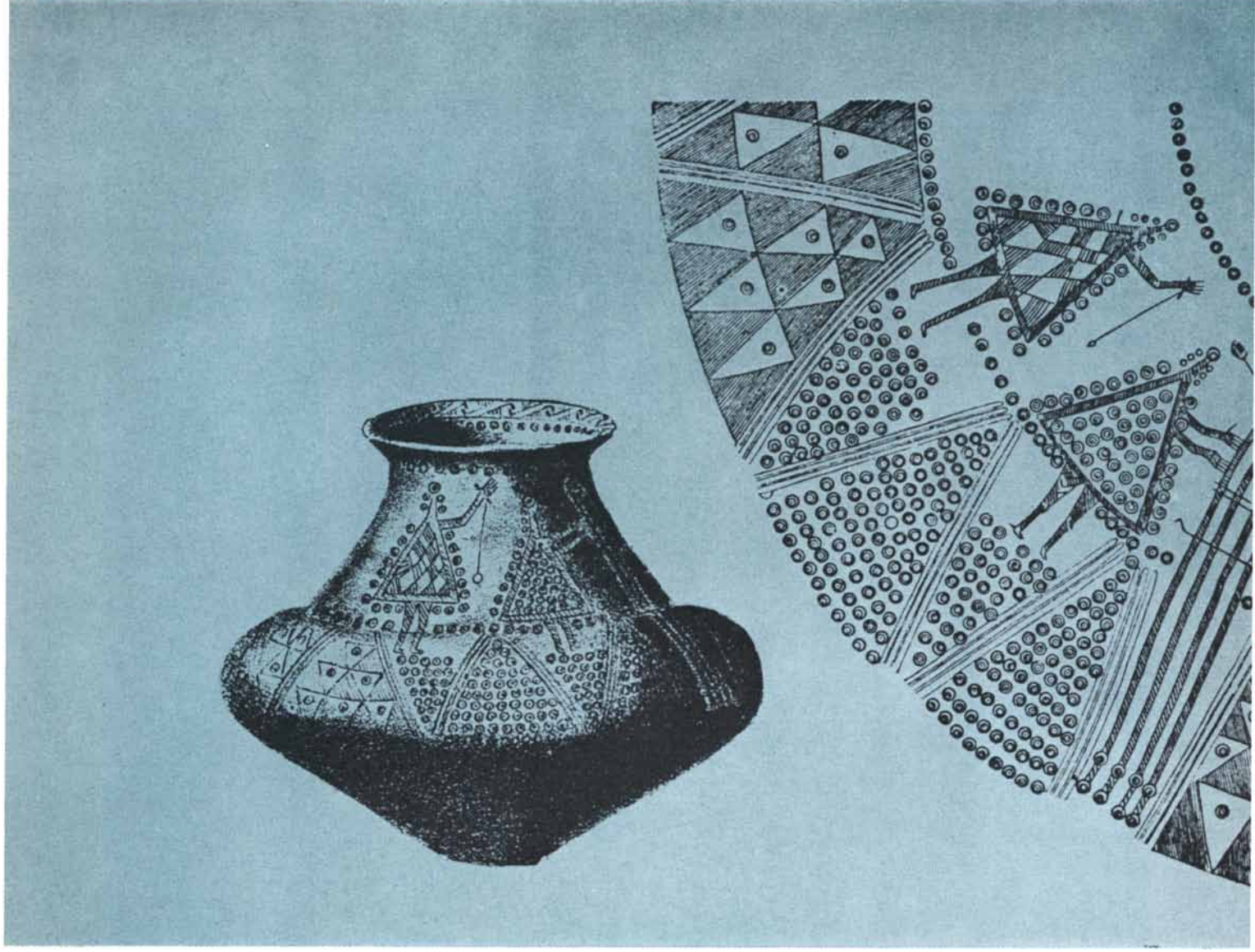


GEOMETRICAL PATTERNS, generally drawn on pottery, are neolithic expressions of interest in mathematics. Those at left and right show attempt to develop triangular numbers, later important in Pythagorean mathematics.

When primitive peoples made the transition from being mere food gatherers to becoming food producers, they progressed considerably in the understanding of numerical values and space relations. This great event in the emancipation of man, which marked the transition from the Old Stone Age (Paleolithicum) to the New Stone Age (Neolithicum), occurred independently in various parts of the earth at different times, beginning perhaps 10,000 years ago. As neolithic man settled down to primitive farming and semipermanent dwellings and villages, he developed pottery, carpentry, weaving, baking, brewing; and the smelting of copper and bronze. Invention followed invention: the potter's wheel, the wagon wheel, the hammer, the hoe, tents, huts, rafts, boats. These inventions did not always spread widely; the American Indian, for instance, did not know the wagon



INDIAN DESIGNS are another example of the geometrical imagination of prehistoric cultures. Those shown on this page, recorded by the anthropologist Leslie Spier, were made by the Plains Indians. The designs were used to decorate parfleches, big envelopes that the Indians made by folding rectangular pieces of rawhide.



POTTERY DESIGN of an early culture in western Hungary shows a certain degree of geometrical sophistication. At left is an urn; at right is a two-dimensional representation of its decoration. Of principal interest to the mathematician are the triangular designs at the bottom of the decoration. Such designs often led to the development of geometrical ideas.

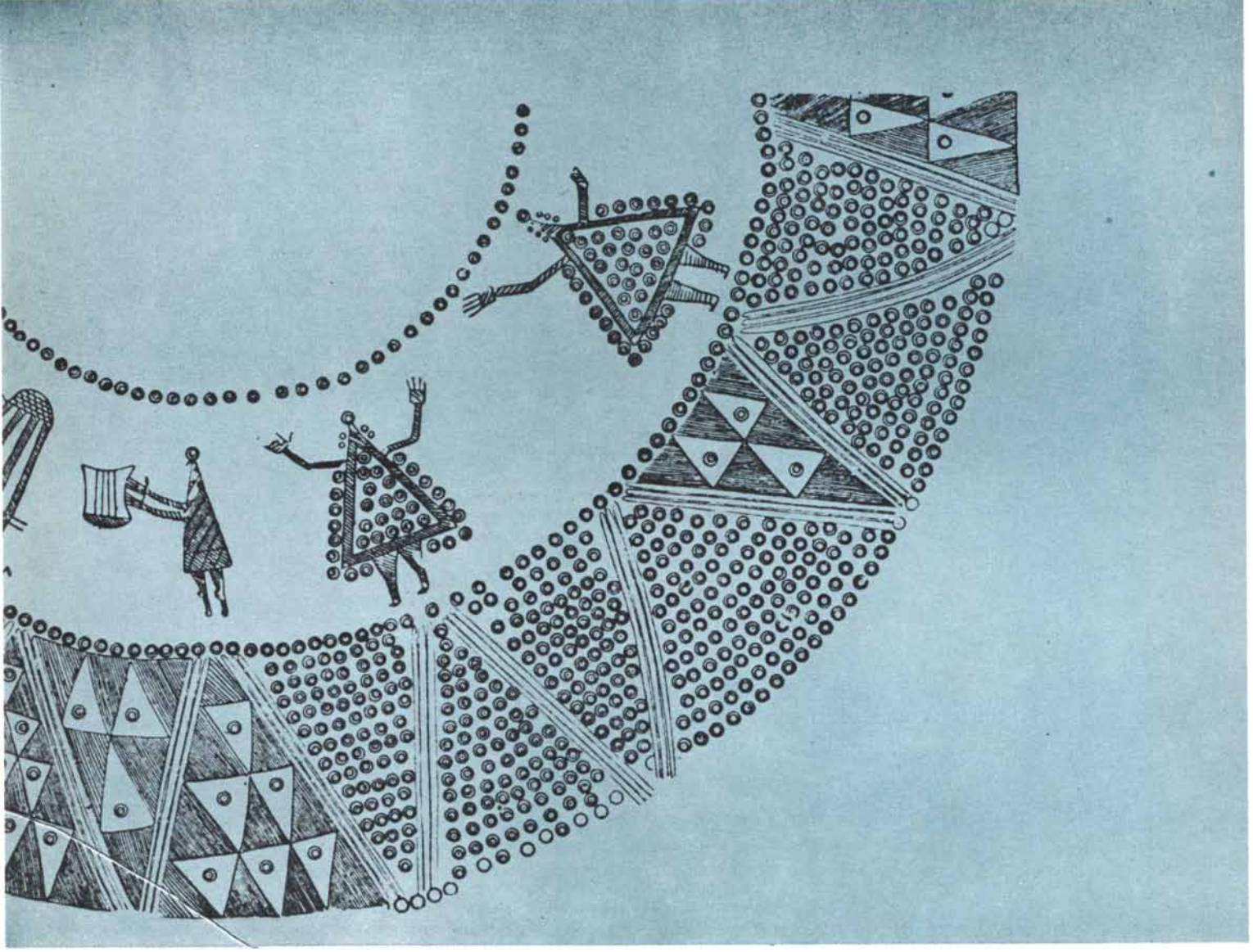
wheel until the coming of the white man. Nevertheless, in comparison with paleolithic times, the tempo of technical improvement was enormously accelerated. A spur to the development of arithmetic was the rise of trading among neolithic settlements. Number systems had to be developed to keep track of catches of fish, the size of the herds and harvests, the requirements of barter and the beginnings of a calendar.

The first step was to bundle numbers into larger units. This is the principle of the old innkeeper's tally stick, which everyone adopts who has to count coins or votes: he takes groups together and considers each group as a new unit. One would naturally assume that man began to count on his fingers—an assumption which seems to be supported by the now almost universal decimal system. Actually counting by 5s and 10s did not appear until a relatively advanced state of civilization. The most primitive peoples bundled things in pairs, counting them in groups of 2, 4 and 6. An occasional variation was the ternary number system (groups of 3), which was used by a number of American tribes.

HOW difficult it is for primitive man to progress to counting on his fingers is illustrated in an account of the Damara, a Bantu tribe of southwest Africa, by the British anthropologist Francis Galton: "When inquiries are made about how many days' journey off a place may be, their ignorance of all numerical ideas is very annoying. In practice, whatever they may possess in their language, they certainly use no numeral greater than three. When they wish to express four, they take to their fingers, which are to them as formidable instruments of calculation as a slide rule to an English schoolboy. They puzzle much after five, because no spare hand remains to grasp and secure the fingers that are required for units. Yet they seldom lose oxen: the way in which they discover the loss of one is not by the number of the herd being diminished, but by the absence of a face they knew."

The quinary (counting by 5s) and decimal systems are biologically so inevitable, however, that they eventually appear among primitive peoples in many parts of the world. Of 307 number systems among primitive American tribes which were investigated by the Stanford University mathematician Walter C. Eells, 146 were decimal, 106 quinary and quinary decimal, 81 binary (counting by 2s), 35 vigesimal (by 20s) and quinary vigesimal, 15 quaternary (by 4s), three ternary and one octonary (by 8s). The vigesimal system occurs in its most characteristic form among the Mexicans, the Mayas and the Eskimos. On the continent of Europe it is typical for the Celtic languages, and traces of it are left in French —80 is *quatre-vingts*.

In the ancient Greek. the word *pempazein* (literally counting by 5s) stands for counting in general. It seems likely that as primitive peoples developed the need for larger numbers they progressed from counting with one hand to using both hands and then in some cases using both hands and feet. From this method of



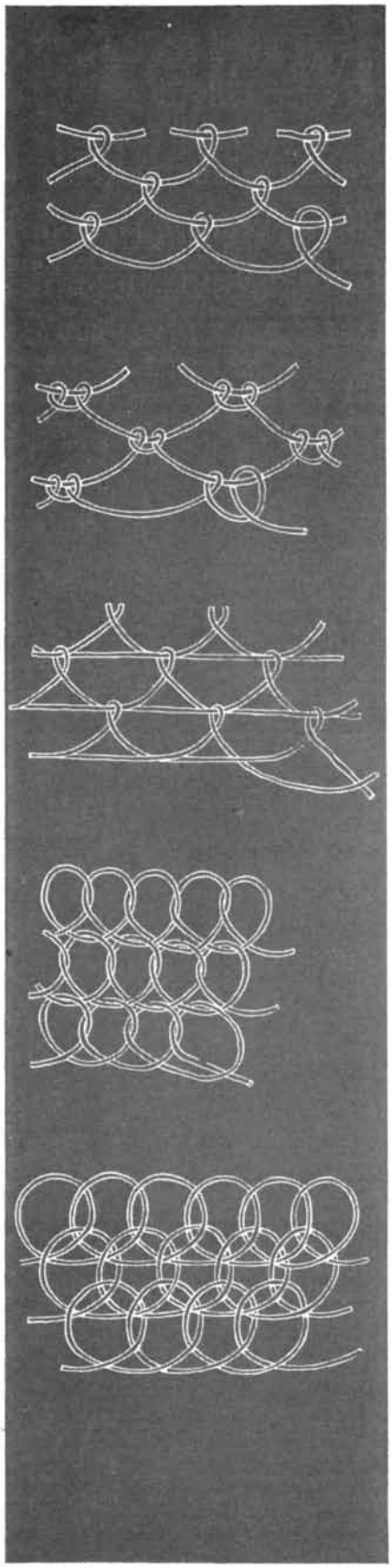
bundling to the introduction of special symbols for 5, 10, 20 and so on was a natural next step. We find exactly such symbols in use at the beginning of written history—the so-called dawn of civilization.

Once the principle of a number system is grasped, there is little to prevent the extension of the system to large numbers. This may happen, for instance, among peoples in possession of large herds, or wherever a well-developed agriculture requires the beginning of a calendar system. The Sioux, Iroquois, Muskoghean and some Algonquin Indians were reported capable of counting in the hundreds of thousands, and occasionally they had words for even higher numbers. Eells remarks that they had developed this ability even though before they came into contact with European civilization these Indians had little occasion to use numbers beyond 1,000. Primitive peoples loved very large numbers, a fondness which was perhaps stimulated by the desire to exaggerate the extent of herds or the number of enemies slain. The ancient Hindus occasionally dealt with no less than 18 powers of 10. In true primitive fashion, they had a special term for each power. Their prowess in counting has occasionally been presented as evidence of the superiority of ancient Hindu mathematics, but in view of the counting achievements of other peoples their mathematical understanding cannot be considered unique.

An important step in the development of arithmetic is the keeping of numerical records. The primitive methods of doing this all used the bundling or grouping system: pebbles or shells arranged in heaps of 5, knots on a string, nails pressed into a board. With the invention of a special token for 5 and 10 a real arithmetic began. Addition started when numbers were written as sums of other numbers greater than 1; in other words, when 4 was expressed, not only as 1 plus 1 plus 1 plus 1, but also as 2 plus 2 or as 3 plus 1. From this it was but a step to subtraction; the number 14, for example, being expressed as 15 minus 1, and 30 as 40 minus 10. The beginning of multiplication came when 20 was expressed as 2 times 10 instead of 10 plus 10. This simple doubling operation, a middle road between addition and multiplication, was used for thousands of years; it was especially prominent in Egyptian mathematics. The use of fractions appears to be a fairly sophisticated development, for it was rare among primitive tribes. Indeed, our words for 1/2, such as half, semi, demi, have no relation to the number 2, which indicates that this concept was not consciously introduced as a fraction.

EQUIPPED with these improvements in counting ability, primitive peoples begin to develop a livelier interest in measuring things. The standards for length are usually taken from parts of the body: the finger, the foot, the thumb, the hand, the forearm, and so on. Volume is measured by shells or by buckets of fairly standardized size. When houses are built, as among the agricultural Indians or the pole house dwellers of prehistoric Central Europe, rules for building along straight lines and at right angles are laid down.

On the coast of British Columbia, for example, the Indians use as the principal measures the width of a finger, a long span (from thumb to tip of fourth finger), a short span (from thumb to tip of first finger) and a cubit (from elbow to tip of second finger). The Hupa of southern California measured their dentalium shells by the length of the finger joints and by



NETTING made without knots by a number of primitive tribes, notably those of South Pacific, requires high order of geometrical imagination.

marks tattooed on the forearm according to certain accepted standards. The Kwakiutl, an Indian tribe of Vancouver Island in British Columbia, had a well-developed procedure for laying out the lines for a square house. From a point which was to be the middle of the front line of the house, they stretched a rope to the middle of the rear line. After staking these two points, they halved the rope and stretched one half to the right and the other to the left of the front stake. Then, using another rope to measure the distance from the rear stake to the ends of the front rope, they adjusted the latter until the distances between the rear stake and the two front corners were equal. In this way the front line was placed exactly at right angles to the middle line. The rear corners were determined in the same way.

Neolithic man showed an early interest in geometrical patterns. This was the result of the growth of handicrafts: the turning, baking and coloring of pottery, the plaiting of rushes, the weaving of baskets and textiles, and later the working of metals. Neolithic decoration abounds in examples of congruence and of various forms of symmetry. Numerical relations may enter and blend with plane and spatial patterns; certain prehistoric ornaments show triangular numbers, others "sacred" numbers.

ASTONISHING examples of very complicated geometrical figures in a very primitive society were discovered by the British anthropologist A. B. Deacon among tribes in the New Hebrides. A few of these drawings are shown on the opposite page. They were apparently once connected with religious ceremonials, but they are now drawn in the sand, as a pastime with no deep symbolism, by tribesmen gathered for amusement.

Some authorities hold that the determining factor in the growth of mathematics was its magical aspect. There is no reason, however, to assume that rational mathematics grew out of mysticism, as some contend. The social roots of mathematics may become obscured in modern times, but they lie clear in earlier ages. There are, to be sure, plenty of indications that mathematics has always been associated with magic; remnants still exist in the belief in lucky and unlucky numbers and in the pseudo-science of numerology.

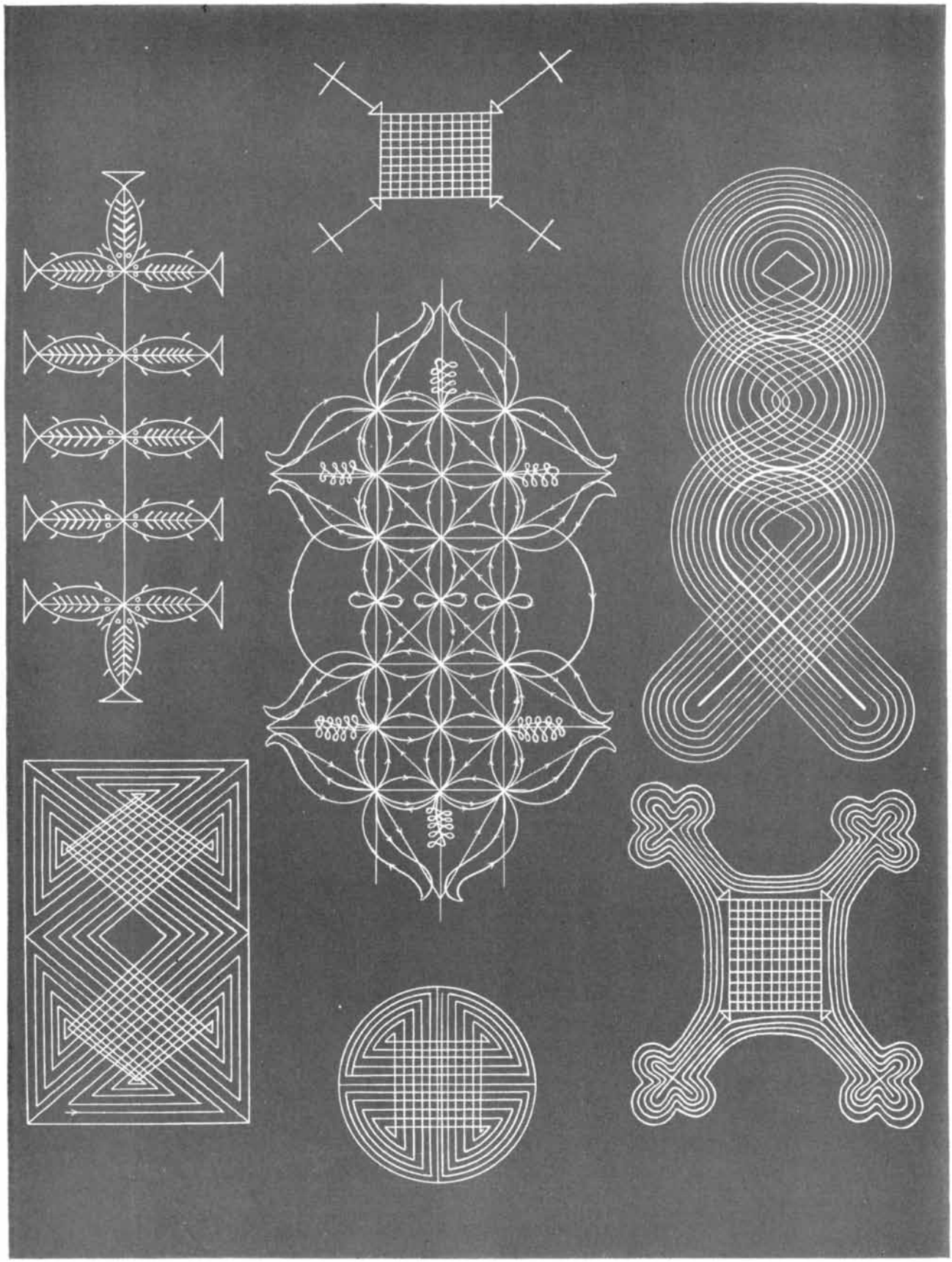
The number 4 was given mystical powers by many primitive peoples. This superstition found expression in cults which attributed a mystical significance to the four quarters of the compass and in the widespread cults of the swastika and other cruciform symbols. Other mystical numbers were 6, 7 and 13. The German anthropologist Leo Frobenius reported on the connection of certain numbers, such as 2 and 3, with sex relations. Many of the geometrical patterns in primitive pottery, weaving and basketmaking probably contained some magical meaning.

The development of mathematics was most strongly influenced, however, by natural science, especially astronomy. Even among very primitive tribes there was some knowledge of the sun, moon and stars, and with the expansion of agriculture this knowledge deepened. Almost universally primitive peoples adopted a lunar calendar, for the lunar period of almost a month is a practical unit for farming. Thus most of the phases of the moon are named for the changing aspects of vegetation or the ripening of wild fruits; other agricultural names were given to the phases of the position of heavenly bodies, the rising of the Pleiades, the solstices of winter and summer. The Micronesians used the constellations as guides in navigation. The Egyptians, Indians and Chinese all ascribed some knowledge of astronomy to their prehistoric periods.

The mathematical interests of neolithic men were not all of what we now consider an elementary nature. Many aspects of their geometrical patterns were so complex that they have found an adequate mathematical analysis only in modern group theory and in topology. The evidence shows that the historical growth of mathematics did not follow the sequence used in modern instruction on the subject. Some of the oldest mathematical topics belong to what we consider modern science, while some of our "elementary" mathematics, such as graphical representation, developed only in relatively modern times. Of course primitive peoples made no abstract or systematic study of their geometrical patterns and knots, to say nothing of group theory or topology. What did exist was a widespread search for new and varied forms. Their gropings are perhaps comparable to the mode of work of painters, architects and sculptors in modern times; modern science has not succeeded even yet in analyzing all the mathematical elements in art.

We can sum up the evidence by saying that the beginning of arithmetic and geometry is found in the Stone Age civilizations of hunters and early farmers. It was based on the necessities of their social and economic life, was influenced by magic and religion, and was perhaps already inspired by a sense of the sheer charm of mathematical order. Certain rudimentary beginnings of a more abstract approach can be discovered in primitive peoples' systems of numbering, addition, multiplication and measurement, in the formation of geometrical symmetries of varied character, and in the beginnings of a calendar.

Dirk J. Struik, author of the recent book Yankee Science in the Making, *is professor of mathematics at the Massachusetts Institute of Technology.*



GEOMETRICAL FIGURES drawn by the natives of the New Hebrides are examples of unusually complicated designs made by the people of a very primitive culture. Originally these figures were worked out for religious ceremonies, but now they are drawn by the New Hebrideans mainly for amusement. The mathematical analysis of many figures such as these requires a knowledge of modern mathematics such as group theory and topology.

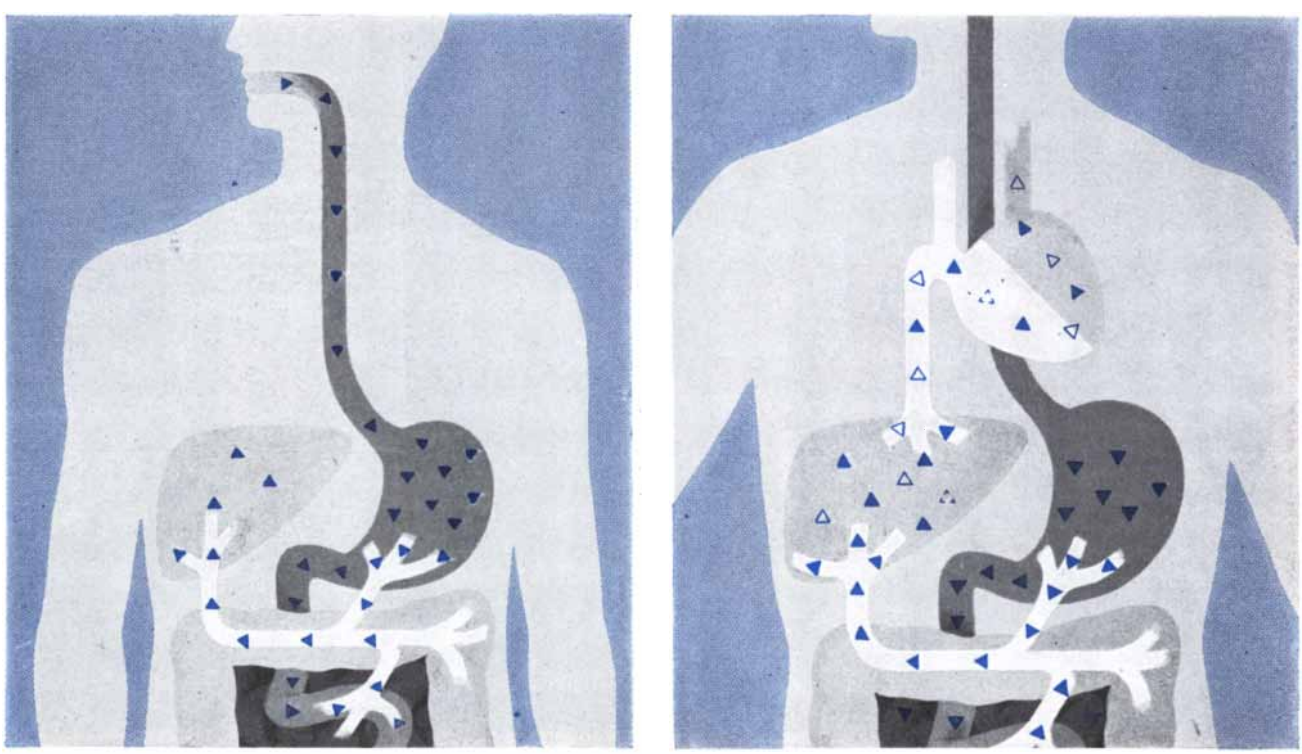
ALCOHOLICS AND METABOLISM

Individuality, points out the author, has a basis in biochemistry. The study of such variations may help in determining what creates compulsive drinkers

by Roger J. Williams

EACH of us is born with a certain color of eyes and of skin, a certain ultimate limit of body size and certain facial features that stamp him as the child of his forebears—and also as a unique individual. The genes that control our inheritance are capable of so many different combinations that no two persons are exactly alike. This uniqueness extends throughout our whole morphology, from the gross and microscopic structure of each endocrine gland, each sense organ and each internal organ to the microscopic texture of our hair and the tiny ridges that cause our fingers, toes, hands and feet to yield distinctive prints.

But inheritance and distinctiveness do not stop there. Recent studies in genetics have shown that our genes control not only our structure but our physiological pattern. Every human being inherits from his forebears the intricate mechanisms which go to make up his entire metabolic machinery or, more specifically, the potentiality for producing the extremely numerous enzymes and enzyme systems about which biochemists are learning more each month and each year. George W. Beadle and his co-workers at the California Institute of Technology, using the technique of knocking out by X-rays the individual genes in the spores of the relatively simple organism *Neurospora*, have established in several cases a one-to-one relationship between genes and enzymes. It becomes inescapable that



METABOLISM OF ALCOHOL is outlined. Small blue triangles in first drawing represent alcohol taken into the stomach and intestines. From them it passes into the bloodstream and is carried to the liver. There alcohol is broken down into acetic acid, represented by open triangles. The broken triangles represent acetic acid

wherever there is a difference in inheritance, there is likewise a difference in the enzymes. And of course, a difference in enzymes means a variation in the course of the chemical reactions associated with metabolism.

These facts suggest that disorders of metabolism may be hereditary, and indeed we know of a few in which the connection between the genes and the disorder has been proved beyond any doubt. This article is concerned with the specific problem of alcoholism, or compulsive drinking. Is alcoholism the result of a peculiar metabolism? Is the tendency toward a craving for alcohol inherited? There is considerable evidence to suggest that it is.

To the layman, metabolism often represents simply the number of calories an individual consumes per day. Actually the term embraces a million chemical processes, more or less, which forerun and accompany the conversion of the chemical energy of food into the energy used by the body and that liberated as heat.

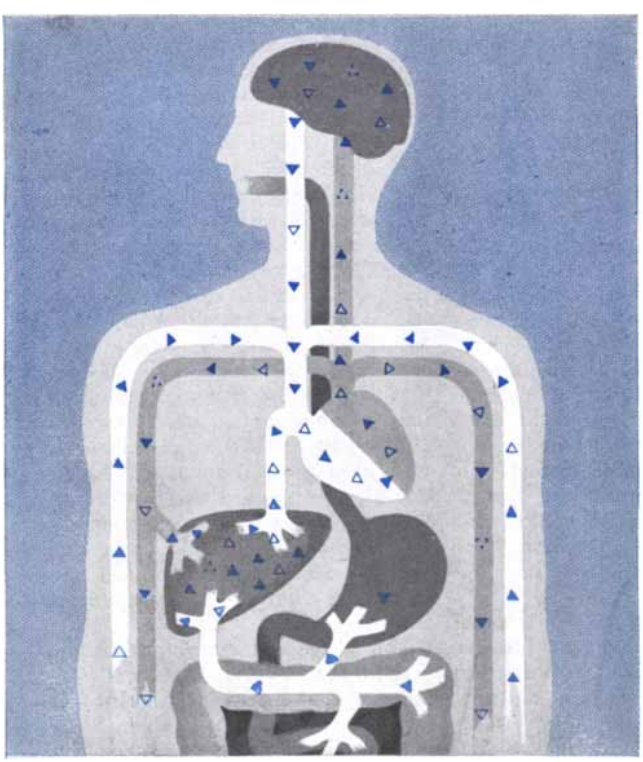
The general course of metabolism is the same in all human beings, but this does not mean that the process is identical in all. From a general point of view, indeed, the metabolism of men is much like that of rats. The same types of food are utilized and the same major end products are formed. When we compare the details of rat metabolism closely, however, we recognize certain marked differences. It is quite easy to concoct an excellent diet for rats upon which human beings will surely die. All that is required is to leave out one of the vitamins—ascorbic acid. This lack does not affect the rats, but it will kill human beings.

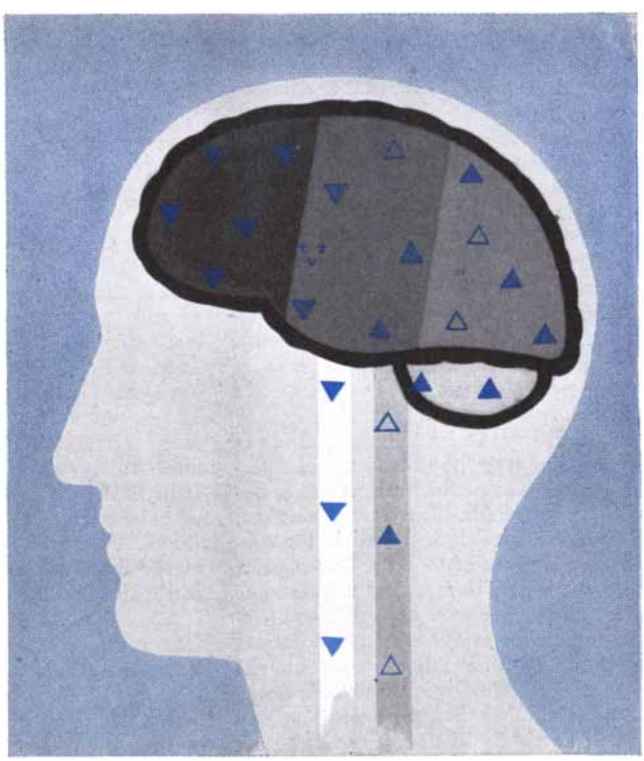
It is well known that individual human beings differ as to the amount of fat they can tolerate in their food, the amount of salt they require, and in their tendency toward obesity or its opposite. Furthermore, the ability of animals, notably dogs, to distinguish people by their odors, can be based only upon the fact that each individual produces his distinctive blend of metabolic products.

If the metabolism of individual people is distinctive, then there must be differences in the chemical processes taking place within them. Decades ago it was discovered that certain people exhibited, for some reason then unknown, metabolic peculiarities which were manifested by the presence of unusual chemicals in the urine. These conditions were not accompanied by disease; they were found to be inherited and were classified as "inborn errors" of metabolism.

Investigations being carried on currently at the University of Texas indicate that inborn differences (the term "error" is unfortunate) are commonplace rather than rare, and that individuals taken at random exhibit distinctive metabolic traits which become evident as a result of a careful analysis of the body fluids. The possession by each of us of a distinctive "metabolic personality" appears then to be established. It is inescapable from the standpoint of genetics; it is demonstrated by the fact that animals can distinguish us by our odors, and it is corroborated by laboratory findings as well as general observation.

OUR development as human beings is dependent not only upon our inherited metabolic patterns but upon numerous indispensable and modifying environmental influences. An individual may inherit the potentiality for producing an excellent and durable set of teeth. This potentiality can never become an actuality, however, unless proper nutrition is furnished and infective agents which might kill or damage the organism are avoided or overcome. It seems certain that metabolism is markedly affected even by psychological influences. Through fear, anxiety and worry people can poison themselves, develop ulcers and knot themselves into all sorts of other physiological difficulties. It appears that the autonomic nervous system which serves the visceral organs is functionally more or less set apart from the nervous tissue involved in the higher intellectual processes. The barriers between the two systems vary in their effectiveness in individuals, so that in some people the digestive and other internal organs are readily upset by any





that has broken down into carbon dioxide and water. In third drawing the heart has pumped the remaining alcohol to the brain. There it first affects surface areas (*black shading in fourth drawing*). Higher concentrations successively affect areas from front to back. Unconsciousness results when cerebellum at base is affected.

unfavorable mental event, and *vice versa,* while in other individuals trouble in one domain has little effect on the other.

If physiological individuality exists, there are a number of consequences which merit examination. One of these concerns the need for vitamins. Since many of the vitamins are used for the building of enzymes, and since our enzyme systems are not identical in make-up, it follows that we should expect quantitative differences, at least, in the vitamin requirements of individuals. While relatively little experimental work has been performed with human beings to test this idea, there is ample evidence to suggest that it is true. Even in inbred animals such as white rats and white leghorn chickens, it has been possible to produce by breeding substrains which differ in their requirements for certain vitamins.

Another evidence of individual differences in metabolism is the varying effect of drugs. It is definitely known that the specific physiological action of certain drugs is due to their ability to interfere with or modify specific enzyme systems in the body. There is good reason to assume that drugs generally act in this way. It follows that drugs should not have identical effects when administered to different people. Experience has shown that they do not. Morphine (from Morpheus, the Greek god of dreams) got its name because it puts most people to sleep. For some individuals, however, it acts as an excitant; it keeps them awake with thoughts rushing madly through their minds. Novocaine, widely used as a local anesthetic, does not work on some individuals. Anesthetics in general show variable effects; they cannot be administered in fixed quantities but are given by a skilled anesthetist, who carefully watches the reactions of the patient and grades the dosage to suit the particular case.

Caffeine is sold in drug stores for use in keeping people awake while driving automobiles at night, and so on. The amounts required by individuals vary widely. Nicotine sometimes produces a diseased condition of the retina of the eye, known as tobacco amblyopia, which results in blind areas. Most people, however, are not affected. In other individuals nicotine may produce Buerger's disease, which involves serious spasms in the blood vessels, particularly in the extremities, and often results in gangrene. The fact that these diseases are rare makes possible the continued wide sale of tobacco. Our interest is in the scientific fact that nicotine has widely different effects upon different people—a further evidence of physiological individuality. Many other examples might be cited. Individuality in response to drugs is the rule rather than the exception.

Still another evidence of physiological individuality is variation in taste and smell reactions. For some people saccharine is 2,000 times as sweet as sugar; for others it is only 32 times as sweet. For some, quinine is 256 times as bitter as cascara; for others it may be only half as bitter. The common sugar mannose, which is a close relative of glucose or dextrose, tastes first sweet and then later bitter to most people (about 55 per cent). To 20 per cent, however, it tastes sweet only; to 10 per cent bitter only; and to 15 per cent it is perfectly tasteless. Such differences are widespread but have been little investigated. Curt P. Richter of Johns Hopkins University even found among children some who could not taste a 20 per cent solution of ordinary sugar!

There are a great many reasons for thinking that physiological individuality as we have described it has an important bearing upon the problem of alcoholism. The most critical phase of the problem centers in the fact that some people, as a result of drinking, develop an intense craving for liquor which is never satisfied. Such an individual, unless his condition is remedied, becomes wholly useless to society and a tremendous problem for his relatives and friends. Compulsive drinkers who are found incurable usually die at a relatively early age.

HUMAN beings show enormous variation in their responses to alcohol. Some people are protected from drunkenness and from alcoholic addiction by the fact that even a small amount of alcohol when taken into the stomach induces spasms of the pylorus and vomiting. Those who can tolerate liquor vary tremendously in the degree of their tolerance and in the concentration in the blood required to produce drunkenness. An appreciable number of individuals show signs of intoxication when the alcohol content of the blood is .05 per cent, while others have been reported sober on the basis of ordinary criteria when the concentration is eight times this high, or .4 per cent. The rate at which alcohol is capable of being burned in the body also varies with individuals.

A similar wide variation is noted in responses to the injection of a minute, standard dose of alcohol beneath the skin. In all individuals a small red spot develops at the point of injection, and in about 18 per cent of the cases this is the only result. In the other 82 per cent, however, an inflamed area develops around the spot. This area varies in size and degree of inflammation from individual to individual. The most severe response is a highly inflamed area more than an inch and a half in diameter.

A study made of young children from four to ten years of age gave further evidence of inherent differences in the taste for alcohol. Most of them did not find the taste pleasant, but eight per cent of the children actually liked solutions submitted to them which contained as much as 50 per cent alcohol.

When people become intoxicated, the results are widely diverse; one may become drowsy, another sad, another happy, another pugnacious, and so on. The most striking example of individual behavior is so-called "pathological intoxication," an unusual form which should not be confused with ordinary intoxication. In these bizarre cases, the individual usually goes berserk and is likely to commit all sorts of crimes and damage before he is overpowered and brought into custody. After a long sleep, lasting perhaps as much as 24 hours, he awakes with no memory of what has gone before. Such a response as this must have its basis in the metabolic peculiarities of the individual afflicted.

The tendency to develop psychoses as the result of continued alcoholic consumption is absent in some and present in others—and the types of psychoses are many. Some become psychotic and incapacitated with very slight provocation, while others show impressive resistance. An authentic case is known of a man who died at the age of 93, having consumed a quart of Scotch whiskey every day during the last 60 years of his life—all the while managing a successful business.

Another striking example of individual response, which fortunately appears to be restricted to a relatively small percentage of people, is the development of an intense craving for alcohol. In such cases the craving generally builds up over a period of years. Yet many people can drink regularly without ever reaching a state where it is impossible to stop or where the thirst for liquor becomes in any sense overpowering.

Alcoholic craving and compulsive drinking must have a physiological basis, and their development in certain individuals must be due to distinctive metabolic traits which the unfortunate individuals possess.

OTHER cravings are known to have a physiological basis. Herbivorous animals and some African tribes living where salt is scarce develop an intense craving for salt, which clearly is based upon a physiological need. This craving may be induced by dietary means or by damaging the adrenal cortex. The sense of taste of such salt-hungry animals is so sharpened that they can detect salt in a solution 16 times as dilute as other animals can detect. Cravings for calcium and phosphorus likewise have a physiological basis. These cravings can be modified by damaging the parathyroid glands or by supplying the parathyroid hormone. Cravings for B vitamins, for protein, for fat, all have a basis in the physiology of the experimental animals used.

The existence of a craving with a physiological basis does not necessarily mean, however, that the craving is based upon a legitimate physiological need. Diabetes is a metabolic disease, the tendency to which incidentally is inherited as a Mendelian recessive. Accompanying it there is sometimes an intense craving for sugar, even though the diabetic

cannot make use of sugar in the usual fashion. This may be regarded as a "false appetite," but it has a physiological basis nonetheless.

An example of a developed craving which is not based on any real physiological need is drug addiction. It is significant that the same treatment does not produce drug addiction in all individuals. When morphine is given over a long period of time to induce rest in those with severe heart ailments, it can as a rule be discontinued without unusual effects. Some patients, however, develop an intense craving—the craving of morphine addiction. Without much doubt this has its basis in physiological individuality.

One of the strongest reasons for thinking that alcoholic addiction depends on the metabolic personality of the individual concerned is the fact that a case has never been known in which an alcoholic reverted to moderate drinking. An alcoholic must either remain an alcoholic or give up drinking entirely; there is something inescapable in his make-up that rules out the middle ground of moderation. Members of Alcoholics Anonymous may become very well adjusted—but they never become moderate drinkers.

Another striking fact bearing out the idea that physiological individuality is at the basis of alcoholism is the existence of wide differences among racial and national groups. The susceptibility of American Indians to alcohol, which is the basis for prohibition as it applies to all Indian reservations, is traditional. Dependable information or statistics on the extent of this susceptibility appear to be lacking, however. The most impressive information with respect to group differences has to do with persons of Jewish origin. In spite of frustrations and intense psychological stresses, coupled with some use of alcoholic beverages, Jewish people are seldom drunkards. That Jews possess common factors of inheritance is shown by the fact that diabetes susceptibility, which is definitely inherited, is far more prevalent among them than among non-Jews. The difference between Jews and other racial stocks in respect to alcoholism is not slight. Alcoholic psychoses have been reported to be 75 times more prevalent among the Irish than among Jews.

A study of physiological individuality, ultimately including physiological changes of psychogenic origin, offers a real hope for understanding the causes underlying alcoholism. There is every reason to hope that once we understand the causes, suitable preventive and remedial measures can be taken. Unless we take physiological individuality into account, we can fight alcohol addiction only as an unknown enemy, and in the dark.

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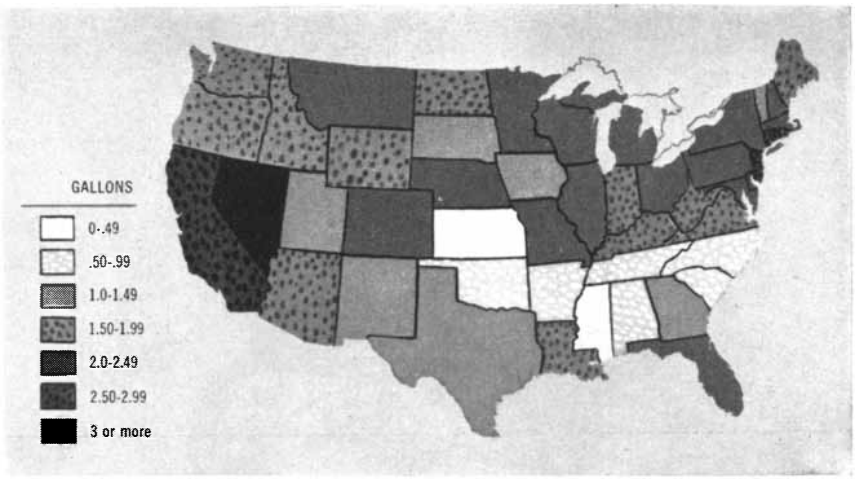
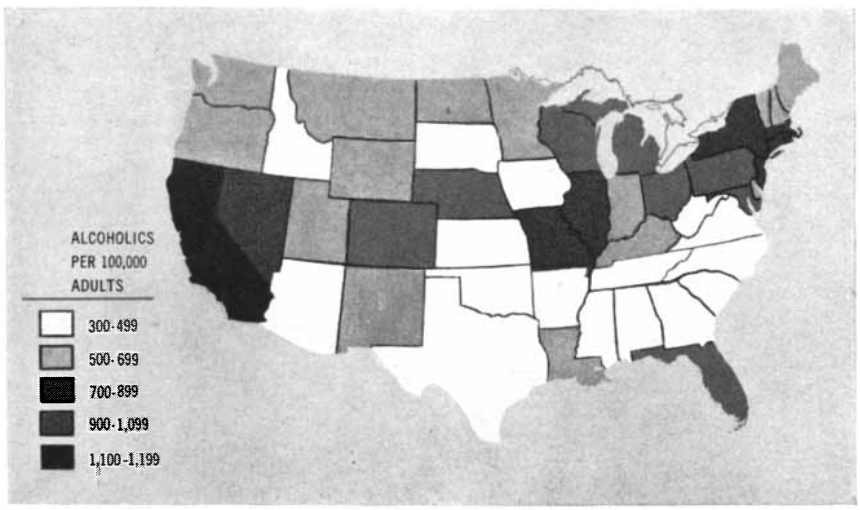
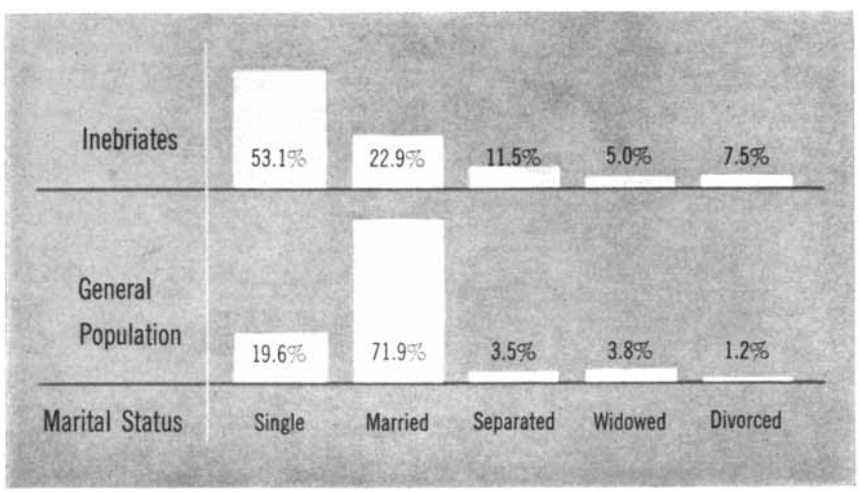


RELATIVE CONSUMPTION of alcohol in various parts of the U. S. is depicted in map. Key at lower left indicates average number of gallons of distilled spirits, wine and beer drunk per person in each state in one year.



CHRONIC ALCOHOLISM is plotted by states. Correlation with map above is not complete. Although Nevada has the highest per capita consumption, California has greatest number of alcoholics per 100,000 adults.



SOCIAL INFLUENCE in alcoholism is demonstrated by variation in the number of inebriates among people of different marital status. Physiological basis discussed by author may influence predisposition to inebriety.

HARVARD'S PRESIDENT James Bryant Conant in his latest book considers the chemistry of international relations and the role of the U. S. therein. His proposal: educational reforms to strengthen the appeal of democracy.

by James R. Newman

EDUCATION IN A DIVIDED WORLD, by James B. Conant. Harvard University Press ($3.00).

THIS is a reasonable and therefore valuable book. Its outstanding merit, in my opinion, lies less in what Dr. Conant has to say about the necessary overhauling of our educational system—although these suggestions deserve careful attention—than in his rational views on the subject of a divided world. At a time when it is safe to peddle any brand of jingoism if only the peddler makes it vehemently plain that he is more anti-Soviet than anyone else ever thought of being, it is no small matter to write disinterestedly about U. S.-Soviet relations. If you consider further that even the more disturbed of our professional patriots would hesitate before accusing the president of Harvard University of being a Soviet "sympathizer," you will recognize the far-reaching importance of Conant's enlightened utterances.

What special responsibilities does the world situation lay upon our educational system? Assuming, as Conant does, that war with Russia can be averted, how can our schools, colleges and universities contribute most effectively not only to the preservation but to the steady improvement of our form of society under the intensely unfavorable conditions of a global armed truce and incessant military preparations? These are the matters which Conant discusses.

The urgency of his recommendations for strengthening our educational system and extending "equality of opportunity for all children" stems from his conviction that our kind of democracy must increasingly put its ideals into practice if it is to survive the crises of the next decade. What Americans face, he points out, is the redoubtable challenge of a competing philosophy—a faith which, aided by hunger, misery and oppression, has won millions of converts the world over. It is a challenge more formidable than a challenge at arms, because hunger must be appeased, misery relieved and oppression lifted; because ideas must be fought with ideas, doctrines with more compelling doctrines, not with bombs, poisons and bacteria. Thus while favoring an adequate military establish-

BOOKS

Two reviews: the rationalism of James B. Conant; Marjorie Nicolson's collection of old-time aeronauts

ment against the catastrophic possibility that the world may "drift" into conflict, Conant asserts that "a global war is nonsense for both sides," and denounces as "criminal folly" the proposals for a preventive war. His appraisal "of the men who now rule so ruthlessly behind that Iron Curtain" deserves to be repeated:

"There are roughly three points of view current in the U. S. which in their extreme forms may be summarized as follows: There are those who think the dwellers in the Kremlin are Slavic followers of Thomas Jefferson and the enlightenment of the 18th century, or at worst the early socialists of the 19th century, that all their aggressive actions are based on fear of the capitalistic and imperialistic United States. The second viewpoint, the antithesis of the first, is . . . that the rulers of Soviet Russia are equivalent to the men who once surrounded Hitler and Mussolini, that they are military gangsters planning to conquer the world by war. . . . The third position, to which I am inclined, lays far greater emphasis on the ideology of Soviet Russia and of the parties which follow the Soviet line. According to this view, the leaders of Soviet Russia and the governors of their satellite countries are fanatic supporters of a philosophy based on the writings of Marx, Engels and Lenin. While military force would be used by the totalitarians whenever it was found advantageous, the chief reliance would be on the efficacy of their own doctrine. . . . The Russian military might based on ground troops hidden behind the Iron Curtain is to my mind but a secondary component of the two-pronged offensive, the Communist ideology and the tight-knit political organizations which are its vehicles being the primary source of strength."

In the defense against this "thrust of ideology," education has a leading part, for our youth are the heart of our strength. No hostile stockpile of atomic bombs can so seriously threaten the nation's survival as the failure to meet the problems of education; no stockpile of our own can compare, as a safeguard of democratic values, with a strong, healthy educational system. Unfortunately, as Conant makes clear, neither the methods nor the opportunities of education have kept pace with our changing and increasingly complex social order.

The process of refurbishing educational methods requires re-examination of the relative weights to be assigned to the humanities, the social and the natural sciences. There is, of course, a real place for the humanities—but what is it? The average humanities program is no more appropriate for the average student than courses in fencing or crocheting. The social sciences are perhaps of the first importance. There is, in our day, no need to make a case for the natural sciences, but here there are dangerous distortions of emphasis (not, I regret to say, mentioned by Conant), including a growing lack of interest in teaching and a frenzy to get aboard the military research gravy train.

The decision as to who shall be taught what must be guided not merely by principles of social equality, but by considerations of actual social and economic requirements. Educational programs must be made to reflect the "diversity of occupational goals," since it is pure folly, however well-intentioned, to attempt to turn everyone who wants an education into an intellectual or a country gentleman. The emphasis of what is taught must be first on "democratic living," second on giving every pupil what he deserves and what he needs to make him most useful within "a social structure as mobile as possible, and becoming more fluid every year."

Federal aid to education is essential in view of the inadequate resources—not to speak of the unwillingness—of many states to provide the kind of training which should be a minimum for all American youth. Conant is as impatient of the meretricious argument that federal aid entails dangerous, "bureaucratic" federal control as he is of high-flown nonsense about the adequacy of existing educational opportunities. "The oft-repeated statement in certain smug circles that 'any boy who has what it takes can get all the education he wants in the U. S. A.,' " he observes, "is contrary to the facts."

Above all, Conant insists, the higher schools must remain sanctuaries for free discussion and "unmolested inquiry." The university must be a representative concourse of diverse views if it is to fulfill its function in society. This means the study of all things and all philosophies, including the study of communism, for "to my mind, Soviet philosophy is something neither to be laughed off, nor to be treated as a vile obscenity; we cannot afford to pass it by in contemptuous silence . . ."

Many of Conant's conclusions will doubtless be regarded as dubious. To some it will appear that he is tainted by a brand of liberalism which the majority of the press, not to speak of other makers and leaders of opinion, now seem determined to extirpate. Others, I am sure, will be unhappy about his comments on the existing educational order, and in particular his suggestions for reform. Too often his generalizations are a good deal better than his specific advice. For instance, I am not convinced that he has adequately thought through the plan for two-year "terminal colleges" to take the place, for many students, of the undeniably random and unsatisfactory four-year liberal arts course. There is also some backing and filling, perplexing to the reader, as to just where Conant stands on the subject of military training. On the one hand he endorses the Compton report favoring such training; on the other, acknowledging that even six months of training "wrecks a college educational year," he seems to prefer a national militia. It is not clear how one can reconcile either view with his criticism of "those who talk in terms of armaments" for failing to see "that an ideological thrust can be answered only in ideological terms." I cannot sympathize with his "worry . . . that we may educate more doctors, lawyers, engineers, scientists, college professors than our economy can support;" nor am I altogether persuaded by his judgment that "the wisest and fairest course would seem to be to graduate somewhat too few rather than too many from our universities in any given year."

Nonetheless, these are the convictions of a sincere and independent mind. The entire book sets Dr. Conant apart from the timid mediocrities who head so many institutions of higher learning; there is much here that deserves the consideration of thoughtful men and women everywhere. No one is required to agree with his conclusions, but no citizen can afford to disregard the urgency of the problems which he has fairly and courageously set forth.

VOYAGES TO THE MOON, by Marjorie Hope Nicolson. Macmillan ($4.00).

MARJORIE HOPE NICOLSON here continues her scholarly work in a field which she has made peculiarly her own: the response of the literary imagination to the speculations of science, in this case on the subject of human flight. Somewhat wider in appeal than such of her earlier writings as *The Microscope and English Imagination* and *Newton De-*

DAEDALUS AND ICARUS, the most famous of the legendary fliers, are here depicted in a 1493 woodcut. Icarus is losing feathers and altitude.

FIRST DOGFIGHT between British and German aviators was described by an 18th-century satirical poet. The Briton (*left*) lost his wings and crashed.

mands the Muse, this book is still something of a learned monograph. Neither the elimination of footnotes—for which all thanks—nor Miss Nicolson's pleasant attempts to enliven the text are sufficient to offset the effect of the many quotations and allusions and of the material itself, which. contrary to what one might expect, is, as Miss Nicolson herself admits, frequently as dull as it is antiquated.

Man's aspirations to fly found early expression in ancient tales and myths, but Miss Nicolson does not pursue her theme in detail until she comes to the "cosmic voyages" of the 17th century. At this point science and literature, for reasons which are not altogether clear, begin to travel "hand in hand." Each new suggestion of a method of flight; each occasion when some intrepid clown soared from a rooftop only to break his bones, or worse; each of the flying-machine proposals of Francis Bacon, Leonardo da Vinci, Robert Hooke and the lesser fry, had its repercussions in fiction, drama and poetry. These adventures inspired a few good lines here and there—in Milton, for example—but much of the contemporary writing of this kind hardly merits exhumation, except by way of illustrating the thesis of the book. On the whole, the better-known writers—Rabelais, Cervantes, Donne, Swedenborg, Rousseau, Burton, Ben Jonson, Voltaire and Samuel Johnson—were not at their best on the fantasy voyages, and as for the lesser writers, some of whom made their entire reputations on moon and planet travel books, it is fair to say that the adjective "lesser" is too kind. Most of their conceptions seem more deficient in imagination than the science pulp fiction of our modern period.

Miss Nicolson divides the journeys into four main classes: "Supernatural Voyages," "Flight by the Help of Fowls," "Wanton Wings" and "Flying Chariots." Among the better-known of the 17th century items in this literary genre is Francis Godwin's *The Man in the Moone: or A Discourse of a Voyage Thither by Domingo Gonsales*. A precursor, according to Miss Nicolson, of *Robinson Crusoe* and *Gulliver's Travels*, this volume describes a voyage of 12 "daies" in which the hero rides to the moon behind a team of trained "ganzas" or wild swans. On the dawn of the first lunar day Domingo felt himself "first dulle, then heavy and willing to sleepe . . ."—which happens also to describe my reaction to his adventures. However, since Defoe and Swift were undoubtedly both in Godwin's debt, it is appropriate to acknowledge our own indirect indebtedness to him. *The Man in the Moone*, one may note further (as justification for Miss Nicolson's interest), was translated into several languages and served as inspiration for scientific popularizations by Wilkins, Fontenelle, Huygens and others. The "ganzas" became, for two centuries, catchwords and "symbols of gross exaggeration." It might still be well,

in fact, to think back on Samuel Butler's lines:

So when our speculations tend
Above their just and useful end,
Altho' they promise strange and great
Discoveries of things far fet,
They are but idle dreams and fancies,
And savor strongly of the ganzas.

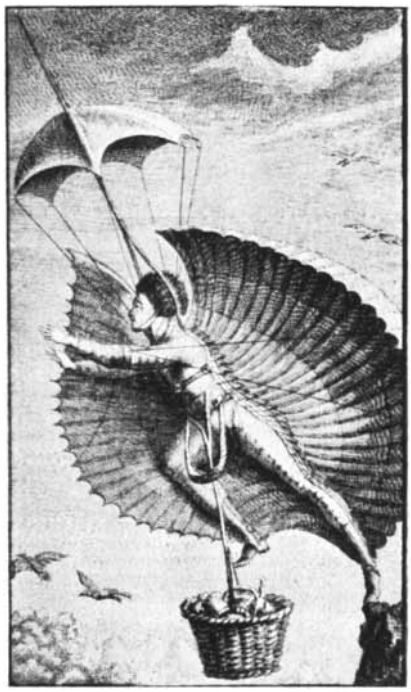
John Wilkins' *Discovery of a New World,* which appeared the same year (1638) as Godwin's fable, was, says Miss Nicolson, "the first important book of modern 'popular' science," a document mingling the "web and woof of old legend and new science in the mid-century." Pre-Newtonian in its scientific conceptions, it kept alive numberless wrong ideas, which was unfortunate, since its lucid style made it accessible even to the "meaner capacities" of ladies. *A Voyage to Cacklogallinia,* author unkown, which came a century later, was the next successful work on the "harnessing of birds." It was a satire based on that fantastic speculative scheme, the South Sea Bubble. Cacklogallinia was a land inhabited by birds, and so impoverished by a chain of victorious but ruinous wars that the Chief Minister spent his entire time thinking up new sources of revenue. "The Tax he approved of most, was on the Light of the Sun, according to the Hours it was enjoyed; so that the poor Peasant, who rose with it, paid for Twelve Hours Daylight, and the Nobility and Gentry, who kept their Beds till Noon, paid only for Six."

Of the relation between aviation and love, a connection which does not leap to the eye, there are two diverting items in Miss Nicolson's chapter on "Wanton Wings." Sitting before the "fyre" one evening in October of 1653, Dorothy Osborne was listening to a "desultory" conversation between her brother and a Mr. Gibson when they "fell into a discourse of fflyeing and both agreed that it was very possible to finde out a way that people might fly like Birds and dispatch theire Journy's soe. I that had not said a word all night [she continues in a letter to her lover, Sir William Temple] started up at that and desyr'd they would say a little more in it, for I had not marked the beginning, but instead of that they fell both into soe Violent a Laughing that I should appeare soe much concern'd in such an Art; but they little knew of what use it might have bin to mee. Yet I saw you last night, but twas in a dream."

Sixty years later, Miss Osborne's idea having apparently occurred to others, Addison commented on the danger to public morals of private flying: "It would fill the world with innumerable immoralities, and give such occasions for intrigues as people cannot meet with who have nothing but legs to carry them. You should have a couple of lovers make a midnight assignation upon the top of the monument, and see the cupola of St. Paul's covered with both sexes like the outside of a pigeon-house. Nothing would be more frequent than to see a beau flying in at a garret window, or a gallant giving chase to his mistress, like a hawk after a lark. There would be no walking in a shady wood without springing a covey of toasts. The poor husband could not dream what was doing over his head; if he were jealous, indeed, he might clip his wife's wings, but what would this avail when there were flocks of whoremasters hovering over his house?"

When it comes to flying chariots, it would not do to overlook Cyrano's "dew machine," nor his later, firecracker-impelled vehicle which, as Miss Nicolson suggests, made him "the first flier in literary history to reach the moon by means of a rocket ship." The flying canoe proposal of Francesco Lana in 1670 made a real contribution to aviation, since the craft was to be borne aloft by the lifting power of four evacuated globes. European scientists debated his theories with enthusiasm. Robert Hooke, in his famous role of modelmaker to the Royal Society, analyzed the plan most carefully and only reluctantly concluded that it was not feasible, because the materials available for constructing the globes would have to be so light in weight that they could not withstand the atmospheric pressure. Nevertheless it remained a somewhat more plausible machine than Pier Jacopo Martello's amber magneto-electric chariot, which was to be rowed to the moon by a hundred blue and yellow apes attached like galley slaves to their oars, or Daniel Defoe's aerial chariot, held up and steered by exactly 513 feathers and driven by an "ambient flame." The main part of the history is concluded (except for an epilogue which brings the account right up to Buck Rogers) with the first balloon flights of the Montgolfiers.

The material here unearthed is not, of course, a highroad of literature but rather a bypath for occasionally entertaining excursions. I have said little about the pictures of the moon and planets given by the several voyagers. Their descriptions are characterized by a sameness and lack of ingenuity akin to the fantastications of magic. They are less exciting or horrifying, so far as I am concerned, than Orson Welles' famous Mars broadcast; Jules Verne and H. G. Wells dreamed up much better worlds of "all monstrous, all prodigious things which fables yet have feigned," and C. S. Lewis' "insect-like vermiculate or crustacean abominable, twitching feelers, rasping wings, shining coils, curling tentacles" and "monstrous union of human intelligence and insatiable cruelty" make me feel considerably more uneasy than anything to be found in the earlier works. This is not to deny that Godwin, Wilkins and company were able to fascinate and frighten *their* contemporaries. But to a generation which has seen the mushroom cloud over Bikini there isn't much of that kind of stuff, old or new, which is likely to be unnerving.



FLYING LOVER in a popular 18th century French romance devised bat-like wings to rescue and elope with his highborn, forbidden mistress.

CYRANO DE BERGERAC is shown in attempt to reach moon by letting himself be sucked up by sun acting upon strapped-on vials of dew.

THE AMATEUR

Conducted by Albert G. Ingalls

READERS of this department often inquire about plastic optics—mirrors and lenses of plastic materials. Will they supplant glass or are they a passing fad? The answer is neither. In what follows, John M. Holeman of Richland, Wash., assesses the good and bad of plastic optics and tells how to work these materials.

Optical elements may be formed from any transparent substance and, due to their unusual properties, plastics may prove superior to glass in some applications. Possible advantages of plastic optics are:

Light weight. In a portable instrument using large or numerous optics this saving of weight may be considerable.

Breakage without shattering. Many plastics do not break into sharp pieces, an often valuable feature in lenses used near the eye.

Unusual combinations in index of refraction and dispersion. Some plastics have combinations of values different from any known glass. This permits the lens designer an additional degree of freedom with, in some cases, a simpler, cheaper and optically superior product.

Transparency to various radiations. Different plastics have a greater range of transparency than the glasses and may be used in scientific work where unusual transmission properties are needed.

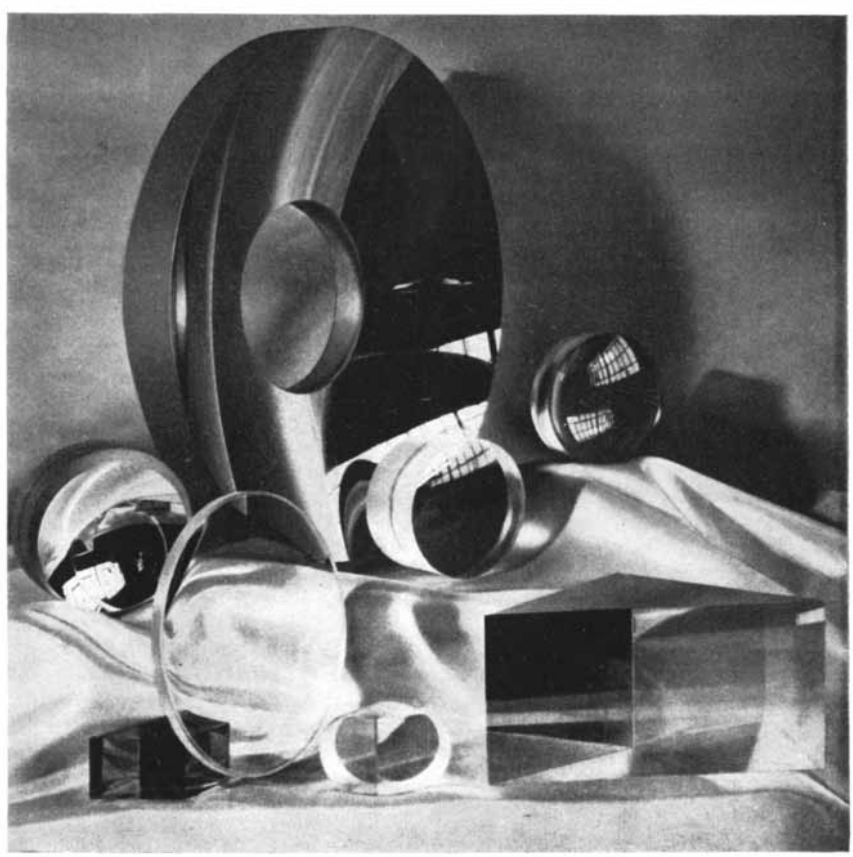
Ease of working. While at present it is more difficult to produce an optical surface on plastics than on glass, the machinability of plastics permits the production of odd shapes and moldability allows the production of unusually large and deep lens elements that would be impracticable in glass.

Thermal insulating properties. Many plastics are such good heat insulators that they make excellent windows into apparatus operated at very low temperatures.

Ease in production of aspherical surfaces. Molding procedure produces any curve in quantity.

Corrosion resistance. Certain plastics resist agents that attack glass and can be used where hydrofluoric acid fumes, for example, are present.

On the other hand, there are several properties of plastics which may make them



Plastic optical elements by Polaroid (small achromat at center)

ASTRONOMER

inferior to glass in most applications:

Softness. Most plastics are so soft that an optical surface cannot be cleaned without scratching.

Variation with temperature. A small change in temperature will change the index of refraction of most plastics several times as much as glass. Also, variation in dimensions is considerably greater.

Dimensional instability. Many plastics, depending on their chemical constitution, may lose solvent and become brittle, check, crack, or develop a crazed surface, discolor or crystallize and become opaque with age.

High cost. At present it is more expensive to make plastic elements than glass of the same degree of precision.

The following optical elements have been successfully made of plastic materials: lenses (simple and achromatic to 18 inches aperture and to exceedingly deep curves); prisms (right-angle, special, and infrared-transmitting, some of unusual size); mirrors (flat and concave, first-surface-aluminized); Schmidt correcting plates; plane-parallel windows; filters incorporating organic dyes.

In general, two methods of fabrication have been used—molding to shape and forming by cutting and abrasion.

The casting process has been highly developed by the Polaroid Corporation of Cambridge, Mass. and details are available from them in a paper by Edwin H. Land, director of research for that organization. The casting process is particularly adapted to mass production and consequently will be only of academic interest to the amateur who wants to make only one or a few elements. Two plastics are generally used, polycyclohexylmethacrylate with an index of refraction of 1.5064, which makes it similar to crown glass, and polystyrene with an index of 1.5916, similar to flint glass. A mold is made of Pyrex and, for casting a biconvex lens, two concave molds are made. Liquid plastic is poured into the mold and allowed to harden, taking the shape of the mold. The mold is opened and the finished lens removed. The surfaces are perfect and need no polishing. The lenses produced by this process are of good optical quality and may be used for any except the most exacting applications. They have not been suitable for astronomical telescope mirrors or objectives. This process is feasible only where a large number of identical elements are justified. Even then the cost per element is as high as that of glass elements of the same quality. The reasons for this are stated in Land's paper. This is distinctly not a cheap process.

Plastic optics may be shaped out of stock blanks by processes similar to those used in making glass elements. This pro-

cedure seems more applicable to amateur needs and small production. A process for making optics where great exactness is not required is useful for making mockups, condenser lenses, magnifiers and simple systems where only low power is to be used. Since such optics are not usually achromatic, a single material such as Lucite or Plexiglas may be used in sheets or rods. This is not made for optical use and may show striae and other obvious optical defects; hence each piece should be selected by eye.

The procedure for making a three-inch plano-convex condensing lens will be described with the assumption that the reader is familiar with common glass lens-making methods.

Out of a plastic sheet of adequate thickness saw a disk somewhat larger than the desired lens. Attach to it a support for holding in the lathe. It is recommended that the blank be attached to a hardwood or plastic backing with pitch, using hot water to warm the surfaces and to melt the pitch. With the blank rotating on the lathe cut the curved side to shape with a sharp tool and water lubrication. Check the curve with a template. Sandpaper or steel wool may also be used to bring the curve to shape.

Now make a concave lap of opposite curvature from the lens. Metal, plastic or wood may be used. Satisfactory laps have been made by the unorthodox process of casting blocking plaster against the turned surface of the plastic lens. Coat the lap with melted pitch and cover with ordinary department-store felt. Shape the felt-covered lap to the lens. When cool, saturate the lap with rouge paste and polish the lens as it rotates on the lathe or transferred to a spindle. Hold the lap in the hand and oscillate it over the lens surface. Comparatively deep scratches and tool marks will polish out quickly.

The process is complete when the surface is polished and all marks are removed. The surface will appear rather dull due to minute scratches produced by the felt hairs. Coat the palm of the hand with dry rouge and stroke the rotating lens a few times, using the palm in a manner similar to a lap. A dozen strokes should put a beautiful polish on the lens.

Detach the lens from the blocking piece by heating in water. Turn it over and finish the other side. A special concave backing block may be helpful in holding the curved face. If the second surface is to be flat, machine it flat on the lathe and polish with a flat lap made by covering a flat tool with felt and forming this lap against another flat surface while warm. Edge the lens, separate it from the backing, and clean it.

Any kind of polishing abrasive is suitable—ordinary, cerium or Barnesite, though cerium is preferred. For final polishing, a lap covered with rayon or silk velvet may be used instead of the palm. Ordinary rouge or precipitated chalk may be used in this step but best is precipitated

titanium oxide, the pigment of good white paint. DuPont Ti-pure R-300 is good, though available only in 50-pound quantities, but Universal Shellac and Supply Co., Brooklyn, N. Y., furnish it in one-pound cans as "White Glassite."

To make a precision surface on plastics a different procedure is followed. For a precision lens or prism optical quality plastic must be used and this is as hard or harder to obtain than optical glass. Each piece must be inspected by the methods used for glass. You can obtain the raw unpolymerized plastic from the manufacturer and mold it yourself in simple molds or buy second-hand plastic lenses and cut them up for material. At present, three-inch plastic achromats may be had from salvage companies at low prices due to scratched surfaces.

Turn the blank on the lathe to approximate shape and check by template. Make a lap similar to a brass "true-tool" (see Twyman, *Prism and Lens Making*, or Dévé, *Optical Workshop Principles*) or a glass one. Both male and female are cut to templates and worked together with fine emery to get true surfaces on the laps. Now grind the surfaces to the lap. This is the hardest part because the abrasives sink into the soft plastic and it grinds the lap, instead of *vice versa*. Some means of anchoring the abrasive is almost a necessity. For rough grinding, sandpaper, preferably the waterproof kind, may be cut, gored, and cemented to the lap. For fine grinding the lap is cleaned, painted with a thin layer of rubber cement and sprinkled with abrasive.

For fine grinding emery is a better abrasive than Carbo, but best of all is cuttlefish powder. Cuttlefish bones in ground form make a most peculiar abrasive. These are sold in pet stores to canary owners. Cuttlefish powder and paper, which looks like sandpaper, are on the market and have long been used by cabinet makers to polish lacquer ware. These materials are, however, so hard to find that personal preparation will be described.

A cuttlebone is pounded in a mortar and sieved through screening. Several grades may be obtained and the finest washed with water and graded like emery by elutriation or levigation. Plastics are so soft that, in grinding, several grades may be skipped, and no definite recommendations may be given. Incidentally, cuttlefish powder will polish quartz and many other hard materials. Some brands of scouring powder can be used as fine abrasives on plastics, but they are so likely to contain coarse particles that they cannot be used without levigation.

Grinding of the plastic is done with a metal lap and various grades of abrasive, using rubber cement when necessary to anchor the abrasive. Lead, brass, copper and wood laps have been used without discovering any special advantage in any.

Polishing is done with a pitch or beeswax-coated pitch lap. Unfortunately, pitch sticks to many plastics to an extent that is most surprising to a worker used to glass. The only way to prevent this is to first work the pitch surface full of rouge. To do this, a glass dummy exactly like the plastic surface is made up and the pitch lap formed to it, channeled, and the glass polished, using rouge that is almost dry. This grinds rouge deep into the lap. When the lap is thoroughly impregnated and no pitch shows, it is cold-pressed to the plastic surface and used as a polisher with little rouge and plenty of water. Slow polishing speeds must be used, as the thermal expansion of plastic is high.

Using the above procedure, plane-parallel windows showing Haidinger's fringes equal to good glass samples have been made. Plastic flats have been made that have retained a quarter wave figure for one year.

Plastic optics are cemented with butyl methacrylate obtainable from the Eastman Kodak Company. The liquid is placed between the elements and set by heating in an oven to 60 degrees Centigrade (140 degrees Fahrenheit) for one half hour. During the war a great many glass lenses were cemented with this material instead of balsam. Such lenses are almost impossible to separate.

At present plastic optics leave much to be desired, especially in cost and permanency. When we have been making plastic lenses as long as we have been making optical glass, big improvements will have arrived. Today its most promising applications are those where glass cannot be used but there are more of these than is generally known. The full possibilities have not been explored, nor can they be in a short length of time. The possibilities of glass haven't been exhausted in 400 years of optic manufacture.

A NEW process, publicly announced, has been developed for economically coating the surfaces of plastic lenses and first-surface mirrors with quartz. Such surfaces are harder than glass and of excellent optical quality. Details may be had by sending $3.00 for the John R. Whipple Report No. P.B. 4158 to the Office of Technical Services, Department of Commerce, Washington, D. C. This report was summarized by N. W. Scott, Engineer Board, Fort Belvoir, Va., before the Optical Society of America. The method resembles aluminizing, except that the material evaporated is silicon monoxide which on exposure to the air becomes silicon dioxide, or quartz. The evaporation is carried on in a very good vacuum and coatings as thin as a few millionths of an inch give surprising protection to soft surfaces. Silicon monoxide is used, instead of quartz directly, because of its comparatively low boiling temperature. The material is made by vacuum distilling a mixture of powdered silicon and silica together. Large lumps which oxidize only superficially may be saved and used as desired.

AN INDEX OF ARTICLES AND AUTHORS

The following index lists all the articles and authors that appeared in SCIENTIFIC AMERICAN *during 1948. Those articles and authors that appeared in this magazine before May, when the first issue of the new* SCIENTIFIC AMERICAN *was published, are indicated by an asterisk.*

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"BELIEVE IT OR NOT, HOPE HAS AN INTELLIGENT IDEA!"

says CROSBY

CROSBY:

Folks, this is fantastic, but old Hope has a great idea. He thinks *everybody* ought to give U. S. Savings Bonds for Christmas presents!

HOPE:

Thanks for the kind words, son. But no kidding, ladies and gentlemen, those Bonds are sensational. They're appropriate for *anyone* on your list. On Christmas morning, nothing looks better in a stocking—except maybe Dorothy Lamour.

CROSBY:

Old Ski Nose is correct. And don't forget how easy it is to buy bonds—you can get 'em at *any* bank or post office.

HOPE:

How about it, Mr. and Mrs. America? This Christmas let's *all* give U. S. Savings Bonds!

Give the Finest Gift of all...

U.S. SAVINGS BONDS

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