SCIENTIFIC AMERICAN

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FIFTY CENTS

July 1950

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Research leading to "45"—confirmed at RCA Laboratories—covered 11 years . . . and resulted in small, non-breakable records which can be stored by hundreds in ordinary bookshelves, yet play as long as conventional 12-inch records. The automatic player, fastest ever built, changes records in less than 3 seconds—plays up to 50 minutes of glorious music at the touch of a button! Every advantage of convenience and cost, marks "45" as the ideal system!

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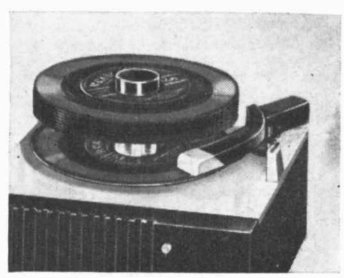

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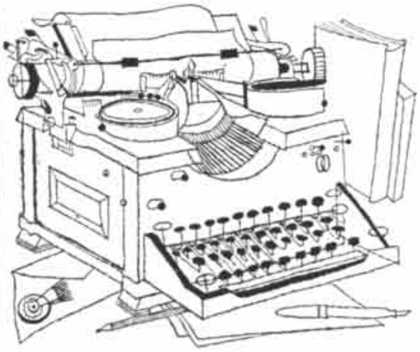

LETTERS

Sirs:

I should like to recall, in connection with the article on the mechanical turtles in your May issue, the "mechanical dog" made by the American inventor, John Hays Hammond, Jr.

This creature was described in the *Electrical Experimenter* in 1915 by B. F. Miessner. It boasted of two selenium cells mounted behind eye lenses and connected through relays with electromagnetic switches; it had a system containing a driving motor and three wheels. Less complex than the turtles, this "dog" moved under the influence of light like any candle-bound moth.

The article was quoted by the physiologist Jacques Loeb in his book *Forced Movements, Tropisms, and Animal Conduct* (1918) as "proof of the correctness of our view" (of animals as machines).

EVA H. SCHWARTZ

San Diego State College
San Diego, Calif.

Sirs:

The article by W. Grey Walter on "An Imitation of Life" was of particular interest to me.

In 1912 the mechanistic view of life, as conceived by such men as the inventor Nikola Tesla and Jacques Loeb of the Rockefeller Institute, was a subject of considerable discussion. There were many popular science articles about Loeb's work with radiant stimuli that produced forced movements in animals. One of these articles explained the forced or involuntary flight of a moth into a flame on the basis that the action of light or heat on areas on each side of the moth reflexly ruddered its tail.

I was at that time associated with John Hays Hammond, Jr., in the development of guided and homing missiles that were responsive to various kinds of radiant energy such as radio waves, light and infrared radiation. Hammond suggested that we ought to be able to make a machine which would, on terra firma, do exactly as the moth does in flight. He set me to work on the development of such a machine in the winter of 1911-12. I saw at once the applicability of the moth mechanism to a homing missile, as well as to a guided missile.

Of present interest, however, in connection with Dr. Walter's article, is the "electric dog" apparatus which I built during the winter of 1911-12 in New York. This apparatus consisted of a body of about 30 inches long by 14 inches wide by 10 inches deep. It had a six-volt drive motor connected to two forward drive wheels through a differential gear box. A rear steering wheel could be turned on a vertical axis by twin solenoids, or left in a spring-biased middle position. The apparatus had two selenium cells in front, behind six-inch condensing-lens "eyes," with an intervening "nose," which cut off the light from one cell when the light was more than 10 degrees to one side or the other of a dead-ahead position. Some relays, batteries and a motor-reversing switch completed the arrangement. The dog would be quiescent so long as it saw no light sufficiently strong to operate the selenium cells' sensitive relays. Raising a window-shade in a darkened room or turning on a light would activate the dog, and start it toward the light.

If the light were moved about, the dog would follow it, at a speed of two or three feet per second, in circles, figure eights or other more complicated maneuvers within its turning radius. If the motor-reversing switch were thrown, the dog would back away like a crab, always facing the light. The movements of its steering wheel were accompanied by clanking noises as the solenoids switched it in response to the movements of the light source.

Dr. Walter's "turtles" add a tactile control to the phototropic controls of

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the electric dog. Numerous other controls might also be added, such as color-selective visual controls, auditory controls, olfactory controls and so forth. The dog could have been made to drool when it smelled meat, bark when it heard certain sounds, growl if kicked, blink if the light were too strong, shake itself when wetted, run away if scolded and so on *ad infinitum*.

B. F. MIESSNER

Morristown, N. J.

Sirs:

Professor Walter's article, "An Imitation of Life," was most fascinating. However, I object to his attribution of "free will" to his *Machina speculatrix*. He has given his creatures random, undetermined activity which indeed differentiates them from machines, but this is not free will. Free will is not randomness, activity freed from the laws of causation. It does not lie in the mere existence of a number of possibilities, but in the exercise of a conscious, active, deliberate choice among these possibilities. Similarly when he writes of the human nervous system; the fact of number does not exclude (1) determinism (2) randomness.

We, like "Elmer," can act only according to our construction, according to the possibilities that are built into us. "Elmer does not blunder into the light, for when the brilliance exceeds a certain value . . . the signal becomes strong enough to operate a relay in the first tube, which has the reverse effect from the second one." Elmer must obey all the impulses he receives, although perhaps at times in an irregular way. We too are unable to control the series of volitions which we term the "will"; but our freedom lies in our ability to control by a process of evaluation their passing into action. All of Elmer's impulses ("volitions") become action.

I wonder whether the shortcoming of science, here and in all matters human, is that it is limited to a quantitative basis. Is it not possible (though unscientific) that there may be also a qualitative difference between a mere pulsation and a feeling of love, hate or jealousy? Is there a difference between "independent activity," mechanical memory, etc., and that quality we call "understanding," which enables us to be conscious of the process we are performing and comprehend it? I do not claim there is, but can we at this point exclude that possibility? When Dr. Walter builds his robot with more "nerve channels" than man, I wonder whether it will be able to formulate a theory, even from its own viewpoint, of good and evil, and whether it will be able to distinguish the beautiful and the sublime.

L. G. CROCKER

Sweet Briar, Va.

50 AND 100 YEARS AGO

JULY, 1900. "A delightful and profitable meeting of the American Association for the Advancement of Science was held in New York City from June 23 to June 30, with several hundred fellows and members in attendance, and a long list of papers and addresses on a host of scientific topics. A rather amusing episode arose in connection with two very able papers read by the well-known statistician, Edward Atkinson, of Boston. The breeze arose from Mr. Atkinson's incidentally affirming that 'the United States Government is spending annually $150,000,000 for the killing off of the Filipinos.' This observation struck several members as out of place, and their sentiments were voiced by William H. Hale, of Brooklyn, who never lets his patriotism be hidden under a bushel. He stigmatized the utterance as seditious, and protested against its being printed among the proceedings of the A.A.A.S. Mr. Atkinson retorted that he hoped it might be barred out, and reminded his critic that when that experiment had been tried by the Government concerning one of his former publications it had ended by 100,000 copies being sent abroad instead of 2,000 copies."

"Of the 46,988 deaths which occurred in Paris in 1899, as many as 12,314 are attributed to tuberculosis, or more than one-fourth. From the age of 20 to 40 tuberculosis counts for three-fifths of the total mortality."

"The automobile industry, though still in its infancy in Germany, is being rapidly developed, and, in the opinion of the United States Consul at Leipzig, is destined to become an important factor in the manufacturing industries of the country. The large amount of capital and energy which is being expended upon this branch of industry indicates that the German businessmen have great confidence in the future of automobilism."

"The statistical report of the Interstate Commerce Commission shows that there has been a steady extension of the railway system of the United States, and a marked increase in traffic, both freight and passenger. The total number of casualties during the year was 51,743, of which 7,123 were killed. The number of passengers killed was 239. During the year no less than 4,040 trespassers were killed, and a slightly larger number injured. With reference to trainmen, in which term are included enginemen, firemen, conductors and other trainmen, it is shown that 1 out of every 155 was killed and that 1 out of every 11 employed was injured. In view of the great risks run by employees, it is gratifying to note that, thanks to the efforts of the Commission, the work of equipping cars with automatic couplers and other attachments calculated to reduce the list of casualties is proceeding rapidly."

JULY, 1850. "The grain worm, or weevil, began its course of destruction in Vermont about the year 1828, and it progresses in the course it takes from ten to fifteen miles a year. It has not yet reached Western New York; but the destroyer is on its march, and desolation will follow its track in this great wheat-growing region."

"England has always boasted of her wooden walls, and recent experiments at Portsmouth, in that country, in testing the effect of shot and shell upon the sides of iron vessels, justify the claim to superiority of oaken sides implied in the boast. The results show pretty conclusively that iron vessels are not fit to cope with vessels of wood. The fatal effects of every shot received on board would be quadrupled by the tendency of the ironwork to splinter and destroy everything in the vicinity of the concussion."

"The expense of fuel to do the same amount of work with steam engines now is only one-third of what it was in 1815."

"The Hudson River railroad one day last week brought down a train of twenty-three large cars, having 1,750 passengers. The train was half a mile in length—the heaviest train, probably, ever drawn in this country by a single locomotive."

"We make an annual tour in the course of our orbital revolution round the sun, which carries us to two points of space nearly 200,000,000 of English miles apart. We are actually tearing through space at the rate of nineteen miles per second, or 68,000 miles an hour. But the most extraordinary fact is this, that, notwithstanding the vast space which separates the position of our earth at opposite seasons of the year, the scenery of the fixed stars is noways sensibly distorted by our change of place. The vast distance from the earth to the sun is seen from the nearest fixed star as an angle not exceeding one second."

"The most extensive powder-mills in the world are those on the Brandywine, Delaware, and the best powder made is at these mills. They manufactured last year 2,500,000 pounds."

"At one of Lord Rosse's recent scientific soirees, Mr. Appold exhibited his curious Register Hygrometer for keeping the atmosphere of the house at one regular moisture. The instrument with a variation at one degree in the moisture of the atmosphere opens a valve capable of supplying ten quarts of water per hour; delivering it to pipes covered with blotting paper heated by a gas stove, by which the water is evaporated until the atmosphere is sufficiently saturated and the valve thereby closed."

"The binary stars: To Sir William Herschel the honor of discovering this extraordinary combination of the heavenly bodies is due. That great man remarked that there were many instances of two stars being placed so close together as to appear to the eye as one, it being only by means of the telescope that their separate orbs could be descried. Extended observation soon showed that this combination occurred far too frequently to be the mere effect of accidental similarity of direction; there is no position in astronomy better established than the fact that two, three, or more stars may be found in combination revolving round each other and exercising a combined influence on the planetary systems relating to each."

"Mr. Bond, of the Cambridge, Mass., University has daguerreotyped a star in Lyra. This is believed to be the first instance in which an attempt to daguerreotype a star has succeeded. The picture of the star, the Boston 'Traveller' says, is quite distinct, and of the size of a common pin head, and was obtained in about 30 seconds, the great refracting telescope of the observatory being used without the eye glass. Scientific men will regard this experiment with interest, as the possible prelude to important astronomical developments."

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Examining specimen on metallographic microscope at Bell Telephone Laboratories.

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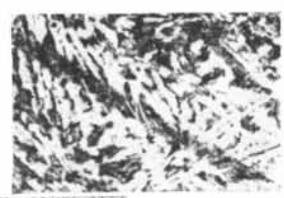
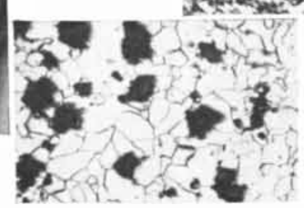
Photomicrograph of white cast iron which is hard and brittle.





Same iron rendered malleable by heat treatment. Shows spots of nodular carbon.

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THE COVER

The painting on the cover shows four stages in the evolution of corn, economically the most important plant in America (*see page 20*). At the lower right of the painting is a single kernel of modern dent corn, the principal variety of the Corn Belt. Just above and to the left of the kernel is the tiny cob of a variety grown by American Indians about 2000 B.C. This cob, discovered in 1948 by an expedition of the Peabody Museum of Harvard University to Bat Cave in New Mexico, is the oldest specimen known. On the left side of the painting is the many-colored ear of a variety grown by Indians at the time of Columbus. Corn of this type is one of the ancestors of modern breeds. In the background of the painting are several branches of a tassel of a possible ancestral form of all the varieties. This is a South American pop corn whose seeds are partially enclosed in glumes. The tassels of this pod-pop corn are mounted on a placard in the Harvard Botanical Museum, where all of these specimens are located. At the lower right on the placard is a blue symbol for pop corn. This painting is the 21st SCIENTIFIC AMERICAN cover that has been done since May of 1948 by the young American painter Stanley Meltzoff.

THE ILLUSTRATIONS

Cover by Stanley Meltzoff

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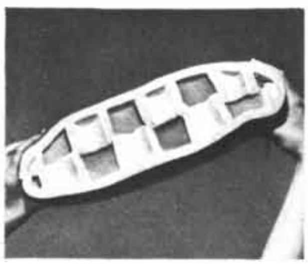

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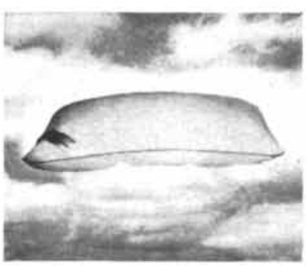

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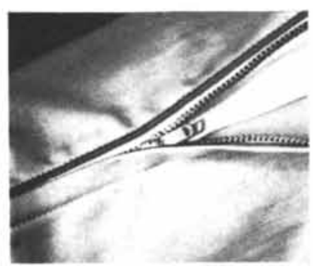

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SCIENTIFIC AMERICAN

JULY 1950 VOL. 183, NO. 1

THE NEW SCIENCE FOUNDATION

An agency unprecedented in U. S. history will soon begin its task. Its most challenging responsibility will be to recruit able youths for work in basic science

by M. H. Trytten

THE LEGISLATION establishing the National Science Foundation is now on the statute books as Public Law 507 of the 81st Congress. That the creation of this Foundation is a milestone in the progress of science in the U. S. is obvious. The Foundation is charged with two main functions: 1) support of basic scientific research, 2) development of the nation's resources of scientific manpower. The legislation recognizes officially for the first time in our history that basic scientific research is a national resource so important that the Government must assume responsibility for its vigor and effectiveness. But perhaps the most definite break with the past is the recognition that the national welfare in a modern world requires large numbers of specialists of advanced training, and that this too is a responsibility of the Federal government.

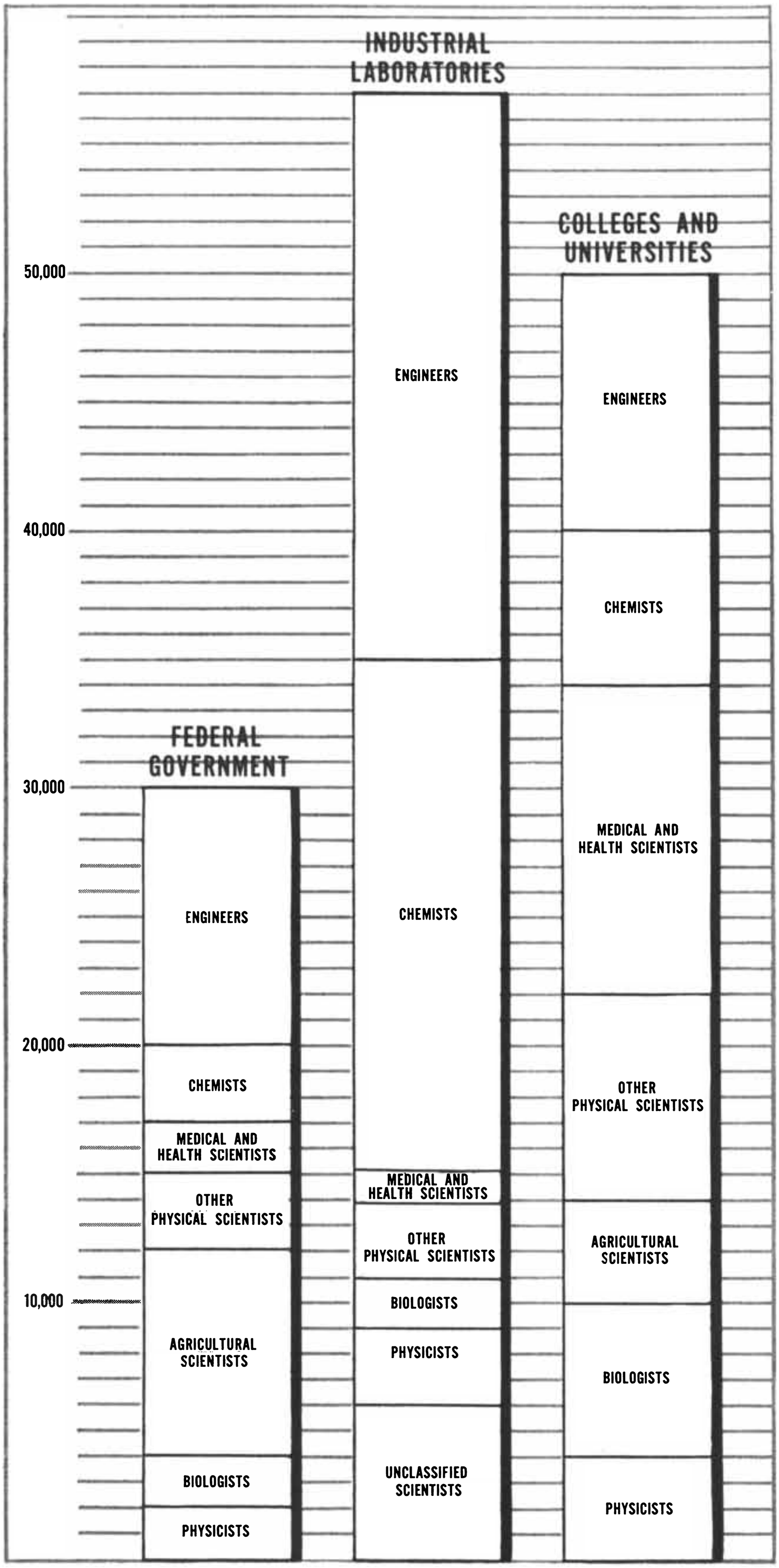
The acceptance by the Congress and the people of the idea of a Science Foundation with such new departures was a direct result of the dramatic successes of wartime research. Science had demonstrated its great power and versatility in developing weapons and drugs. But from this realization to the support of basic research rather than applied science was a long step. To the taking of that step two historic reports contributed greatly. One of the reports grew out of a request by Franklin D. Roosevelt to Vannevar Bush, director of the wartime Office of Scientific Research and Development, for a plan whereby the successful experience of this Office could be used for postwar progress in the improvement of health and the national standard of living. The result of surveys of these questions by four committees of citizens appointed by Bush was the well-known "Science—The Endless Frontier." The other report, "Science and Public Policy," was prepared at the request of President Truman by the President's Scientific Research Board under the chairmanship of John R. Steelman.

The two reports showed remarkable unanimity in their conclusions, particularly in their emphasis on the paramount importance of basic research and scientific education and in their recommendations for furthering those purposes. Their argument in substance went as follows: Although American ingenuity has always been preëminent in many fields of applied science, invention and engineering, in these activities we have been exploiting a stockpile of basic scientific discovery developed largely in Europe. Our own contributions to basic research in the past have been less impressive. Now that scientific work abroad has been seriously reduced, we can count on much less basic progress from foreign efforts. We must take up the slack by increasing our own efforts in fundamental research, not only for the sake of the vigor of our own science, but because we are now the world's chief trustees of the tradition of free inquiry.

The universities and colleges are the most logical places for carrying on such work. But they cannot shoulder the load of increased responsibility without substantial help. They are caught in the squeeze between decreasing returns on endowments and rising costs of research. They are hard put to it to retain the services of their able scientists in competition with outside bidders seeking scientists for the applied research on which an expanding economy depends. Consequently the Federal government must find a way to strengthen the hands of the colleges and universities where basic research and the education of scientists is conducted.

THIS is the basic reasoning on which the National Science Foundation has been established, and the law reflects the recommendations of both reports. To make sure that the complex pattern of higher education and science will be kept in proper balance, the Foundation is to be governed by a board of 24 eminent men from many fields. Under their understanding guidance the possibilities of the Foundation will be very great.

In structure the Foundation is like no other Federal agency; its organization and form of responsibility are so novel that it is too early to attempt to evaluate them. An interesting step in the evolution of Government agencies, the new Foundation is set up in a manner designed to strike a balance between two conflicting principles. On the one hand, there is an urge to place the highly intricate and technical problems of our complex society in the hands of competent experts and insulate them from



NUMBER OF RESEARCH WORKERS in each discipline and the fields where they work are shown here. Data are from the Steelman report. They demonstrate that applied research gets more support than basic science.

transient political influences. On the other hand, in a democracy an agency too carefully insulated from politics may also be insulated from understanding and support by the Administration, the Congress and the people, with whom the ultimate decisions rest. The new Foundation seeks to reconcile intellectual authority with public responsibility by providing that the members of the governing Board, appointed by the President with the consent of the Senate, shall be persons of distinction in the sciences, education and public affairs, and shall serve for six-year terms.

THE law still reflects some military considerations, for the Foundation is instructed to undertake researches "in matters relating to the national defense" if the Secretary of Defense requests them. But it is interesting that the emphasis on military research steadily receded in successive versions of the Foundation bill as we left World War II farther behind. In the early versions the Foundation was to include a division of defense research, but this demand yielded to a more mature concept of support of pure science for its own sake. The final version goes far, though not quite all the way, to remove the possibility that applied military research will interfere with the basic purposes of the Foundation.

To many the most interesting challenge presented by the new Foundation is its scholarship and fellowship program. The nature of this problem in American science has changed somewhat since the program was first proposed. The original argument for it rested heavily on the need for replacing a "lost generation" of scientists—lost because the training of young scientists was greatly curtailed during the war. While the predicted shortage of scientists did indeed materialize, some new factors have entered the picture. The influx of students, especially veterans, into the universities after the war was so great, and their interest in engineering and the sciences so unprecedented, that many have begun to wonder whether we are not training more scientists and engineers than we shall be able to employ. If so, what need is there for more fellowships?

This question, fundamental to the future activities of the Foundation, requires careful analysis. The answer to it will call for detailed studies of supply and demand and a philosophy as to the proper magnitude of the eventual science effort in the nation.

Obviously the activities of the Foundation will have a dominant effect on both the supply and demand: the size of its basic research program will help determine the demand for scientists, and its fellowship program will affect the supply. Thus the Foundation in effect

PROFESSIONAL FIELD	REGISTRATION			AGE					EDUCATION			
	TOTAL	MALE	FEMALE	29 AND UNDER	30-39	40-49	50-59	60 AND OVER	DOCTORS	MASTERS	BACH-ELORS	OTHER
	396867	376655	20212	96869	120606	107951	48281	23160	34084	52240	225033	85510
BIOLOGICAL AND AGRICULTURAL SCIENCES	23886	21511	2375	4694	8293	6198	3190	1511	6406	5988	10321	1171
AGRONOMY AND SOIL SCIENCE	2221	2214	7	345	748	722	298	108	394	557	1189	81
ANATOMY	473	432	41	32	157	136	78	70	344	60	68	1
ANIMAL AND POULTRY SCIENCE	1201	1193	8	288	302	374	176	61	122	324	716	39
BACTERIOLOGY AND IMMUNOLOGY	2593	2016	577	762	880	498	326	127	721	627	1125	120
BOTANY	1041	817	224	194	333	238	152	124	586	298	146	11
DAIRY SCIENCE	1158	1155	3	231	451	285	150	41	112	268	704	74
ENTOMOLOGY	1526	1495	31	171	520	454	275	106	476	531	459	60
FORESTRY AND RANGE MANAGEMENT	4383	4373	10	535	1981	1130	502	235	129	1022	2783	449
GENERAL BIOLOGY AND NATURAL HISTORY	1917	1421	496	869	493	339	136	80	410	462	921	124
GENETICS	371	335	36	55	133	93	62	28	248	76	33	14
HORTICULTURE	1115	1104	11	121	320	384	213	77	252	359	461	43
HUMAN NUTRITION	435	132	303	153	95	97	69	21	127	137	155	16
PARASITOLOGY	316	286	30	40	125	92	40	19	193	74	45	4
PATHOLOGY	640	580	60	24	113	247	161	95	94	109	428	9
PHARMACOLOGY	306	287	19	47	120	81	33	25	159	45	96	6
PHYSIOLOGY	840	731	109	149	300	217	113	61	543	143	146	8
PLANT PATHOLOGY	708	678	30	65	221	210	148	64	399	196	105	8
PLANT PHYSIOLOGY	330	290	40	39	140	78	48	25	244	65	20	1
WILDLIFE AND FISH	397	391	6	62	195	96	32	12	83	143	145	26
ZOOLOGY	1490	1185	305	434	533	288	130	105	690	410	338	52
OTHER	425	396	29	78	133	139	48	27	80	82	238	25
PHYSICAL SCIENCES	89791	82499	7292	32804	30905	15675	7050	3357	15269	17306	46976	10240
ASTRONOMY	344	283	61	53	111	78	44	58	182	81	66	15
CHEMISTRY	61509	56906	4603	23778	21022	10224	4602	1883	9648	9427	33791	8643
GEOLOGY	6113	5864	249	1387	2216	1562	633	315	1063	1473	3179	398
GEOPHYSICS	1173	1165	8	158	653	288	49	25	99	199	702	173
MATHEMATICS	9972	8015	1957	3356	3345	1738	944	589	1620	3325	4683	344
METEOROLOGY	1072	1051	21	292	442	194	68	76	35	188	506	343
PHYSICS	9608	9215	393	3780	3116	1591	710	411	2622	2613	4049	324
ENGINEERING	200202	199807	395	45128	59825	56006	26164	13019	2347	14682	134203	48970
CIVIL	47710	47614	96	4550	11668	16634	9329	5529	204	2740	30675	14091
SANITARY AND PUBLIC HEALTH	2108	2103	5	245	756	618	313	176	39	361	1352	356
OTHER	45602	45511	91	4305	10912	16016	9016	5353	165	2379	29323	13735
ELECTRICAL	39935	39870	65	8077	12826	13000	4322	1710	385	3065	28107	8378
RADIO AND COMMUNICATIONS	12254	12231	23	2820	4299	3893	985	257	159	1075	7820	3200
OTHER	27681	27639	42	5257	8527	9107	3337	1453	226	1990	20287	5178
MECHANICAL	54166	54070	96	14479	16536	13588	6543	3020	259	3145	35933	829
AERONAUTICAL	8835	8814	21	4397	3179	938	283	38	81	658	6112	1984
AUTOMOTIVE	2311	2310	1	323	676	715	462	135	7	159	1159	986
HEATING, AIR CONDITIONING, AND REFRIGERATION	4914	4910	4	364	1549	1906	786	309	10	196	2694	2014
MARINE ENGINEERING AND NAVAL ARCHITECTURE	2402	2397	5	587	781	521	307	206	6	172	1487	737
OTHER	35704	35639	65	8808	10351	9508	4705	2332	155	1960	24481	91108
OTHER												
AGRICULTURAL	789	789		152	306	199	91	41	8	132	544	105
CERAMIC AND GLASS	1714	1700	14	341	595	477	218	83	82	185	1193	254
CHEMICAL	23776	23719	57	11903	7288	3005	1224	356	895	2762	16940	3179
MANAGEMENT	11631	11607	24	1845	3829	3528	1715	714	55	805	7102	3669
METALLURGICAL	5195	5186	9	1446	1850	1111	546	242	159	539	3624	873
METALLURGY	2988	2975	13	774	1100	629	334	151	162	394	1908	524
MINING AND MINERAL	5455	5444	11	671	1489	1457	990	848	49	418	3815	1173
PETROLEUM AND NATURAL GAS	3731	3726	5	738	1460	1063	365	105	81	390	2740	520
SAFETY	3112	3107	5	152	938	1315	487	220	8	107	1622	1375
MANAGEMENT AND ADMINISTRATION	42324	40858	1466	3989	10644	19196	6144	2351	471	3628	18541	19684
ACCOUNTING	20318	20130	188	1933	5350	10292	2060	683	94	1210	8062	10952
MANAGEMENT AND ADMINISTRATION	17417	17068	349	1555	3755	7278	3377	1452	109	1038	8673	7597
PERSONNEL MANAGEMENT	4589	3660	929	501	1539	1626	707	216	268	1380	1806	1135
SOCIAL SCIENCES	28376	21052	7324	9306	7854	6816	3037	1363	8091	8417	10134	1734
ACTUARIAL SCIENCE	755	727	28	49	286	256	112	52	12	168	450	125
ANTHROPOLOGY	683	551	132	104	256	181	76	66	313	187	149	34
ECONOMIC	7349	6188	1161	2673	1744	1911	725	296	1642	1923	3133	651
GEOGRAPHY	580	490	90	91	220	148	84	37	208	220	131	21
HISTORY	3964	3132	832	944	1123	1119	501	277	1714	1445	756	49
POLITICAL SCIENCE AND PUBLIC ADMINISTRATION	2742	2398	344	713	863	728	283	155	772	883	892	195
PSYCHOLOGY	6985	4254	2731	2771	1914	1300	725	275	2430	2167	2273	115
SOCIOLOGY	2729	1430	1299	1346	548	487	238	110	653	615	1239	222
SPEECH PATHOLOGY	571	257	314	130	199	146	66	30	110	295	142	24
STATISTICS	2018	1625	393	485	701	540	227	65	237	514	969	298
ARCHITECTURAL PLANNING	8458	8226	232	425	1966	2884	2031	1152	16	904	4113	3425
ARCHITECTURE	6830	6729	101	324	1396	2301	1761	1048	12	585	3125	3108
LANDSCAPE ARCHITECTURE	1208	1085	123	75	435	434	199	65	2	226	784	196
PLANNING	420	412	8	26	135	149	71	39	2	93	204	121
FOREIGN LANGUAGES	3830	2702	1128	523	1059	1176	665	407	1484	1315	745	286

NATIONAL ROSTER of scientists, engineers and managers provides a ready catalogue of manpower in the various skills. Started during the war, this listing shows situation at end of 1945. List is now being used by the U. S. Employment Service. Maintaining such a roster will be a major function of the new Science Foundation.

will operate a control valve, and it can use this to establish what seems to it to be the optimum level of fundamental and, to a certain extent, applied research in the U. S. It is generally agreed that the level should be considerably higher than it now is.

To find the optimum level, the Foundation will need a deep and understanding perspective on our age and the U. S. society. It will need to examine and interpret the scientific revolution of the past five decades. It will need to take inventory of the stockpile of human resources in the U. S., and to take care that science does not preëmpt the lion's share of the nation's ablest youth, leaving too few for other professions and callings of great importance.

WE already have some significant information on our reserves of human ability and the trends in the training of this intellectual manpower. The salient facts are summarized in the charts on the opposite page. In analyzing the problem we must take as a starting point that scientific work requires high ability. Since the beginning of the century the number of young people going into advanced scientific training in the U. S. has risen rapidly. The rate of expenditure nationally for research and development has expanded even more rapidly, so that except during the depression scientists with graduate training have never had much difficulty finding employment, and for the last several years there has been an acute shortage of them.

Clearly the further expansion of our scientific enterprise will soon raise a serious question as to how enough persons of the requisite ability are to be obtained for science without diverting too many from other fields where relatively high intellectual ability is required. What is the level of required ability, and how large a reservoir of persons with such ability do we have in our total population?

A preliminary study of this question has been made under the sponsorship of the Conference Board of Associated Research Councils under a grant from the Rockefeller Foundation. Its results have been reported in *The Educational Record* by C. Gilbert Wrenn of the University of Minnesota.

This study showed that the median I.Q. of a sample group of 600 persons with the Ph.D. degree in the sciences was 141. Among the 2,400,000 18-year-olds in the U. S. in 1946 there were 144,000 with I.Q.'s of 125 or higher; of these only 14,000 were in the range of 141 and above, the Ph.D. median.

This, then, permits an estimate of the annual U. S. potential from whom the Ph.D.'s would come. But to estimate the true present potential we must consider the population that actually goes to college. A total of about 187,000 persons now graduate from college each year (discounting the recent swollen G. I. enrollments). Of these some 65,000 have I.Q.'s of 125 or higher. Less than five per cent, some 8,300, of the college graduates reach or exceed an I.Q. of 141.

Clearly this is a narrow base from which to recruit persons for advanced training. And of this small potential the sciences and other specialties already may get a disproportionate share. In 1949 a little over 5,000 Ph.D.'s were awarded in the U. S., 2,800 of them in the sciences. It can be assumed that some 2,500 of these recipients are in the I.Q. range of 141 or higher, since 141 seems to be the median for doctorates. This means that about 30 per cent of the 8,300 most able students graduating from our colleges each year are going into science or some other special intellectual discipline, leaving only 70 per cent for all other activities in our civilization that require top-flight personnel.

Of course one may question the validity of the I.Q. as a measure of ability, and in any case these figures are only rough estimates. Yet there seems little doubt that the general meaning of these data is valid and important. In the past four or five decades we have undergone a scientific revolution which has created a demand that absorbs a large share of our ablest personnel. This demand appears to be steadily increasing. Furthermore, the revolution in the natural sciences and in technology also creates a steadily increasing demand for highly trained persons of substantial ability in other fields, such as social science, the humanities, business and government. What will happen if the demand for highly trained specialists, which has approximately doubled each decade for a half-century, doubles again in the next decade?

The obvious answer, of course, is to give more youngsters an opportunity to go to college and to encourage more of those in college to go on to advanced study, thus providing a broader base of trained intellectual manpower from which to draw. But there seem to be limits to what can be accomplished here. In the first place, the learned professions are already drawing a large share of the more able members of the population. According to the Wrenn study, 8,300 of the total of 14,000 youngsters with I.Q.'s of 141 or above in each age group of the population now finish college. In other words, well over half of the total potential of ablest people already is graduating from college, and the number of additional persons at the upper levels of ability who might be recruited for advanced training is not large.

Furthermore, it is not altogether certain that we can greatly broaden the base of the college population merely by making a college education more widely available. The greatest step in this direction in our history was the G. I. Bill of Rights, which has financed college training for hundreds of thousands of veterans since the end of the war. Yet over the long term this did not add greatly to our college-trained population. It appears that most of the swollen postwar enrollment was made up of men who would have gone to college anyway had the war not interfered. This is made clear by the chart at the top of the opposite page: the hump of postwar enrollment is largely offset by the dip representing the interruption of the war. It seems improbable that the G. I. Bill added more than 200,000 to the number who would normally have gone to college. These 200,000 were spread over age groups representing more than 10 classes, so the increase was no more than 20,000 in each age group.

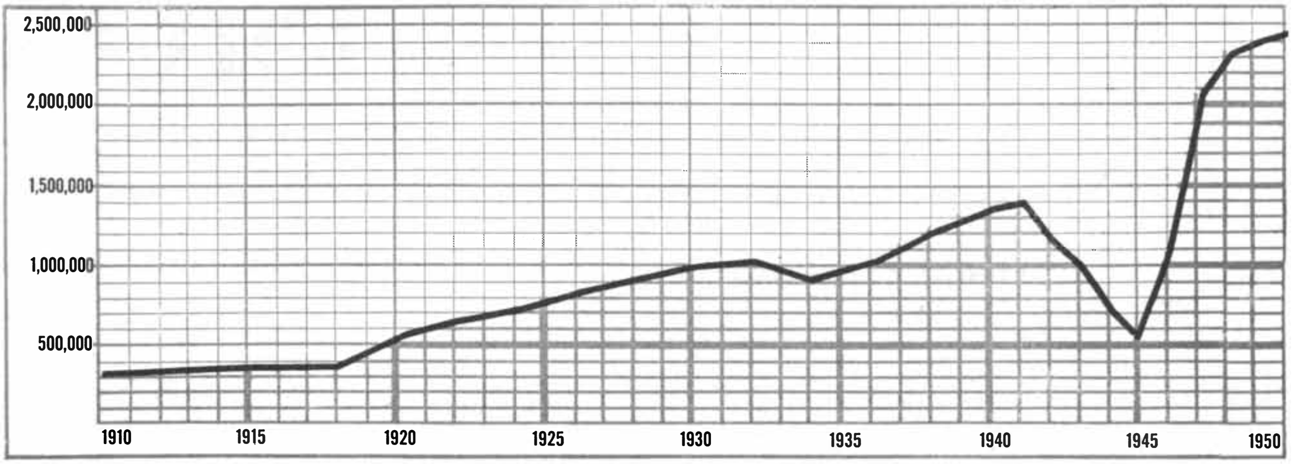
On the other hand, there is no question but that we are failing to make the most of our potential resources of gifted youth. A follow-up study of Minnesota high-school graduates in 1948 indicated that only four per cent of high-school graduates with I.Q.'s of 125 or higher continue their education to the point of obtaining advanced degrees.

These considerations point to a real problem for the National Science Foundation. To identify, recruit and finance the training of promising youths for science without making the error of merely diverting able personnel from one field to another will be a formidable task. The Foundation, in undertaking it, will also in a sense be undertaking a larger responsibility for husbanding the total personnel resources of the nation.

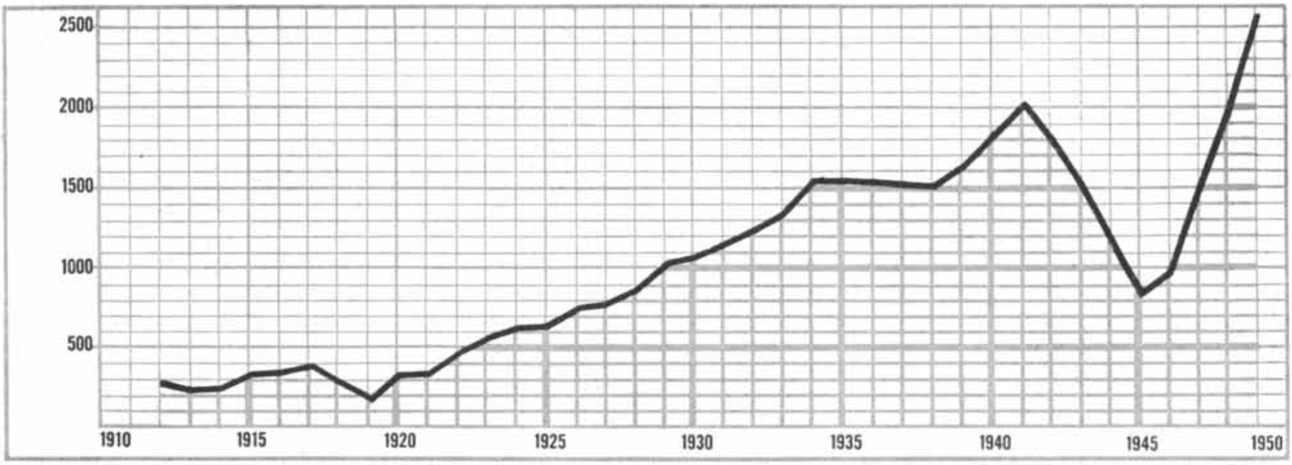
THE Foundation's charter is very broad. It is required "to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences." It is to maintain a register of scientific personnel and in other ways provide a central clearing house for information covering such personnel. It is to foster the interchange of scientific information. Obviously all this gives the Foundation wide latitude and responsibility for the scientific progress of the nation.

It is hoped that the new agency can complete its organization by June, 1951, so that in the following fiscal year it will be able to get underway in its major tasks. Perhaps the first fellowships and scholarships will not actually be distributed until the fall of 1952. By that time what to scientists is the most significant agency in the long history of our Federal government should be a fully functioning ally, and its fruits should begin to burgeon, at least in the blossom.

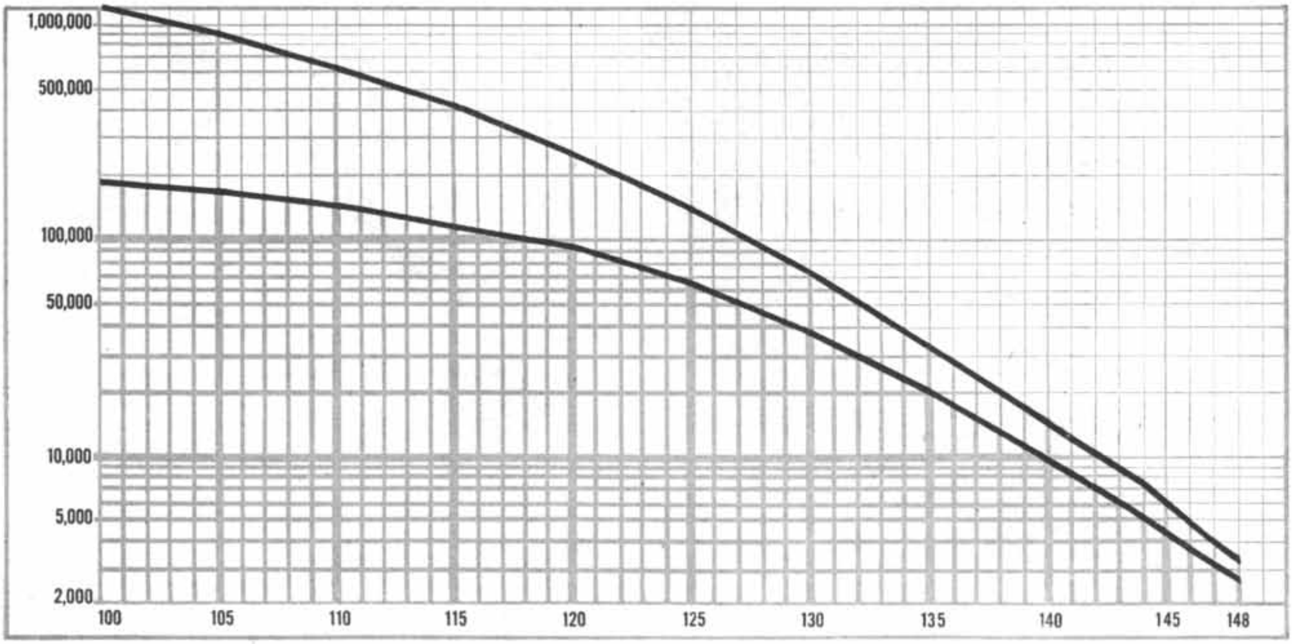
M. H. Trytten is director of the Office of Scientific Personnel of the National Research Council.



COLLEGE ENROLLMENTS in U. S. have risen steadily since 1910 except for war's interruption. Temporary postwar spurt due to G. I. Bill, now leveling off, about balances wartime loss, indicating deferred education.



DOCTORAL DEGREES in the sciences closely follow the trend in college enrollments. Candidates for advanced study for the Ph.D. are recruited largely from upper third, in I.Q. scores, of college graduating classes.



INTELLECTUAL POTENTIAL of the nation's youth is here shown graphically. Top curve shows the number of 18-year-olds in population at each I.Q. level. The other (on logarithmic scale) shows number finishing college.

ARRESTED VISION

In which chimpanzees raised in the dark shed light on the relationship between visual experience and visual development

by Austin H. Riesen

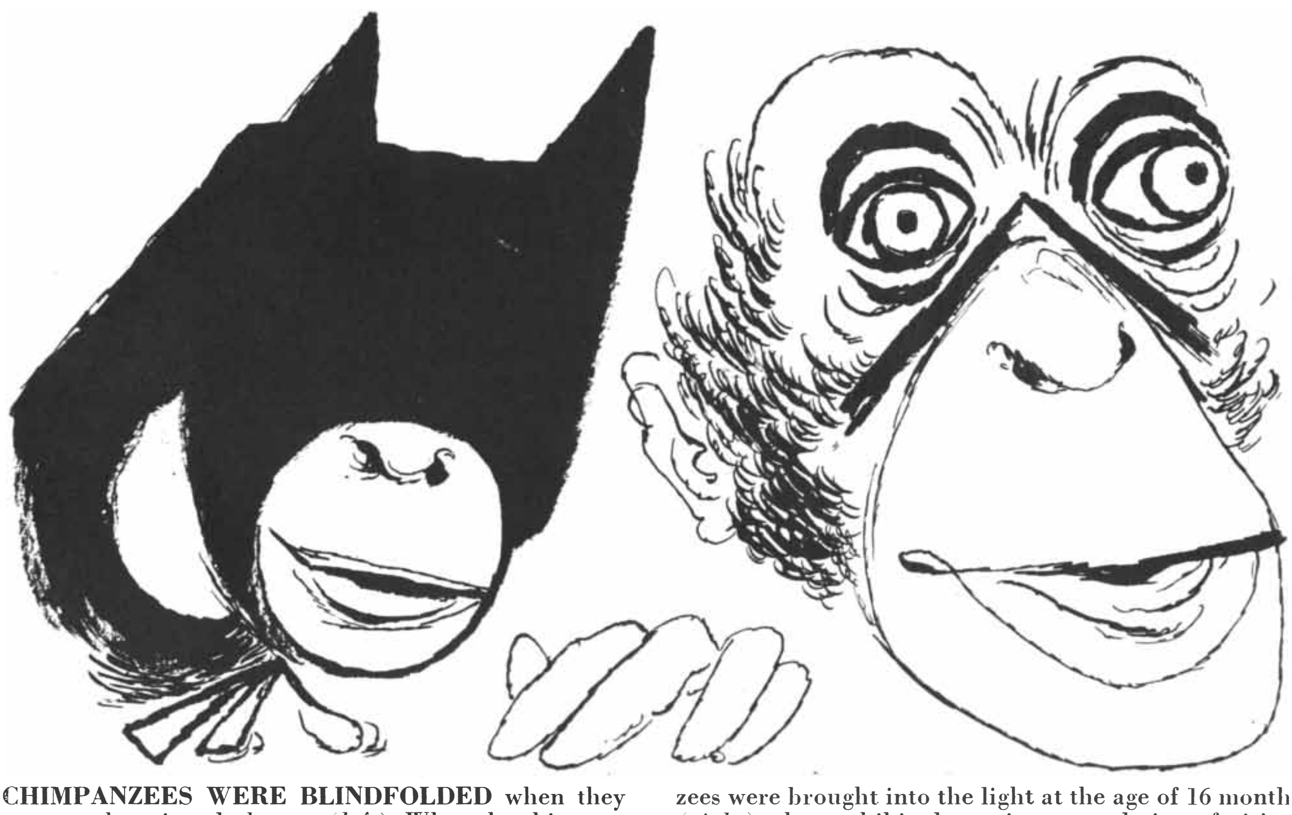
MANY primitive organisms show immediate and highly uniform reactions to light from the moment of birth. In man vision is a much more complex skill that develops gradually through the years of infancy and childhood. How much of this capacity is innate and how much is acquired by learning or through the natural maturation of the eyes during the child's early years? What are the factors that determine visual perception? If we knew the answers to these questions we could do a great deal more than we can now to improve defective vision.

The task of separating the hereditary factors from the effects of experience in human vision obviously is not easy. For example, a newborn infant at first shows no clear indication of any response to a bright disk presented before its eyes. Only after several weeks does the growing infant begin to look at the disk. Is this the result of growth, of experience or of both? Does the change in response come about through practice in the use of the eyes, or through a natural maturation that occurs, quite independently of use, in the retina of the eye, in the eye or neck muscles, in fiber tracts of the central nervous system or in several of these parts combined?

Scientific studies of the growth of behavior have shown that certain abilities do develop without use as animals mature. Thus tadpoles raised under anesthesia to prevent swimming movements nevertheless improve in swimming ability. Chicks and rats kept in darkness for a time show some progress in vision-controlled behavior. Children also demonstrate a basic rate of maturation in some capacities: there is a limit to the degree of retardation or acceleration of these abilities that can be effected by restricting or expanding their training.

But some of these studies have revealed curious contradictions. Wendell Cruze at North Carolina State College found that after newly hatched chicks had been kept in darkness for five days, they were generally able to peck at and hit 24 of the first 25 grains presented to them; this score was 12 per cent better than the average of hits by chicks immediately after hatching. On the other hand, S. G. Padilla at the University of Michigan showed that if the period of darkness was extended to 14 days, the pecking response failed to appear, presumably because the instinct to peck at spots on the ground died out through disuse. The chicks began to starve in the midst of plenty. So it appears that lack of practice, at least if sufficiently prolonged, can interfere with the development of behavior which is basically instinctive or reflex in nature.

In human beings the most nearly pertinent evidence on this problem has come from studies of patients operated upon at advanced ages for congenital cata-



CHIMPANZEES WERE BLINDFOLDED when they were not kept in a darkroom (*left*). When the chimpanzees were brought into the light at the age of 16 months (*right*), they exhibited a serious retardation of vision.

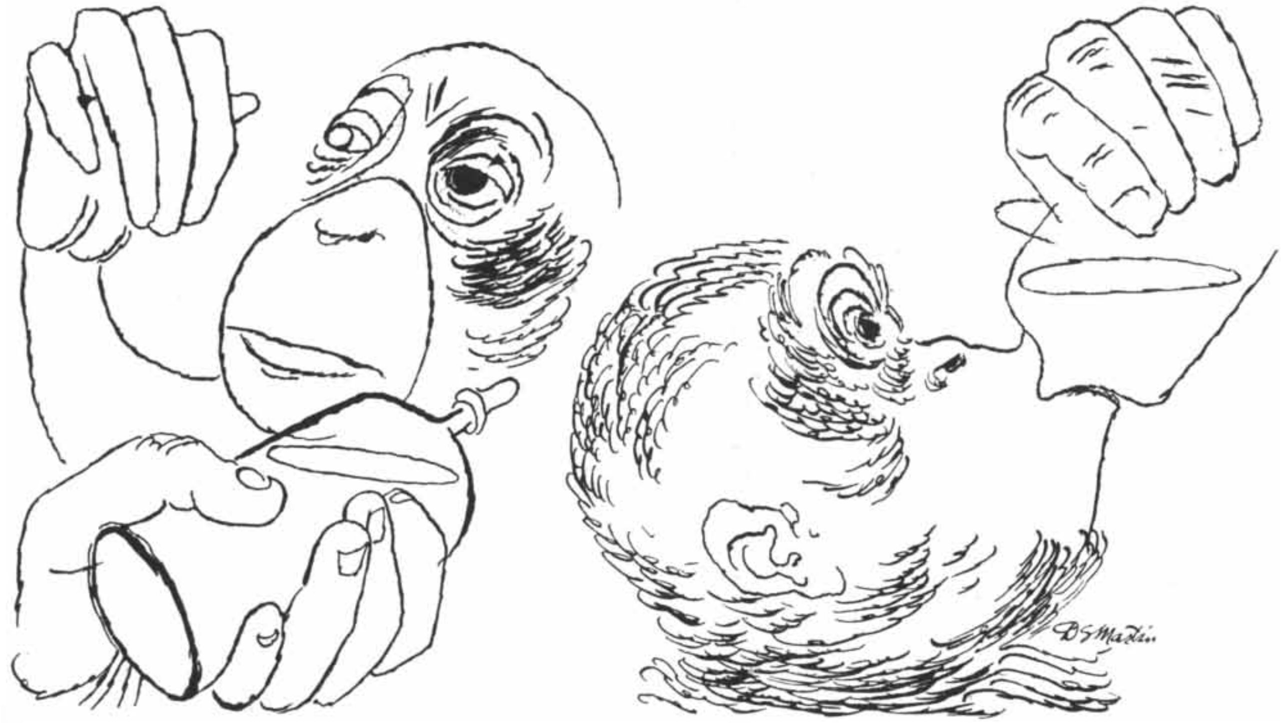
racts. These patients, who have passed all their lives in near-blindness, ranging from the bare ability to tell day from night to some ability to distinguish colors and localize light, invariably report an immediate awareness of a change after a successful operation. They begin at once to distinguish differences in the parts of the visual field, although they cannot identify an object or describe its shape. After a few days' practice they can name colors. From this point on progress is slow, often highly discouraging, and some patients never get beyond the ability to distinguish brightness and color. Others, over a period of months and even years, develop the ability to identify simple geometric figures, read letters and numbers and, in rare cases, to identify complex patterns such as words, outline drawings and faces. During their efforts to improve their visual skill the patients go through a long period of picking out elements in an object and inferring the nature of the object from these elements—often erroneously. For example, a child of 12, some months after her operation, is reported by her doctor to have pointed to a picture and called it "a camel, because it has a hump." What she identified as a hump was the dorsal fin of a fish.

But such cases of congenital cataract do not give us very satisfactory evidence on the elementary problem of how disuse affects the development of visual behavior. There are too many other variables; we must take into account (1) the degree of the patient's previous blindness, since he was not in total darkness, (2) the limit that is imposed on his potentialities for improvement by the fact that the eye operated on lacks a lens, and (3) the circumstance that in all these cases there appears to be another visual handicap—jerky movements of the eyeballs known as spontaneous nystagmus. The effects of these combined difficulties are not readily calculable. For a more meaningful study it is highly desirable to eliminate these variables by setting up a controlled experiment that will determine the effects of disuse on normal eyes. Obviously such an experiment cannot be risked in human beings; no one would wish to impose permanent reading difficulties on any person having to adjust himself to a civilized society. The most logical subject for the experiment is another higher primate. The chimpanzee was chosen, because its behavior, like man's, is dominated by vision, and because it is intelligent and tractable.

In 1942 at the Yerkes Laboratories of Primate Biology in Orange Park, Fla., an infant male chimpanzee was separated from its mother on the day of birth and blindfolded with a gauze bandage and adhesive tape. This animal defeated the experimenters by loosening the tape at the side of his left nostril and habitually peeking down his nose with his left eye. By the age of 16 weeks he gained full freedom from facial bandages. Although he did not recognize his feeding bottle at this time, nor show fixation of persons or objects, he developed fairly adequate visual behavior within a few weeks.

In 1945 the experimenters tried again. This time two newborn chimpanzee infants, a male and a female respectively named Snark and Alfalfa, were housed in a completely darkened room. During the first 16 months the only light these infants experienced was an electric lamp turned on for intervals of 45 seconds several times daily for their routine care and feeding. When they were first tested for visual perception at the age of 16 months, both chimpanzees showed extreme incompetence. Their reflex responses indicated that their eyes were sensitive to light—the pupils constricted; sudden changes of illumination startled the animals; they responded to a slowly waving flashlight with jerky pursuit movements of the eyes and side to side following motions of the head. But both chimpanzees failed to show any visual responses to complex patterns of light until after they had spent many hours in illuminated surroundings. They did not respond to play objects or their feeding bottles unless these touched some part of the body. They did not blink at a threatening motion toward the face. When an object was advanced slowly toward the face, there was no reaction until the object actually touched the face, and then the animal gave a startled jump.

After the 16-month period of darkness, Alfalfa was placed on a limited light schedule until the age of 21 months and Snark until 33 months. When Alfalfa was later moved into a normal daylight environment, in the course of many months she developed normal recognition of objects, began to blink in response to threats and ceased to be startled by a touch. Snark was much more retarded. Between the ages of 20 and 27 months, while he was still on rationed light, he learned after many hundreds of trials to



CHIMPANZEES WERE FED during tests of their visual development. Chimpanzee raised in the dark (*left*) was unable to grasp a bottle, even after several trials. Normal chimpanzee grasped it after one trial.

tell the difference between contrasting signs, differing in color or pattern, which indicated either food or a mild electric shock. His visual acuity, as measured by ability to discriminate between horizontal and vertical lines, was well below that of normally raised animals. At the end of 33 months he began to live in the normally lighted chimpanzee nursery and later out of doors with chimpanzees of his own age. It was expected that he would rapidly acquire normal visual behavior. He did improve slightly at first, but after this small initial improvement he actually lost ground in visual responsiveness, until even reflex activity began to die away.

What is the explanation of this deterioration? Had the development of his eyes been permanently arrested by the absence of light? There had been no previous evidence that stimulation by light is essential for the normal growth of the primate retina or optic nerve. It was a surprise to find that, while the eyes of these chimpanzees remained sensitive to light after 16 months in darkness, the retina and optic disk in both animals did not reflect as much light as normal chimpanzee eyes do. Snark later developed a marked pallor of the optic disk in both eyes. There is other evidence suggesting that fish and amphibians, at least, need light-stimulation for normal eye development. So the physiological effects of the lack of light may be part of the explanation for Snark's loss of visual function. But it is not the whole explanation for all the visual abnormalities in these two chimpanzees, nor does it explain the visual difficulties of the cataract patients. These patients have excellent color discrimination, and, incidentally, do not show pallor of the optic disk. Moreover, we now have clear evidence from further experiments with chimpanzees that not merely light itself but stimulation by visual patterns is essential to normal visual development.

In these experiments three other newborn chimpanzees, two females and a male, were put into the darkroom. Debi was raised for seven months in complete darkness, even during her feedings and other care. Kora was raised for the same period on a ration of an average of one and a half hours of light daily, but the light, admitted through a white Plexiglas mask, was diffuse and unpatterned. Lad was given one and a half hours of patterned light daily: he could observe the edges of his crib, the variations in pattern introduced by movements of his own body and appendages, and all the accompaniments of bottle-feeding, including the moving about of persons in the moderately lighted room.

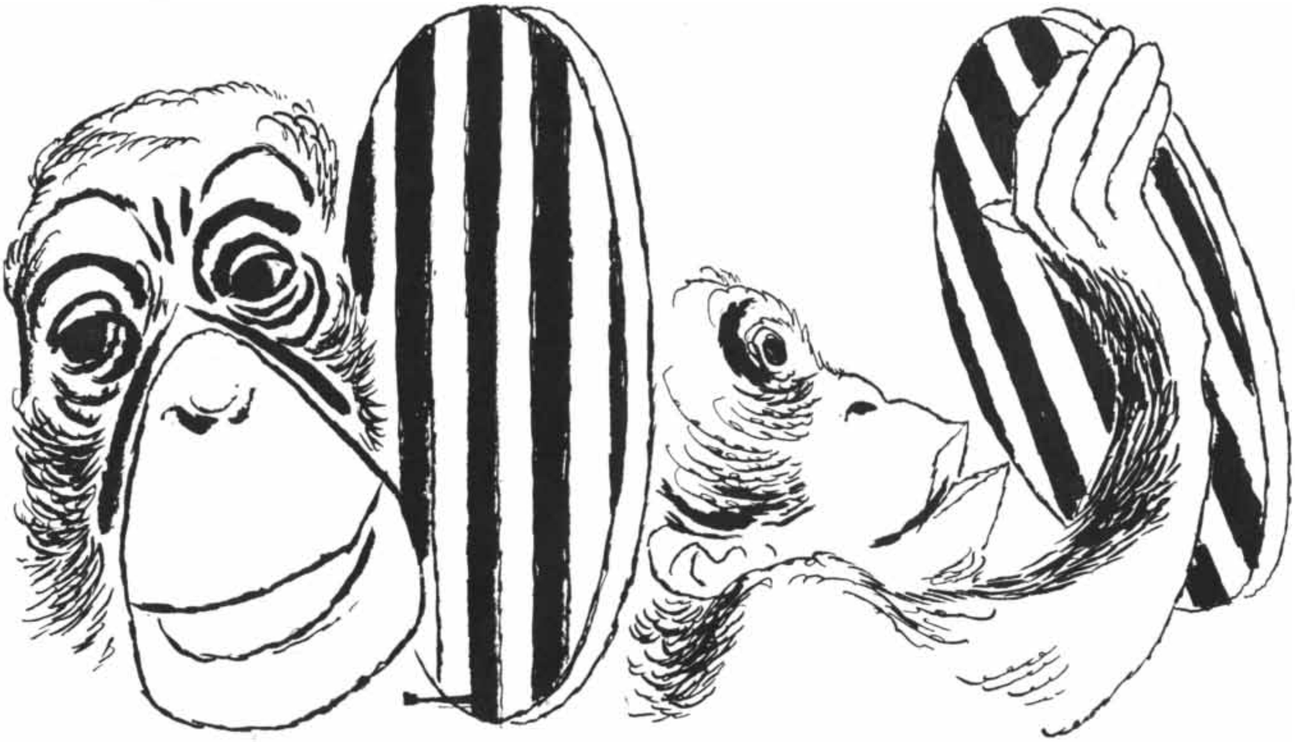
At seven months, when the three subjects were removed to normal daylight surroundings, Lad's visual performance was indistinguishable from that of chimpanzees raised normally. Kora and Debi, however, showed the same kinds of retardation as had Snark and Alfalfa, with some minor exceptions. Kora did not develop the blink response to a moving object until six days after her removal from darkness, and Debi not until 15 days. It took Kora 13 days and Debi 30 days to acquire the ability to pursue a moving person with the eyes, and they did this by a series of refixations instead of following smoothly as normal animals of comparable age do; it took Kora 20 days and Debi 16 days to pursue visually a moving feeding bottle; Kora 13 days and Debi 30 days to fixate the image of a stationary person.

These differences between Debi and Kora may lie within the range of variation that would occur in a group of animals treated exactly the same as either Debi or Kora. This question could be checked only by repeating the experiment many times.

Between seven and 10 months of age Debi and Kora both showed a moderate and intermittent outward (wall-eyed) deviation of the eyes. This gradually was overcome. Both infants also showed an initial spontaneous nystagmus, *i.e.*, jerky eye movements. It appeared only sporadically, and was more pronounced under general excitement than when the animals were well relaxed.

Normal animals of seven months learn to avoid a large yellow and black striped disk after receiving one or two mild electric shocks from it. Debi and Kora, however, were shocked by the disk twice a day for six and nine days, respectively, before they so much as whimpered when it was shown. Only after 13 days in Kora's case and 15 days in Debi's did they consistently indicate by some sort of avoidance response that they saw the disk within five seconds of the time that it was raised in front of their eyes.

In still another study an infant chimpanzee named Kandy was put in the



NORMAL AND ABNORMAL ANIMALS were subjected to the same stimuli. At the left an abnormal chimpanzee is given a mild electric shock by a disk with a contact at bottom. At right normal chimpanzee is shocked.

darkroom for only the first three months of life. After she was removed to daylight surroundings, her progress on the same tests was approximately parallel to that of Debi and Kora. There were three interesting differences: 1) Kandy showed a convergent squint (cross-eyes), which cleared up in a little less than two months; 2) she did not have spontaneous nystagmus; 3) she required 24 days, as compared with 13 or 15, to develop consistent avoidance of the black and yellow shock-disk. The last difference suggests that Kandy learned more slowly because of her younger age; in other words, that the development of visual discrimination was a matter of maturity as well as learning. This conclusion was strongly supported by the finding that an infant chimpanzee started through the same training at the age of two days failed to show avoidance in a month's time.

All these observations demonstrate that vision must be put to use if it is to develop normally, but they also indicate that during the first few months of an infant's life visual development is advanced by growth factors which are entirely independent of practice. Normally reared animals, for example, do not blink in response to the movement of objects across the visual field until they have reached the age of two months; the older darkroom animals, despite previous lack of experience, began to show this response within about two weeks after they were transferred to daylight surroundings.

The development and maintenance of normal visual functions in higher primates depends on a whole complex of interrelated factors, hereditary and environmental, and it can readily be disturbed at any stage of the individual's growth. This was shown in an experiment with a chimpanzee named Faik. Faik was raised in the normal light of the laboratory's nursery until the age of seven months. At that time the standard series of tests described above showed that he had excellent use of vision. Then from the age of eight to 24 months he was kept in the darkroom. He lived an active life filled with tactile, auditory, olfactory, gustatory and kinesthetic stimulation. He invited rough-house play from his caretakers at feeding times, and his general state of health remained entirely satisfactory.

When Faik was returned to daylight living quarters at 24 months, he had lost all ability to utilize vision in his interplay with the environment. He no longer recognized the feeding bottle, and failed to look at objects or persons, either stationary or moving. More than this, he possessed a strong spontaneous nystagmus and was even unable to follow a moving light in a darkroom until the fifth day after he was put back into a lighted environment. His first visual following movements, like those of all the darkroom-raised subjects, were not smooth but a series of jerky refixations, made even more jerky by the pronounced spontaneous nystagmus.

Even in direct sunlight Faik failed to grimace or close his eyelids; he gave no indication of the slightest discomfort when the sun shone in his eyes. (The chimpanzees raised in the darkroom from birth did close their lids in intense light.) Faik showed pallor similar to that of Snark and Alfalfa in his optic disks. His recovery of vision has been slow and is still only partial. Explanation of his case, and that of Snark, remains a challenge to further research.

These chimpanzee studies have established several fundamental points. They show that newborn animals, and older infants that have been kept in darkness for a time, exhibit visual reflexes when they are first subjected to light. Some responses that bear a close resemblance to reflex behavior, such as blinking at something rapidly approaching the face, become automatic only after considerable practice. Visual pursuit of moving objects, the coordination of the two eyes and convergent fixation, and the first recognition of objects come only after many hours or weeks of experience in use of the eyes. It takes the chimpanzee hundreds of hours of active utilization of the eyes to develop its vision to the stage where it can adequately guide locomotion and complex manipulations. The findings in the cases of two subjects that were kept in darkness for long periods indicate that the postponement of light exposure for too long can result in making the development of normal visual mechanisms extremely difficult if not impossible.

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NORMAL AND ABNORMAL RESPONSE to shocking-disk was exhibited by animals. At left a normal chimpanzee responds violently after one shock. At right abnormal chimpanzee fails to avoid disk after many shocks.

The Mystery of Corn

The wild ancestor of the most important plant in America is lost in antiquity. Once it was thought to be the grass teosinte; now the evidence points to a primitive pop corn

by Paul C. Mangelsdorf

THE most important plant in America is corn. It is grown in every state and on three fourths of all the farms of the U. S. Corn is the backbone of our agriculture. It is the most efficient plant that we Americans have for trapping the energy of the sun and converting it into food. True, we consume only small amounts of corn directly, but transformed into meat, milk, eggs and other animal products, it is the basic food plant of our civilization.

Yet corn is also a mystery—a botanical mystery as baffling and intriguing as any in the pages of fiction. The plant has become so highly domesticated that it is no longer capable of reproducing itself without man's intervention. A grass, it differs from all other grasses, wild or cultivated, in the nature of its seed-bearing organ: the ear. This is a highly specialized inflorescence, or flower cluster, enclosed in husks, which when mature bears several hundred or more naked seeds upon a rigid cob. The pollen-bearing inflorescence, the tassel, occurs separately on the same plant. The ear of corn has no counterpart anywhere else in the plant kingdom, either in nature or among other cultivated plants. It is superbly constructed for producing grain under man's protection, but it has a low survival value in nature, for it lacks a mechanism of seed dispersal. When an ear of corn drops to the ground, scores of seedlings emerge, creating such fierce competition among themselves for moisture and soil nutrients that usually all die and none reaches the reproductive stage.

What could have been the nature of the wild or primitive corn from which this pampered cereal has developed? Where, when and how was a species, once so hardy that it could survive in the wild, converted to a cultivated plant so specialized and so dependent upon man's ministrations that it would soon become extinct if deprived of man's help? These are questions that have puzzled botanists and anthropologists for more than a century. Now, as a result of research in botany, genetics, archaeology and history, the answers are a little nearer. The mystery has not been solved, but the web of circumstantial evidence is drawing tighter and the final solution is almost in sight.

THERE is no evidence that corn was known in any part of the Old World in ancient times. Seeds of wheat and barley, and fabrics woven of the fibers of flax and hemp, have been found in ancient Near Eastern sites—but never grains of corn. The Babylonians and Egyptians pictured and described many plants, but nowhere in their art or literature does corn appear. Corn as a plant is not mentioned in the Bible, although some English translations do use the word as a synonym for grain. The Greeks, who had a word for almost everything, had no word for corn. The extensive ancient Chinese literature and the Vedas of India also are completely lacking in any reference to corn. There is no evidence of any kind—archaeological, linguistic, ideographic, pictorial or historical—of the existence of corn in any part of the Old World before 1492.

ZAPOTEC GODDESS of Pre-Columbian Mexico clasps small ears of corn.

The first reference to corn in recorded history occurs on November 5, 1492. On that day two Spaniards, whom Christopher Columbus has delegated to explore the interior of Cuba, return with a report of "a sort of grain they call maiz which was well tasted, bak'd, dry'd and made into flour." Later explorers to the New World found corn being grown by Indians in all parts of America, from Canada to Chile. Corn proved to be as ubiquitous in the New World as it was unknown in the Old. There was a great diversity of corn varieties; all of the principal types we recognize today—dent corn, flint corn, flour corn, sweet corn and pop corn—were already in existence when America was discovered.

Thus the evidence that corn originated in America is so overwhelming that it seems sensible to concentrate, if not to confine, our search for its wild ancestor to the Western Hemisphere. In America corn has obviously had an ancient history. The seminomadic hunting and fishing Indians in both North and South America augmented their diet of fish and game with corn from cultivated fields. The more advanced Mound Builders of the Mississippi Valley and the Cliff Dwellers of the Southwest were corn-growing and corn-eating peoples. The highly civilized Mayas of Central America, the warlike and energetic Aztecs of Mexico and the fabulous Incas of Peru and Bolivia all looked to corn for their daily bread. The abundant harvest that corn yielded gave these ancient peoples leisure for weaving beautiful fabrics, for molding exquisite pottery, for building magnificent highways and towering pyramids, for inventing a system of arithmetic and for perfecting a calendar more accurate than the Old World calendar of the same period. Corn was indeed "the grain that built a hemisphere."

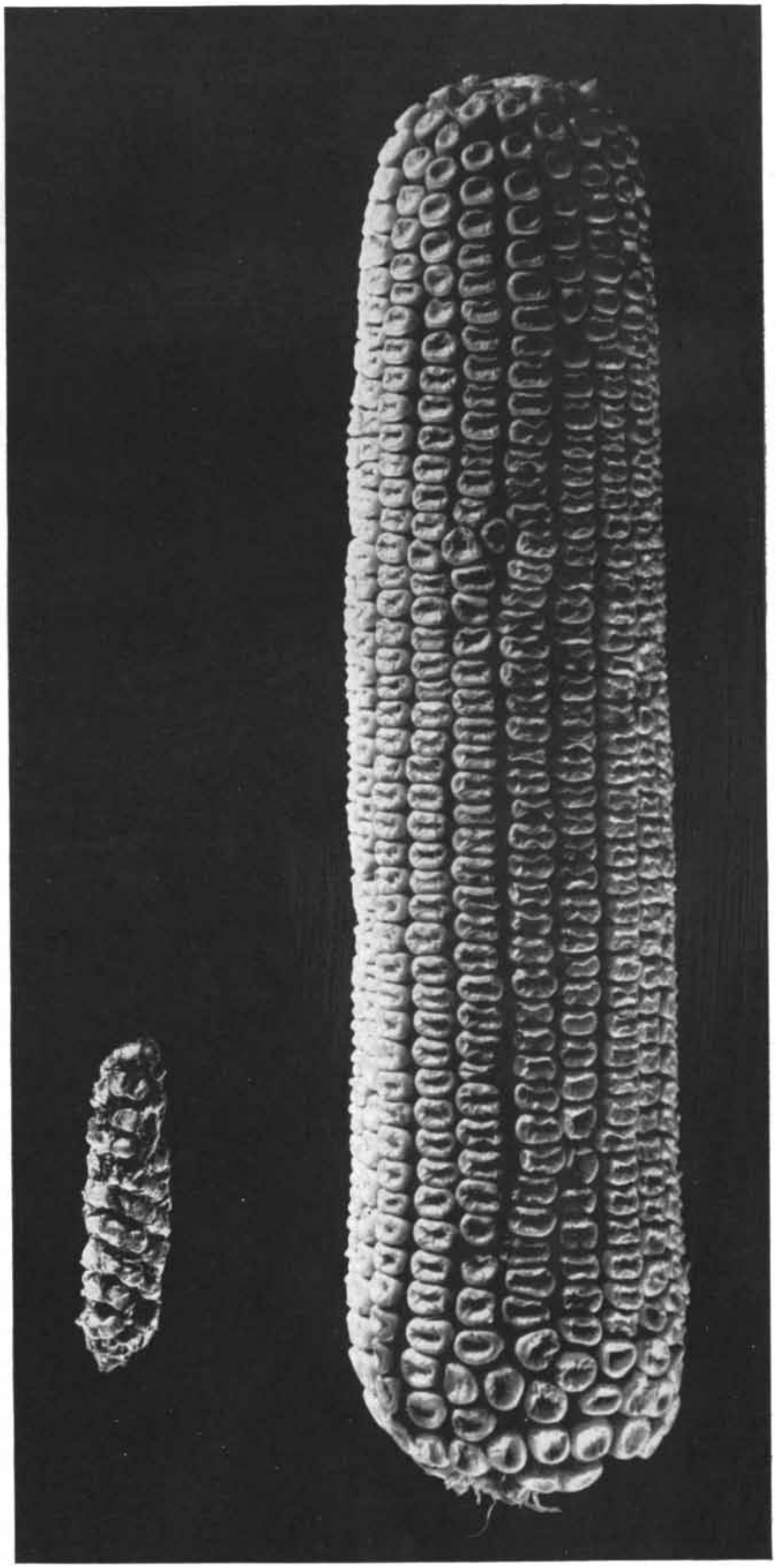
This universal reliance of the pre-Columbian cultures on corn as the basic food plant, and its great diversity of varieties, greater than that of any other cereal, bespeak a long period of domestication. How old is corn as a cultivated plant? Fortunately this investigation is no longer wholly a matter of guesswork. Reasonably reliable estimates can be obtained by the ingenious method devised by Willard F. Libby, of the University of Chicago, for determining the age of ancient vegetal remains. The method is to measure the radioactive carbon in the remains; from this one can then determine how much of the radiocarbon originally taken by the plant from the atmosphere has disappeared, and the amount of radioactive decay is a measure of the age of the remains. Libby's determinations of radiocarbon in archaeological remains of corn (not yet published but communicated to the author) tend to bear out previous archaeological and geological estimates that the oldest corn yet found in South America goes back to about 1000 B. C., and the oldest in North America to not earlier than 2000 B. C. The oldest prehistoric ears in both North and South America are small and primitive; they differ decidedly in several characteristics from the modern varieties of the Corn Belt. Yet almost any American farm boy would recognize them instantly as corn. So some 4,000 years ago corn was already well on the road to becoming the unique cereal it is now.

IN WHAT part of America did corn originate? And what kind of wild grass was it that gave rise to the multitude of present-day varieties of corn?

One theory has corn originating from a plant called by the Aztecs *teocintle* (now Anglicized to teosinte). Teosinte is undoubtedly the closest wild relative of cultivated corn. Like corn, it has tassels and ears borne separately, although its "ears" contain only five or six seeds, each enclosed in a hard, bony shell—characteristics that make teosinte a most unpromising food plant. Also like corn, it has 10 chromosomes, indicating that it is a closely related species. Teosinte can readily be crossed with corn to produce hybrids that are completely fertile or almost so. If corn came from teosinte, as many botanists have supposed, it must have originated in Guatemala or Mexico, for teosinte is found only in those two areas.

The second principal theory is that corn originated in South America from a peculiar primitive plant called "pod" corn. Primitive pod corn today has virtually vanished; it is no longer found in pure form but as an admixture in modern varieties. As described in early references, and as obtained by inbreeding from present-day mixtures, pod corn has its kernels enclosed in a pod or chaffy shell similar to that found in all other cereals—a condition which almost certainly was characteristic of wild corn.

Which, if either, of these two theories is more likely to be correct? Botanists, in attempting to determine the place of origin of a cultivated plant, place considerable reliance upon two criteria. One is the occurrence of wild relatives of the plant in question; the other is diversity in the cultivated species itself. It is assumed that, other things being equal, the



OLDEST EAR OF CORN (*left*), dated about 2000 B.C., was found in New Mexico's Bat Cave in 1948. A specimen of modern dent corn is at the right.

TEOSINTE is the closest wild relative of corn. Its tiny ear is on the right side of the stalk beneath the tassel.

TRIPSACUM is a wild grass that can be hybridized with corn. It is thought to be an ancestor of teosinte.

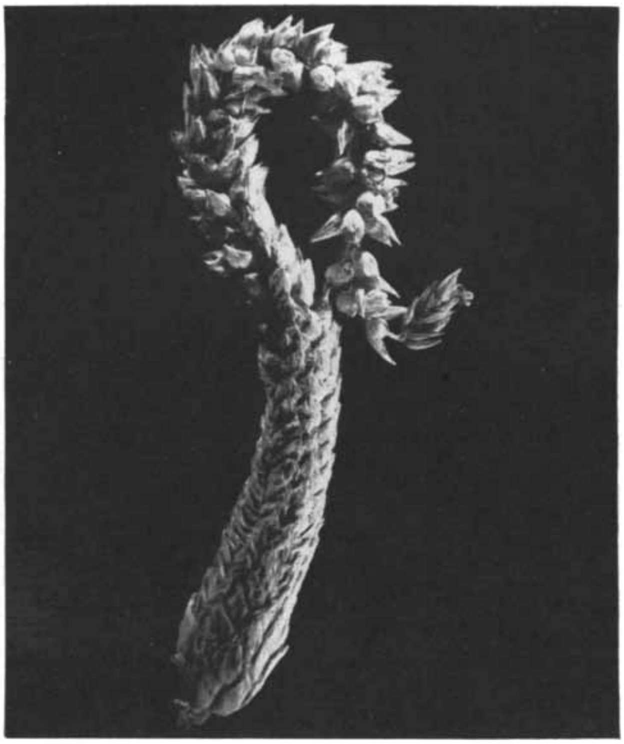
region of maximum diversity should coincide with the center of origin, since diversification has progressed longer at the center than at the periphery of the plant's present range. In the case of corn the two clues point in opposite directions: the wild-relative clue points to Guatemala and Mexico, where teosinte, corn's closest relative, grows; the diversity clue points to South America, where, on the eastern slopes of the Andes, occurs the greatest diversity of corn varieties found anywhere in America in a region of comparable size.

Some 20 years ago my colleague Robert G. Reeves and I began working at the Agricultural Experiment Station of Texas A. & M. College on a series of genetic and cytological studies of corn and its relatives to test these two conflicting theories. We hybridized corn with teosinte to determine how the genes that differentiate the two species are inherited and how they are distributed on the chromosomes. We also hybridized corn with Tripsacum, a more distant wild relative of corn, which occurs in both North and South America. Our hybrids of corn and teosinte revealed that corn differs from teosinte not by a relatively few genes, as might be expected if the one had been derived from the other as a result of domestication, but by a large number of genes inherited in blocks. Our hybrids of corn and Tripsacum, the first such hybrids ever to be made, showed that the chromosomes of Tripsacum, 18 in number, differed greatly from those of corn. Microscopic studies of the reproductive cells of the Tripsacum-corn hybrids showed little pairing (a criterion of relationship) between the chromosomes of the two species. Nevertheless, there was some chromosome association and consequently some opportunity for exchange of genes. Especially important was the discovery that some of the plants that occurred in later generations of the Tripsacum-corn hybrid resembled teosinte in some of their characteristics. This discovery led to the conclusion that teosinte might well be not the ancestor but a descendant of corn—the product of the natural hybridization of corn and Tripsacum. Such a possibility had been suggested years earlier by Edgar Anderson of the Missouri Botanical Garden.

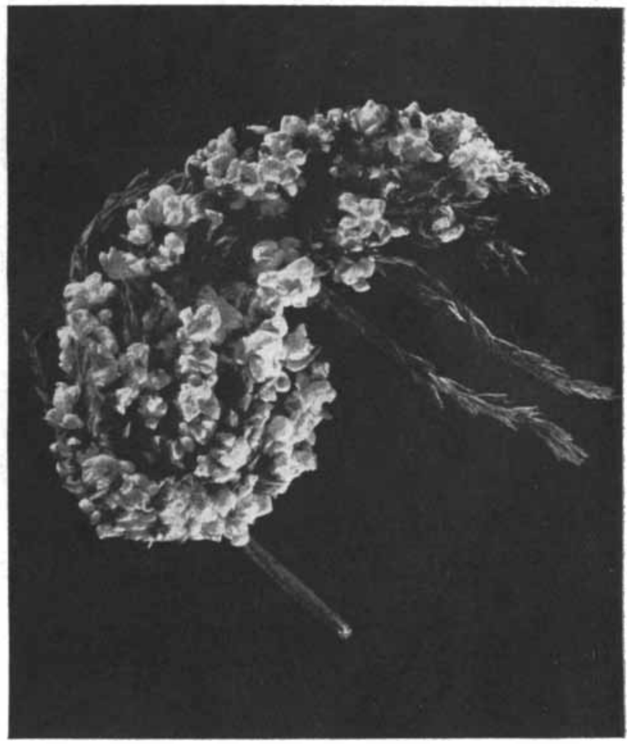
SINCE 1937, when we arrived at this working hypothesis, much additional research has been done on corn, pod corn, teosinte and Tripsacum, and upon their hybrids. There is abundant circumstantial evidence, but still no conclusive proof, that teosinte is the product of the hybridization of corn and Tripsacum. There is even more evidence to show that teosinte could scarcely have been corn's ancestor. Reeves, who has made an intensive study of the botanical characteristics of corn, teosinte and Tripsacum, has found that teosinte is intermediate between corn and Tripsacum or is identical with one or the other of these two species in the 50 or more features in which they differ.

John S. Rogers, also working at the Texas Experiment Station, has hybridized corn with five different varieties of teosinte obtained from various parts of Mexico and Guatemala. He has found that numerous genes, many more than previously supposed, are involved in differentiating teosinte from corn. One of the Guatemalan teosintes, for example, differs from corn in certain ear characteristics controlled by genes borne on two chromosomes. It differs in its photoperiodic response through differing genes on three other chromosomes. (In contrast to corn, teosinte is a "short-day" plant, blooming only in seasons when the days are appreciably shorter than the nights.) It differs in the number of tillers, or "suckers," in genes on four chromosomes, one of which is also involved in the ear characteristics. All together eight different chromosomes and possibly numerous genes on each are involved in just these three of the many differences between corn and teosinte. The possibility that these considerable genetic differences could have originated during a few thousand years of domestication seems remote indeed.

So the teosinte theory has become increasingly untenable. Meanwhile the theory that corn originated from pod corn has become more and more plausible. When a modern hybrid form of pod corn is inbred (a process that usually intensifies inherent traits) the result is a plant quite different from ordinary cultivated corn. The ear disappears and the kernels, now borne on the branches of the tassel, are enclosed in glumes, or chaff, as in other cereals. This pure pod



POD CORN is a primitive form of the modern variety. Each kernel on its slender cob is enclosed in a glume.



SYNTHETIC WILD CORN is produced by crossing pod and pop corn. Here kernels have been popped by heat.

corn possesses a means of dispersal, since its seeds are not on a heavy ear but on fragile branches. In the proper environment it could undoubtedly survive in the wild and reproduce itself. It has characteristics like those of many wild grasses; indeed, in its principal botanical features it is quite similar to its wild relative Tripsacum. Pure pod corn has virtually all of the characteristics we would expect to find in the ancestral form of corn. Furthermore, it is more than a relative of corn; it *is* corn—a form of corn that differs from cultivated corn in exactly the way a wild species ought to differ from its cultivated counterpart. Finally, all the hereditary differences between pod corn and cultivated corn are traceable to just one gene on one chromosome. Thus a single mutation can change pod corn to the non-podded form, and it has actually done so in my cultures.

The aboriginal wild corn that man began to cultivate undoubtedly had other primitive characteristics in addition to those of the ancestral pod corn. Its kernels, for example, were probably small, hard and pointed. Kernels of this kind are found today in varieties of pop corn. Indeed, the U. S. botanist E. Lewis Sturtevant, one of corn's most astute investigators, concluded more than half a century ago that primitive corn must have been both a pod corn and a pop corn. Evidence is now accumulating to show that Sturtevant was right.

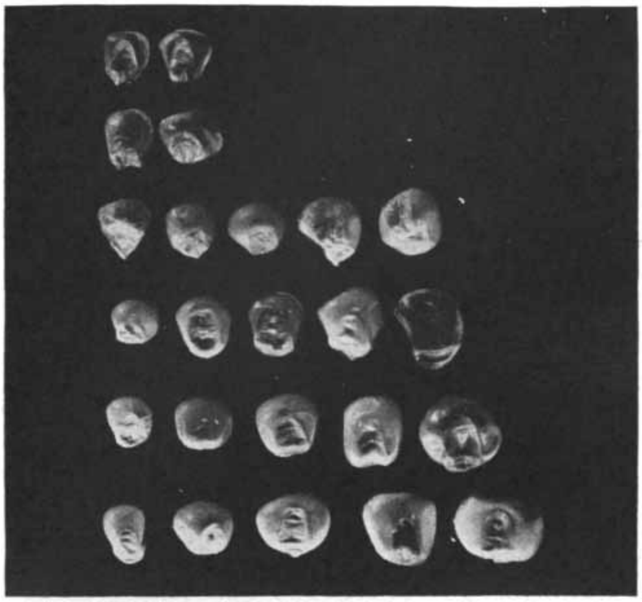
In the remains of prehistoric civilizations unearthed in South America, pop corn predominates over other types. Pottery utensils for popping corn, as well as actual specimens of the popped grains, have been found in prehistoric Peruvian graves. Certainly there is nothing new about the pop corn which modern Americans consume so lavishly as part of the movie-going ritual. Pop corn is an ancient food, and it is quite possible that primitive man first discovered the usefulness of corn as a food plant when a wild corn was accidentally exposed to heat. This would have exploded the small, vitreous, glume-covered kernels, and transformed what to people with no grinding tools other than their own teeth was a very unpromising food into tender, tasty, nutritious morsels.

THERE is an interesting historical reference which lends support to Sturtevant's conclusion that primitive corn was both a pod corn and a pop corn. A century and a half ago Félix de Azara, the Spanish Commissioner to Paraguay, wrote of a peculiar variety of corn in Paraguay in which small seeds enclosed in "envelopes" were borne in the tassel. When the tassels were heated in hot oil, the kernels exploded to produce "a superb bouquet capable of adorning at night the head of a lady."

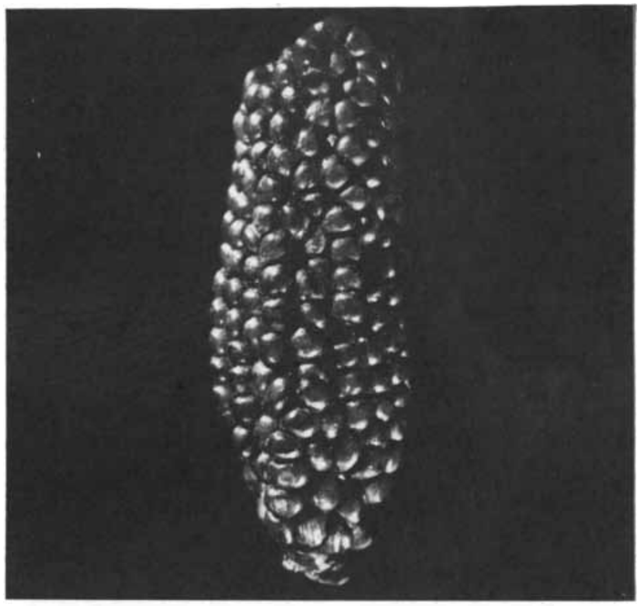
By a very simple experiment in our breeding plots, we have succeeded in duplicating exactly the corn Azara described. Pod corn was hybridized with pop corn and was then inbred to produce an earless plant bearing in the branches of the tassel small hard seeds enclosed in glumes. When a tassel of this pod-pop corn was heated in hot oil, it behaved exactly like the corn of Azara. The kernels exploded but remained attached to the tassel to produce the "bouquet" he described.

These recent findings have quite naturally given new impetus to the search for wild corn in South America, since the most convincing and conclusive proof of the pod-corn theory would be the discovery of a primitive pod corn still existing in the wild state. The search for a wild corn has not so far been successful in its primary objective, but it has been quite fruitful in turning up new types of corn, especially less extreme forms of pod corn whose kernels are only partially enclosed in glumes. Perhaps wild corn will still be discovered in some remote protected spot in a region not yet thoroughly explored. The odds are at least even, however, that it no longer exists. Corn in the wild may well have been a plant with low survival value, restricted in its range, and already well on the road to eventual extinction when first used by man.

In the meantime a wholly unexpected discovery, made within the past two years, has furnished direct evidence for the theory that primitive corn was both a pod corn and a pop corn. During the summer of 1948 an expedition sponsored by the Peabody Museum of Harvard University and led by Herbert W. Dick, a graduate student in anthropology, uncovered many cobs and other parts of corn from the accumulated refuse in an



BAT CAVE KERNELS show rapid evolution. Kernels in each row are of the same age; oldest row is at the top.



PERUVIAN EAR, dated about 300 A.D., is larger than the Bat Cave ear. Bat Cave ear is stripped of kernels.

abandoned rock shelter in New Mexico known as Bat Cave. This shelter was occupied from about 2000 B. C. to 1000 A. D. Uninhibited by modern concepts of sanitation, its successive generations of occupants allowed refuse and trash to accumulate in the cave to a depth of about six feet. Carefully removed and sifted by the archaeologists, the refuse yielded 766 specimens of shelled cobs, 125 loose kernels and various fragments of husks, leaf sheaths and tassels. The cobs are of particular interest, since they reveal a distinct evolutionary sequence. The oldest, at the bottom of the refuse heap, are the smallest and most primitive. These cobs and loose kernels from the same level prove that the earliest Bat Cave people grew a primitive variety of corn which was both a pop corn and a form of pod corn. The pod corn, however, was not as extreme as the earless synthetic "wild" corn described above. It probably represents a type already partly modified by domestication, more nearly like the weak forms of pod corn still found in South American varieties.

THE BAT CAVE corn has answered another of our questions: What is the relationship of corn to teosinte? The oldest and most primitive of the Bat Cave corn shows no evidence whatever of having stemmed from teosinte. But beginning about midway in the sequence there is strong evidence of the introduction of a corn that had become contaminated with teosinte. Thus the Bat Cave cobs suggest that early botanical investigators were not completely wrong in believing that teosinte played a role in the evolution of corn. Although teosinte clearly was not the progenitor of corn, it contributed its genes to corn's progress toward its present form.

The Bat Cave remains still leave unanswered the question: Where in America did corn originate? It seems improbable that corn could have been a native of the region where these remains were found, since corn is a moisture-loving plant and the region is now and was then quite dry. Probably it was brought into the Bat Cave region as a cultivated plant from Mexico. Whether corn was native to Mexico or had been introduced there still earlier from South America is an open question.

How did the primitive pod-pop corn that the Bat Cave people grew 4,000 years ago evolve in so short a period, as evolutionary time is measured, into the modern ear of the Corn Belt? Some botanists are inclined to endow the American Indian with unusual abilities as a plant breeder. If the great changes that have occurred in corn in this relatively brief period are the product of his skill, he was indeed remarkably adroit. The corn from Bat Cave does not, however, support this view. On the contrary, there is no evidence that the Bat Cave people were any more concerned with plant improvement than they were with sanitation. If selection was practiced at all, it was probably an unplanned "negative" selection—the good ears were consumed and the leftover nubbins were used for seed. Nevertheless, thanks probably to accidental hybridization with teosinte and with other races of corn, there was a gradual increase in the average size of ears and kernels and an enormous increase in total variation during the 3,000 years of the Bat Cave's history.

The evolutionary sequence in the Bat Cave indicates that four principal factors operated in the evolution of corn during this period: 1) The pressure of natural selection, one of the most important suppressive factors in evolution, was greatly reduced; 2) mutations from the more to the less extreme forms of pod corn occurred; 3) corn was modified by contamination with teosinte; 4) crossing of varieties and races produced new combinations of characters and a high degree of hybridity.

ALL of these factors contributed to a tremendous increase in variation, so that when man finally did begin to practice selection in corn, he had a rich diversity at his disposal. From this, by accident or design, he chose a combination of characteristics that makes corn the most efficient of all cereals as a producer of foodstuffs. The ear of modern Corn Belt corn is a highly functional botanical structure. The massive cob provides an extensive surface for grain-bearing. It encloses an enormous system of vessels which supply and nourish the grains. The entire ear, once an aggregate of kernels individually enclosed in glumes, is now protected as a single unit by the husks. The glumes have been reduced to mere vestiges—no energy is wasted on structures now useless and obsolete. The elements of strength necessary to support this greatly enlarged inflorescence have come from teosinte, which contributes genes for hardness and toughness when it is hybridized with corn. Teosinte is to the modern ear of corn what steel is to the modern skyscraper. Indeed, in structure the skyscraper and the ear of corn are not too unlike. Both are massive, strong, efficient, functional and superbly designed to fit a particular purpose. At their best both are distinctly beautiful.

Paul C. Mangelsdorf is professor of botany at Harvard University.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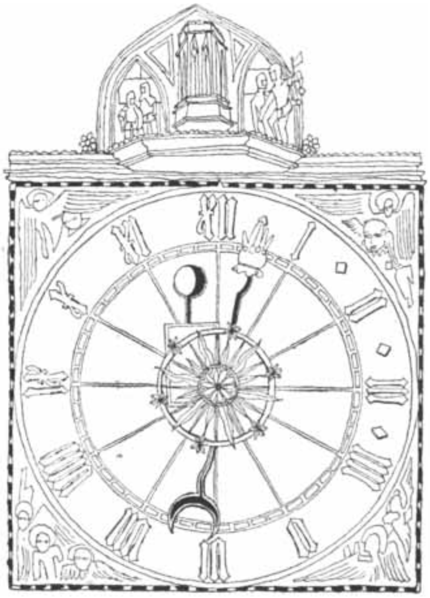


Scientific Intelligence

SINCE the end of the war groups of U. S. scientists have been urging that the State Department form a special scientific branch, with trained attachés stationed in foreign countries, to promote the international exchange of scientific information and keep the U. S. better posted on scientific developments abroad. The plan has now won the Department's official approval. It made public last month a report entitled "Science and Foreign Relations," prepared after several months of study by the physicist Lloyd V. Berkner, of the Carnegie Institution, who had been assigned by the Secretary of State to examine the Department's "responsibilities in international science."

Berkner, who had consulted more than 1,000 eminent persons in his survey, recommended that the Department establish a Science Office in Washington, headed by a "front-rank" scientist and with a staff of specialists in the physical, biological and engineering sciences. He also proposed that staffs of scientists be attached to 13 of the most important U. S. diplomatic missions abroad and to the U. S. administrations in Germany and Japan. There would be area staffs in London for Western Europe, in Johannesburg for South Africa, in Rio de Janeiro for South America and in Sydney or Canberra for Australasia. In addition local staffs would be stationed in Paris, Rome, Berne, Stockholm, Ottawa, Lima, Oslo or Copenhagen, The Hague, Brussels, Tokyo and Berlin.

The report called attention to the many obstacles and barriers to the international flow of scientific information that had developed from the war. It urged that the U. S. take "a more positive and active interest" in promoting the exchange of unclassified information, particularly in basic science. The report observed that "certain definite benefits which are highly essential to the welfare and security of the U. S. . . . stem from international cooperation and exchange with respect to scientific matters."

According to the New York *Times*, Berkner and some State Department officials who commented on the report believe that the U. S. should send official delegations of scientists to international scientific meetings in other countries, including the U.S.S.R., and should admit Russian and "fellow-traveling" scientists to similar meetings in the U. S.

Spark Machining

CUTTING and drilling hard alloys by machine tools is slow and costly; even with carbide tools and diamond powder it may take hours to drill a hole less than an inch deep. Some extremely hard materials, such as carbides and borides, cannot be machined with cutting tools at all.

An ingenious solution to this problem has been worked out at the Technical University in Budapest, Hungary. It consists essentially in using an electric spark to boil away the metal that must be removed. The apparatus has an electric circuit with a condenser. The "cutting" tool is an electrode connected with the negative pole of the current source; the material to be drilled or cut is attached to the positive pole and immersed in petroleum. When the electrode touches the object, the condenser discharges and the resulting spark at the point of contact eats away a little of the material. The spark is immediately quenched by the petroleum; the success of the process depends on this quenching operation, which prevents the formation of an arc between the object and the electrode. By an oscillating series of contacts with the material the electrode drills a hole.

The process, announced in a Hungarian publication last year, has just been brought to the attention of Western Europe through a translation in the British *Engineers' Digest*. The Hungarian inventors reported they had found that spark machining is more costly than conventional methods for cutting soft or medium-hard materials, but it is "very advantageous," from the standpoint both of cost and quality of the work, for machining very hard metals, and for the hardest metals it is the only possible method apart from diamond grinding.

New "Smyth Report"?

AS this issue went to press, there were reports in Washington that a major change in U. S. policy on the release of atomic energy information was impending. The Atomic Energy Commission, the Joint Congressional Committee on Atomic Energy, other Government officials and scientists were said to be discussing the possibility of declassifying a large amount of material that can no longer be considered strictly secret.

The move stems from the two recent evidences that much of this information is no longer secret to the U.S.S.R.—the Soviet atomic explosion and the disclosures of the spy Klaus Fuchs. Those who are pressing for the relaxation of AEC secrecy argue that information well known to the Russians is being withheld from U. S. industry and scientists.

Charles A. Thomas, executive vice president of the Monsanto Chemical Company, proposed in a speech last month that U. S. industry be permitted to build and operate atomic energy plants for producing power and plutonium, the uranium to be leased from AEC.

One of the chief areas under consideration for declassification, according to the reports, is the design and operation of nuclear reactors. Whether the information would be released piecemeal or in the equivalent of a second "Smyth Report" is not indicated.

Meanwhile the AEC, which prohibited public discussion by its scientists of progress on the hydrogen bomb, has found it necessary to issue a cautionary word on the project's prospects. Acting Chairman Sumner T. Pike told a press conference that the chances of making the bomb were "somewhere between 'probable' and 'possible.' "

Stories that the Defense Department and AEC had developed artillery shells and guided missiles with atomic warheads appeared in the press last month. They were immediately denied by Administration spokesmen. The New York *Daily News* later reported that Secretary of Defense Louis A. Johnson was to be summoned before the Joint Congressional Committee on Atomic Energy for questioning as to whether the Defense Department had inspired the story.

Artificial Seasons

PLANTS use sunlight not only as a source of energy but also as a calendar of the seasons. Their rate of growth, time of sprouting and time of blooming may be regulated by the quality, intensity and duration of light. Laboratory workers of the Netherlands engineering firm N. V. Philips have recently learned some facts about the light control of plants that are now being applied by Dutch nurserymen.

They have found that plants raised

under blue light are usually shorter, but stronger, than those raised under white light. Red light stimulates blooming. Tulips can be forced to bloom at a predicted date, and the lighting system can also control the length of stem, the size of leaf and the brilliance of the flower. Seed potatoes can be kept from sprouting by storing them in a lighted room. Plants can be raised in winter in a closed shed, instead of a greenhouse, by the use of fluorescent light. This work was described in the *Industrial Bulletin* of Arthur D. Little, Inc.

Self-Correcting Machine

AUTOMATIC computers are like human brains in at least one respect—they too make mistakes. Designers have been trying to make them still more human by endowing them with the ability to correct their errors. Some of the more advanced computers can tell when they have gone wrong, but the most they can do then is to shut themselves off and sound an alarm for help from their human attendants. R. W. Hamming of Bell Telephone Laboratories has now gone a step further: he has developed a system whereby a computer should be able to locate and correct its own mistakes—provided it does not make too many.

His system is designed for a digital computer using a binary code. In this code any number is represented by a string of ones and zeros; for example, the number 53 is expressed as 110101. Hamming points out that it is easy to provide for automatic detection of an error by adding a symbol as a check, designed, say, to fill the requirement that the number of ones in the transmitted signal shall always be even. Thus to the signal 110101 a zero would be added, since there is already an even number of ones (namely, four); if it had three, a one would be added instead of a zero. The transmitted signal for 53, then, is 1101010, the final zero being the so-called "parity" check. Now if, through some failure in the computer, the signal becomes 0101010, the machine can recognize that this is an error, because the signal has an odd number of ones.

Hamming reasoned that a computer could correct its error if it were given a means of determining which symbol in the series was incorrect. If the faulty symbol was a zero, the machine would automatically change it to a one, or *vice versa*; in the case of 0101010, the incorrect signal for 53, the error is in the first symbol, and the machine would change the zero to a one and correct the signal to 1101010. Hamming proceeded to work out a system, using additional checking symbols, which will permit a computer to locate the erroneous symbol.

Although such a computer has not yet actually been built, the system has been proved workable in a demonstration model with some of the necessary circuits. Hamming observes that it would not be practical to build a computer capable of correcting more than one error at a time; the circuits would have to be much too elaborate. But the occurrence of two or more simultaneous errors in a computer is rare.

The value of a self-correcting computer is that it could be left unattended for long periods with reasonable confidence that it would not be stopped by an error. But Hamming notes that such a machine would be expensive. As in the human brain, the ability to correct mistakes is gained only at the cost of increased complexity and some loss in efficiency. A self-correcting machine not only would need more equipment but, because of the extra symbols (inhibitions) it would require for policing itself, it would operate with less economy of effort.

Pluto's Mass

PLUTO, the outermost planet of the solar system, has a mass 10 times smaller than hitherto supposed. This has been determined by the first measurements of the planet's disk, made by Gerard P. Kuiper of Yerkes Observatory with the 200-inch telescope on Palomar Mountain.

On the basis of deviations in the path of the planet Neptune, supposedly caused by Pluto's gravitational attraction, it used to be estimated that Pluto's mass was approximately equal to that of the earth. Kuiper, making his observations visually, was the first human being to see the planet as anything more than a pinpoint of light, since no measurable disk can be shown by any telescope less powerful than the 200-inch. He calculated that Pluto's diameter is 3,600 miles, 46 per cent that of the earth, and its mass is one tenth of the earth's. The latter estimate is based on the assumption that Pluto's density is about the same as the earth's.

The new measurement makes Pluto the second smallest planet, the smallest being Mercury. It leaves unsolved the mystery of Neptune's perturbations, which are too great to be accounted for by so small a planet as Pluto.

Supersensitive Detector

A RADIATION detector so sensitive that it can locate radioactive deposits deep underground from a high-speed airplane has been invented by Canadian physicists. The device, known as a "gamma-ray spectrometer," is a variation of the well-known scintillation counter.

Unlike Geiger counters, which detect radiation through ionization in a gas (*see page 40*), a scintillation counter records radiations by means of tiny sparklike scintillations produced when the radiation strikes a crystal. The gamma-ray spectrometer uses a sodium iodide crystal activated by thallium iodide. The amount of light produced by a scintillation when a gamma ray strikes the crystal is believed to be proportional to the energy of the secondary electrons created by the ray and hence to the energy of the ray. This makes it possible to identify the source material from which the gamma rays are emitted.

The inventors of the device, Robert W. Pringle, Kenneth I. Roulston and Harry W. Taylor of the University of Manitoba, report that it has been used "with considerable success" in uranium prospecting in Canada. They add that it will also be useful for "the rapid investigation of geological formations" from airplanes. Built with tiny hearing-aid tubes, the instrument weighs only eight pounds.

Youngest Embryo

WHAT happens in the human embryo during the first few days after conception? This is obviously a rather inaccessible subject for investigation. Arthur T. Hertig of the Harvard Medical School resorted to a stratagem to make it more accessible. He enlisted the cooperation of a number of married women patients with ailments that required the removal of their reproductive organs. He timed their operations to take place soon after the optimum time for conception—14 days before menstruation. In 11 years at the Free Hospital for Women in Brookline, Mass., 158 patients were operated on at this stage, and of these 33 were found to be pregnant. Their young embryos, removed with the diseased organ, ranged from a few days to about three weeks in age. The youngest fertilized ovum was 60 hours old—the earliest ever available for examination.

Hertig and the embryologist John Rock of the Carnegie Institution in Washington made a careful study of these embryos. They found that at 60 hours the fertilized ovum has split into only two cells and is still situated in the Fallopian tube. By the fourth day the embryo has reached the uterus and has from five to 12 cells. On the sixth day it attaches itself to the lining of the uterus; it is then less than eight one-hundredths of an inch in diameter. Two weeks after conception—the usual time of menstruation—the embryo is ready to receive an influx of blood from the mother. A week later fetal circulation starts, and the embryo is then ready to begin rapid growth.

Reporting these observations at the

recent International Congress on Obstetrics and Gynecology in New York City, Hertig said that only 60 per cent of the 33 recovered embryos were normal. Many of the abnormal ones were so defective that they probably would have aborted even before there was any clinical evidence of a pregnancy.

Smokers' Cancer

TOBACCO has often been suspected of complicity in the great increase in lung cancer since 1900. But the evidence has been fragmentary and conflicting. Now two well-documented reports in the *Journal of the American Medical Association* present what appears to be the strongest evidence thus far that smoking may cause cancer.

Ernest L. Wynder and Evarts A. Graham of the Washington University School of Medicine found in a national survey that among 605 men with cancer of the lung, 96.5 per cent had smoked at least 10 cigarettes a day for many years, and half of them had smoked more than 20 a day; whereas in the general male hospital population without cancer only 73.7 per cent were regular smokers, and four fifths of these smoked fewer than 20 cigarettes a day.

The other study was by Morton L. Levin, Hyman Goldstein and Paul R. Gerhardt of the New York State Department of Health. They reported that 84.8 per cent of 1,045 cancer patients in Buffalo were smokers; in a group of 605 patients without cancer 77.8 per cent were smokers. Cigarette smokers appeared to be prone to cancer of the lung, and pipe smokers to cancer of the lip.

Wynder and Graham suggest that cigar and pipe smokers are less susceptible to lung cancer than cigarette smokers are because they are less likely to inhale the smoke. Lung cancer is rare, they report, in nonsmokers or persons who smoke less than the equivalent of five cigarettes a day. (One cigar or two pipes is rated as equivalent to five cigarettes.) They also find that heavy smokers may develop cancer 10 years or more after they stop smoking.

These investigators note that, since nonsmokers do occasionally have cancer of the lung, and obviously not all heavy smokers develop it, smoking cannot be the sole cause of the disease.

"From the evidence presented, however," they add, "the temptation is strong to incriminate excessive smoking, and in particular cigarette smoking, over a long period as at least one important factor in the increase of bronchiogenic carcinoma."

Terramycin

SOMETHING of a speed record among antibiotics for the trip from laboratory to wide clinical use has been set by the new drug terramycin. Reports on its clinical performance began to appear only three months after its development was announced by experimenters of Charles Pfizer and Company in Brooklyn, N. Y.

A group at the Mayo Clinic headed by Wallace E. Herrell has found the new drug effective for pneumonia, blood poisoning, urinary infections and various other diseases. Workers at the Food and Drug Administration and at Freedmen's Hospital in Washington, D. C., after testing it on 30 patients, concluded that "terramycin appears to be a useful addition to the important class of antibiotic drugs." The drug has been shipped to be used against shingles epidemics in Chile and Peru, undulant fever in Argentina, France, Italy and Portugal, bubonic plague in India, and yaws and dysentery in the Philippines.

The Mayo group said: "Its activity is similar but not identical to that of aureomycin. The evidence of nausea and vomiting with terramycin is definitely less than with aureomycin."

Hoarders

IS avarice a natural tendency or an acquired habit? Two Harvard psychologists have been investigating this question with rats. Louise C. Licklider and J. C. R. Licklider provided six rats with all the food they could eat and more. Their food after weaning consisted of pellets of Purina Laboratory Chow. Although none of the rats had ever experienced a food shortage, all immediately started hoarding pellets. Even after they had accumulated a hoard and the food-supply bin was empty, they kept coming back to hunt for more.

This behavior confirmed what previous investigators had found. But the Lickliders refined the experiment to try to unearth the rats' motives for hoarding. They covered half of the pellets with aluminum foil, thus eliminating their value as food. The experimenters discovered that four of the six avaricious rats actually preferred the worthless, inedible pellets in hoarding.

The rats were then put on short rations for six days. After this "deprivation period" they hoarded even more greedily and showed more interest in the plain food pellets, but some still hoarded foil-wrapped pellets and continued to prefer them.

The Lickliders conclude, in a report to the *Journal of Comparative and Clinical Psychology*: "The factors that lead to hoarding and that determine what is hoarded are by no means entirely alimentary. The initiation of hoarding seems to be for the rat, as for the human being, a complex motivational problem to which sensory and perceptual factors, rather than blood chemistry, hold the key."

SOIL

The loose material of the earth's surface is in constant process of evolution. Its variety deeply influences the life of man

by Charles E. Kellogg

WHAT is soil? A farmer would answer simply: "Something to grow crops in." An agricultural chemist would probably answer: "A foothold from which plants get their water and most of their nutrients." A pedologist (soil scientist), on the other hand, would have quite a different reaction to the question. From his point of view the query itself is awkwardly vague—like asking what is rock, or mineral, or gas. His reply would be that there are thousands of kinds of soils, each as individual in character and properties as a species of rock, of plant or of animal. Every soil has its own unique history; like a living organism it is the creature of a dynamic process of evolution, and a revealing subject for scientific study.

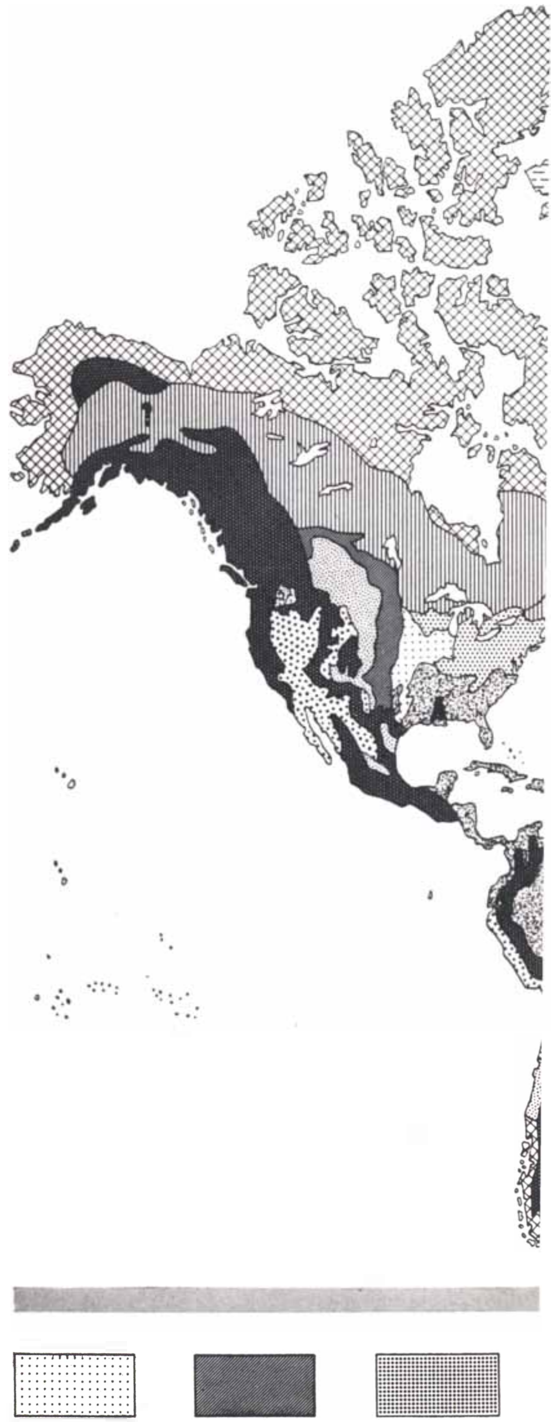
All three of these points of view have contributed to the development of modern soil science. Over the centuries farmers have learned by trial and error how to use their soil more efficiently. During the past 150 years biologists and chemists have determined rather accurately, through thousands of experiments in laboratories, greenhouses and field plots, what nutrients plants need. We now know that plants require some 15 elements for growth. From the air and water they get carbon, hydrogen and oxygen. From the soil they need phosphorus, potassium, calcium, magnesium, nitrogen, iron, sulfur and trace amounts of boron, manganese, copper, zinc and molybdenum. The result of this knowledge has been the development of more effective methods of fertilization, crop rotation and so on. But this is far from the whole story. The physical texture, structure and chemical relations of a soil play a vital part in its ability to store nutrients and supply them to plants. Hence for the scientific management of soil it is necessary to study the history and fundamental characteristics of the particular soil concerned.

Broadly speaking, soil is that part of the outer mantle of the earth that extends from the surface down to the limit of biological forces, *i.e.*, the depth to which living organisms penetrate. Five factors shape the evolution of a soil. They are (1) the parent rock, or hereditary material; (2) relief, or the configuration of the land where the soil lies; (3) climate and (4) living matter, acting on the parent materials, and (5) time. The history of their combined effects is etched in the profile of the soil. Climate, plants and soil are so intimately related that they form predictable patterns: thus black soil, subhumid climate and tall grasses usually go together; light-colored leached soil, cool, moist climate and evergreen forest form another combination; deep-red leached soil, hot, moist climate and rain forest form still another.

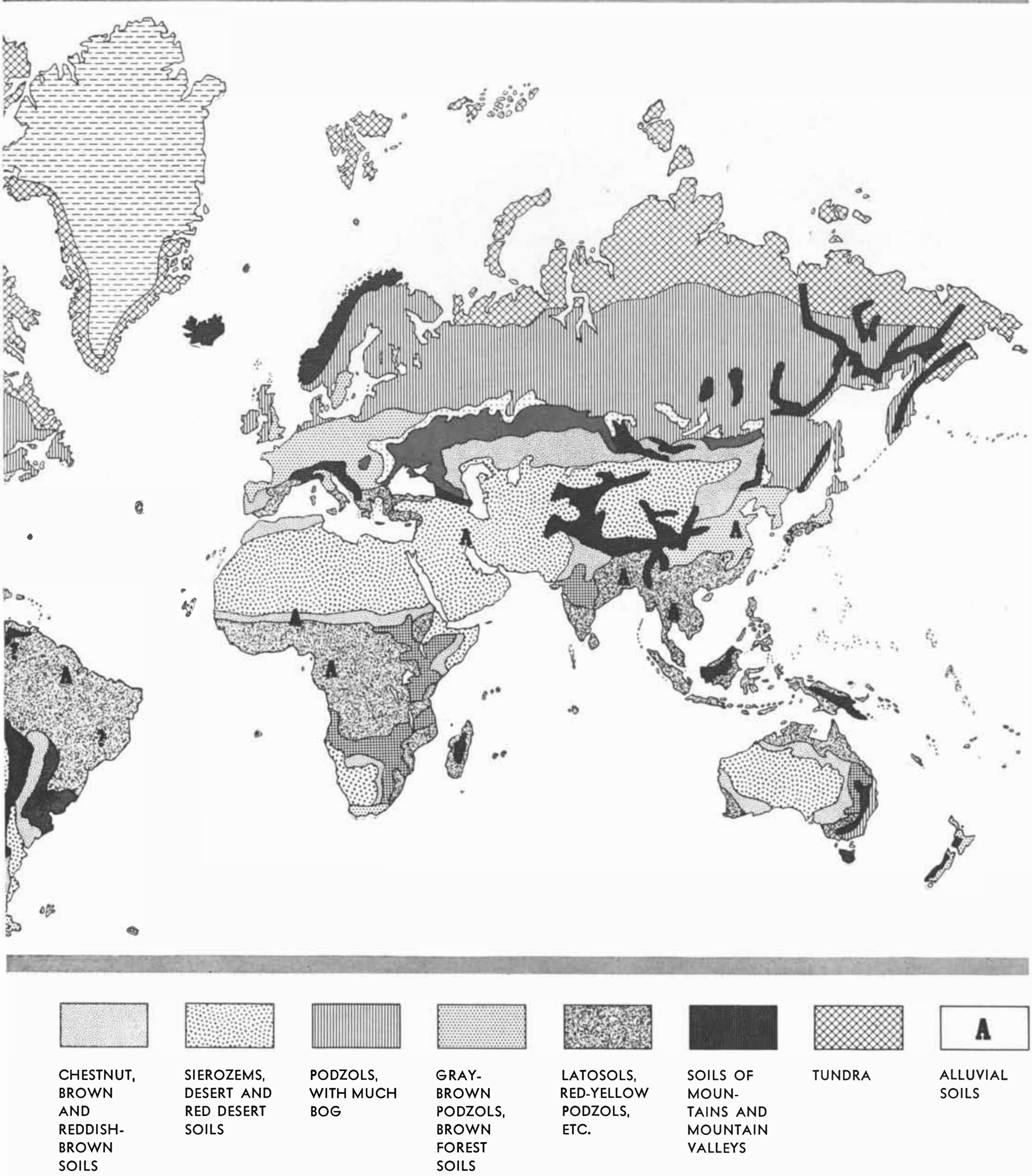
Every type of soil in the world has a unique profile. When the profile is laid bare, as in a fresh road-cut or in a deep pit, it can be seen that the soil consists of a series of differing layers, which the soil scientist calls "horizons." The profile is divided into three general levels called A, B and C, corresponding loosely to the surface soil, the subsoil and the substratum, or weathered material beneath the soil proper. Each of these main horizons may have several subdivisions. Soils vary greatly in depth, of course; they tend to become deeper toward the equator and thinner toward the poles. In the U. S. farm soils range from about two to five feet deep, taking the A and B horizons together.

Components of the Soil

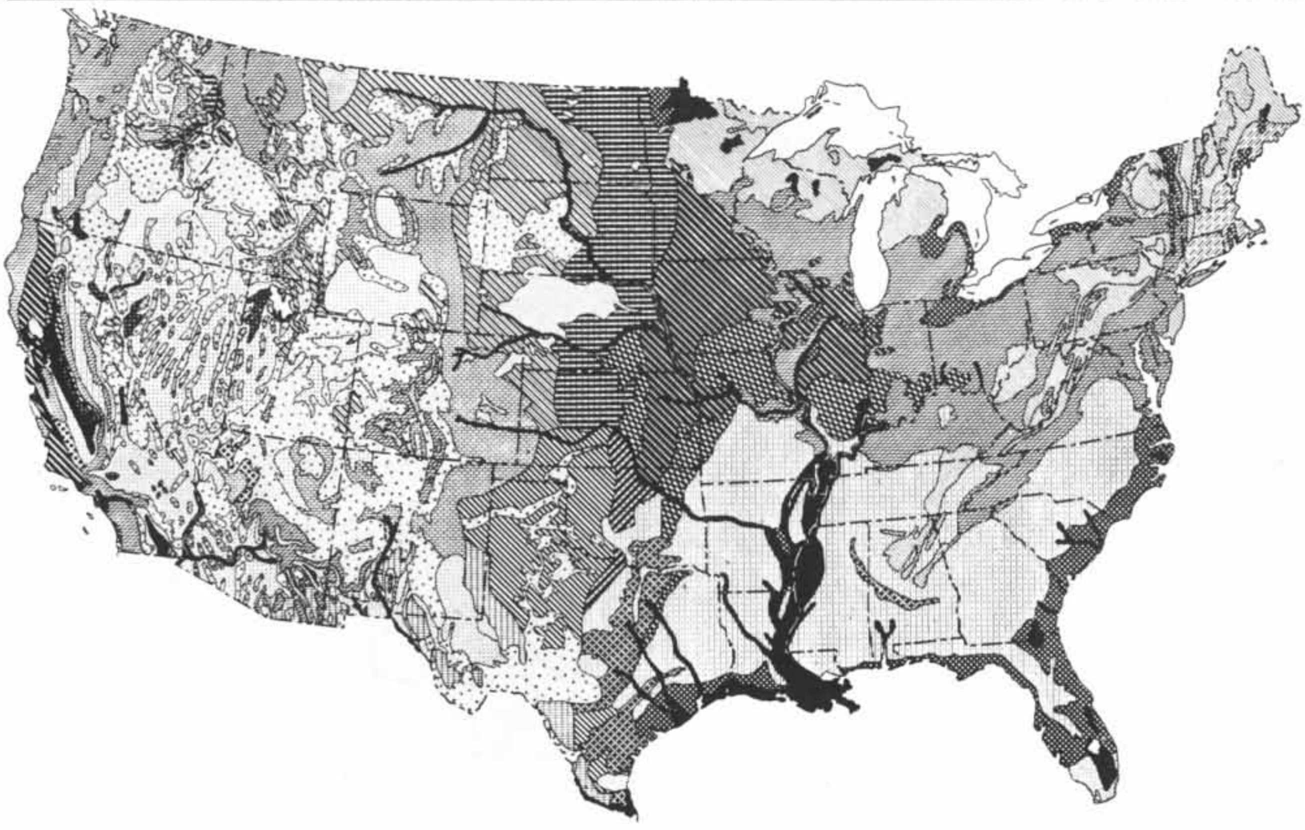
Most soil horizons are mixtures of sand, silt and clay, along with some organic matter. Of these constituents, clay has the greatest influence on the chemical activity of the soil. This is because many of the chemical reactions occur at the surfaces of soil particles, and the clay particles, being very small (less than .002 millimeter), are most numerous and offer the most surface. The clay parti-



SOILS OF THE WORLD are located in a general way on this map. Although each pattern on the map is



a rough approximation of the soil type of the region, many of the patterns include thousands of soil types. The symbol A, which stands for alluvial soils, denotes only a few of the most important alluvial areas. Many small but important alluvial areas are not shown. The pattern on the interior of Greenland is its ice cap.



ZONAL

Great groups of soils with well-developed characteristics, reflecting the dominating influence of climate and vegetation.

PODZOL SOILS
Light-colored leached soils of cool, humid forested regions.

BROWN PODZOLIC SOILS
Brown leached soils of cool-temperate, humid forested regions.

GRAY-BROWN PODZOLIC SOILS
Grayish-brown leached soils of temperate, humid forested regions.

RED AND YELLOW PODZOLIC SOILS
Red or yellow leached soils of warm-temperate, humid forested regions.

PRAIRIE SOILS
Very dark brown soils of cool and temperate, relatively humid grasslands.

REDDISH PRAIRIE SOILS
Dark reddish-brown soils of warm-temperate, relatively humid grasslands.

CHERNOZEM SOILS
Dark-brown to nearly black soils of cool and temperate, subhumid grasslands.

CHESTNUT SOILS
Dark-brown soils of cool and temperate, subhumid to semiarid grasslands.

REDDISH CHESTNUT SOILS
Dark reddish-brown soils of warm-temperate, semiarid regions under mixed shrub and grass vegetation.

REDDISH BROWN SOILS
Reddish-brown soils of warm-temperate to hot, semiarid to arid regions, under mixed shrub and grass vegetation.

BROWN SOILS
Brown soils of cool and temperate, semiarid grasslands.

NONCALCIC BROWN SOILS
Brown or light reddish-brown soils of warm-temperate, wet-dry, semiarid regions, under mixed forest, shrub, and grass vegetation.

SIEROZEM OR GRAY DESERT SOILS
Gray soils of cool to temperate, arid regions, under shrub and grass vegetation.

RED DESERT SOILS
Light reddish-brown soils of warm-temperate to hot, arid regions, under shrub vegetation.

INTRAZONAL

Great groups of soils with more or less well-developed characteristics reflecting the dominating influence of some local factor of relief, parent material or age over the normal effect of climate and vegetation.

PLANOSOLS
Soils with strongly leached surface horizons over claypans on nearly flat land in cool to warm, humid to subhumid regions, under grass or forest vegetation.

RENDZINA SOILS
Dark grayish-brown to black soils developed from soft limy materials in cool to warm, humid to subhumid regions, mostly under grass vegetation.

SOLONCHAK (1) SOLONETZ (2) SOILS
(1) Light-colored soils with high concentration of soluble salts, in subhumid to arid regions, under salt-loving plants.

(2) Dark-colored soils with hard prismatic subsoils, usually strongly alkaline, in subhumid or semiarid regions under grass or shrub vegetation.

BOG SOILS
Poorly drained dark peat or muck soils underlain by peat, mostly in humid regions, under swamp or marsh types of vegetation.

WIESENBODEN (1), GROUND WATER PODZOL (2), AND HALF-BOG SOILS (3)
(1) Dark-brown to black soils developed with poor drainage under grasses in humid and subhumid regions.

(2) Gray sandy soils with brown cemented sandy subsoils developed under forests from nearly level imperfectly drained sand in humid regions.

(3) Poorly drained, shallow, dark peaty or mucky soils underlain by gray mineral soil, in humid regions, under swamp-forests.

AZONAL

Soils without well-developed soil characteristics.

LITHOSOLS AND SHALLOW SOILS (ARID-SUBHUMID)
(HUMID)
Shallow soils consisting largely of an imperfectly weathered mass of rock fragments, largely but not exclusively on steep slopes.

SANDS (DRY)
Very sandy soils.

ALLUVIAL SOILS
Soils developing from recently deposited alluvium that have had little or no modification by processes of soil formation.

SOILS OF THE U. S. are located here in greater detail than on the map on pages 30 and 31. With the key to each pattern on this map is the name and a brief description of each soil type and the climate and vegetation with which it is associated. Within the area of each pattern are areas of other soils too small to be shown.

cles hold on their surface various positive ions, notably those of hydrogen (H^+), sodium (Na^+) and calcium (Ca^{++}). The acidity or alkalinity of a soil depends on which of these ions predominates: a soil dominated by hydrogen is acid, and one in which sodium prevails is highly alkaline. The type of ions held by a clay affects its transportability through the soil. Clays dominated by sodium or by hydrogen are more sticky and more easily suspended in water than those bearing calcium. Hence if the fine clay becomes acid or highly alkaline, in the absence of excess salts, it can be carried in suspension to lower horizons or even be leached completely out of the soil by percolating waters. Calcium clay, on the other hand, tends to stay where it is.

The proportions of sand, silt and clay in a soil horizon, which may range from pure sand through the various loams to pure clay, determine its texture. Obviously a soil's texture affects its permeability to water and root penetration. Even more important is the soil's structure. This depends on how the primary particles in it are clumped. There are four kinds of structure: granular, blocky (lumpy), columnar (vertically elongated blocks) and platy. For most plants a granular structure or mixed granular and blocky structure is best. A soil's texture stays practically constant, but its structure can be changed drastically, for better or worse. In soil management the maintenance of proper soil structure is as important as the maintenance of plant nutrients.

Also vital for a good growing soil is organic matter: it promotes granular structure, aids in the retention of plant nutrients, supplies food for microorganisms and small animals that help enrich the soil, and, when decomposed, itself furnishes a balanced, slowly available supply of plant nutrients. The organic matter of the soil is a complex of things that includes living roots, microorganisms, a fairly stable brown or black decomposition product called humus and a host of intermediate products. The organic material ultimately breaks down, of course, to water, ash, carbon dioxide and a small amount of other gases.

It is the processes of solution, decomposition, addition and leaching, acting on the original mixture of minerals, that account for most of the great differences in chemical composition among soil horizons and types. These processes cause losses of some compounds from the parent material and increases of others.

Chemical Activity

In most soils only a very small part of the material present is soluble in water at any one time. If this part is leached out, a bit more comes into solution. This mechanism for maintaining a small but replenishable supply of soluble material is essential to plant life. Most crop plants require soils that have no more than .5 per cent readily soluble material, and many have a much lower tolerance. Only a very few wild plants will live in soils that contain as much as 10 per cent of such material.

There is also a self-balancing mechanism that maintains the content of free ions in a soil. The clay and organic matter absorb ions from the soil solution when the ion content is high and release them when it is low. This buffering effect causes a soil to resist any permanent change in its degree of acidity or alkalinity. For example, in an acid soil the free hydrogen ions can be quickly neutralized with lime, but then other hydrogen ions come into solution from the insoluble clays and humus. Thus to reduce the acidity permanently one must keep adding lime until the reserve of hydrogen ions has been used up; or, we could also say, until the calcium ions have replaced nearly all the replaceable hydrogen ions in the humus and clay. Since it is the clay and organic matter that hold the reserve of ions, much more lime is needed to change a heavy clay soil than a sandy soil low in organic matter. We say that the clayey soil is well buffered. Speaking loosely, similar mechanisms maintain low but stable concentrations of potassium, phosphate, magnesium and other ions in the soil.

Every gardener knows that the acidity of a soil is measured on the so-called pH scale. A neutral soil has a pH of 7; a lower pH means that the soil is acid and a higher one that it is alkaline. Natural soil horizons range in pH from about 3 (extremely acid) to above 10 (very strongly alkaline). For most crop plants the most productive pH value is between 6 and 7. A few plants, notably blueberries and cranberries, need an acid soil with a pH of about 4.5.

Over a long period the cumulative effects of the cycle of plant feeding, growth, death and decay greatly influence the character of the soil in which the plants grow. The different types of plants, and even individual species, vary greatly in the kind and amount of nutrients they take from soil, air and water and deposit in the soil when they decompose. Under desert shrubs the amount of nutrients deposited in the soil is very low; under tropical rain forests it is very high. Even under adjacent desert shrubs the soils often differ, ranging from slightly alkaline to very strongly alkaline and from very low in soluble salt to very high, because of the different feeding habits of unlike species and the different salts returned to the surface. In New Zealand, soils under kauri gum trees have a very thick, exceedingly acid, white horizon leached of clay and humus; under adjacent broad-leafed trees the soil is brown, well charged with organic matter and only moderately leached. In the northern part of the U. S., hardwood trees deposit roughly twice as much calcium, magnesium, potassium and phosphorus on the soil as do pines and spruces.

In subhumid, temperate regions, near the boundary between trees and grass, the grasses feed heavily on mineral nutrients, and the soils become dark-colored. Under the nearby forest more organic acids are produced, and the resulting soils are lower in nutrients and organic matter. If, however, we count the nutrients embodied in the plants and animals as well as those in the soil, the forest area has more nutrient material, acre for acre, than the adjacent prairie.

In the humid tropics, near the boundary between rain forest and savanna (grassy plain), the soils present another picture. There during the hot rainy season everything soluble leaches out of the soil; the only nutrients retained are those held by plants in their roots, stems and leaves. In the forest the trees hold a large supply of nutrients; the grasses of the savanna, on the other hand, hold very little, and of this little some is lost because the grass usually is burned off during the dry season and much of the ash washes away with the first heavy rains of the wet season, especially through cracks in the earth.

Thus the fertility of soils varies with climate in a paradoxical fashion: in a subhumid region such as the Minnesota-Dakota boundary more productive soils develop under wild grasses than under forest, whereas near the tropical Congo the reverse is true.

This continual cycle of nutrients out of the soil into plants and back to the soil is perhaps the most important fact of soil dynamics. If the cycle is broken by the removal of nutrients through the harvesting of crops, the soil may deteriorate rapidly. On the other hand, farmers and gardeners can build up the soil to a much higher level of nutrients than its natural condition by adding chemical fertilizers or organic matter "from over the hedge."

Other cycles of change influence the soil. Rains alternately aerate the soil and expel air from it, so that gases are continually exchanged between soil and air. Dust from deserts and distant volcanoes also brings important additions to soils: some highly productive soils, as in Java, exist in the very shadow of volcanoes. The periodic overflow of great rivers and small streams leaves a film of fresh new minerals on the flooded soil. Perhaps nearly one third of the world's population gets its food supply from such alluvial soils, continually being renewed.

Erosion

What does erosion do to the soil? Contrary to a common impression, erosion has beneficial aspects as well as harmful ones. It is one of the great natural processes forming the landscape and soil materials. As a result of erosion old lands are continually being removed and new ones built. Slow, normal soil erosion is an essential process by which upland soils maintain their productivity. As the surface of the upper horizon of a plant-covered soil is gradually eroded away, at the rate of perhaps one inch in 100 to 1,000 years, the upper part of the horizon beneath is gradually changed and becomes part of the top horizon, and so on in turn down through the soil profile, until finally new, fresh minerals from the underlying rock come within reach of plant roots and are incorporated into the bottom horizon of the productive soil.

The damage comes when natural erosion is greatly accelerated, as a result of excessive burning, grazing, forest-cutting or tillage, so that the horizons are removed faster than they form. The most serious erosion injuries to soils are not chemical, not the loss of plant nutrients, but the changes in structure arising from the loss of granular surface horizons and the exposure of massive clay, hardpans or even rock.

We cannot stop all rapid erosion. In regions of active uplift and near the margins of spreading deserts, active erosion is inevitable, even under wild vegetation. But we can and should control it where practicable. The basic method of control is to maintain a protective cover of plants. This sounds simple enough, but in practice it is complicated by the fact that the cover must be productive as well as protective.

These, then, are some of the general principles governing the formation of soils. They should make clear why many thousands of soil types exist in the world. Now let us look at some actual soils in the field.

The Gray-Brown Podzolic

Suppose we drive out into Marion County, Iowa, some 30 miles southeast of Des Moines. Here we see a gray-brown soil such as can be found in almost any county east to the Atlantic Ocean. This type of soil is known as Gray-Brown Podzolic, from the Russian word *podzol,* meaning ashes. Until 150 years ago the Gray-Brown Podzolic soils supported the heartland of Western civilization. They have developed under a humid temperate climate and are generally associated with hardwood forests (here in Marion County the trees are mainly oaks and hickories).

The profile of this soil is not particularly dramatic. At first glance it looks like just a plain, brown-colored garden soil. Generally the upper six inches of the A horizon is very pale brown or light brownish-gray silt loam, crumbly and mellow. This surface horizon receives the decomposition products of fallen leaves, and in it the small animals, surface roots and microorganisms are most active. Directly underneath it the soil is more leached. This A_2 horizon, some five to 10 inches thick, is a yellowish-gray, floury silt loam. The particles are oriented into thin plates, easy to crumble. Next comes a transitional zone in which soil of the B horizon is slowly being transformed to A. Under this thin transitional layer lies the main B, some eight to 12 inches thick. It is much richer in clay, coarser in structure and a darker brown than the A above. Its silty clay loam has a blocky structure; the blocks are the size of filberts or walnuts and often sharply angular at the corners. Its coarse, open structure is maintained by the penetration of growing tree roots and by the slight movements of the roots as the wind sways the trees. If it is cleared, plowed and exposed directly to the sun and rain, this horizon is likely to become massive—sticky when wet and hard when dry. Beneath the main B is another B subdivision some four to eight inches thick; this is a dark yellowish-brown, tough clay, packed into larger blocky aggregates with sharper angles.

Thus the A and B horizons of this soil together are some 30 to 36 inches thick. The C horizon, or parent material from which the soil is made, is a blocky, light yellowish-brown and pale olive clay.

Gray-Brown Podzolic soils may develop from limestone, shale, glacial drift or other rocks. However derived, all of them have similar profiles, though they may differ in some details; some are more sandy, a few richer in clay, some reddish in color because of the red color of the parent rocks. The Gray-Brown Podzolic soils are normally acid—too acid for the best growth of crops. So liming is essential. Because these soils need occasional rotations of alfalfa and other good legume hays to maintain organic matter and good structure, the best farming systems usually keep some livestock on them.

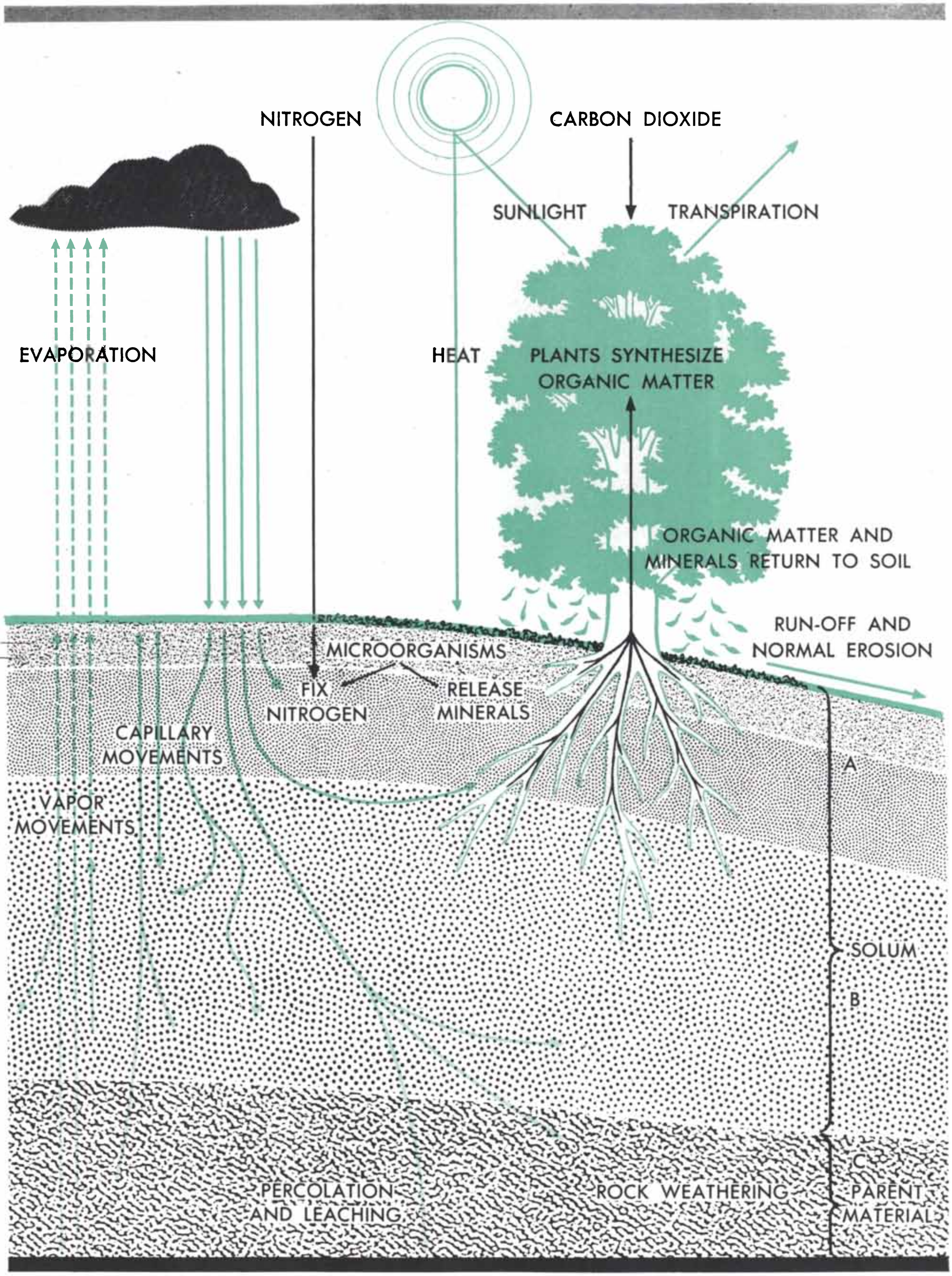
Perhaps more is known about this group of soils than about any other. The soil of the famous Rothamsted Experimental Station in England—the oldest agricultural experiment station in the world—is quite a bit like this. After 106 years of continuous culture for a single crop—wheat—without fertilizers, manure or legumes, the soil of this station still yields 10 to 12 bushels of wheat per acre, a little over the world average! But of course this is no way for a farmer to handle such soil. By using lime to correct acidity, phosphate and potash fertilizers, farm manure from the livestock and rotation plantings of clover, a farmer can get 40 to 45 bushels of wheat per acre from this soil.

The outstanding feature of this type of soil is the wide range of cereals, grasses and legumes, root crops, fruits and vegetables that grow well in it. If well managed, it is dependable. But some farmers are neglecting lime, minerals and legumes, and even allowing the soil to erode. With poor farming, this soil deteriorates rapidly to low levels of productivity. Thus on what was originally the same kind of soil one can find both very poor fields and excellent fields that have been made even more productive than the natural soil.

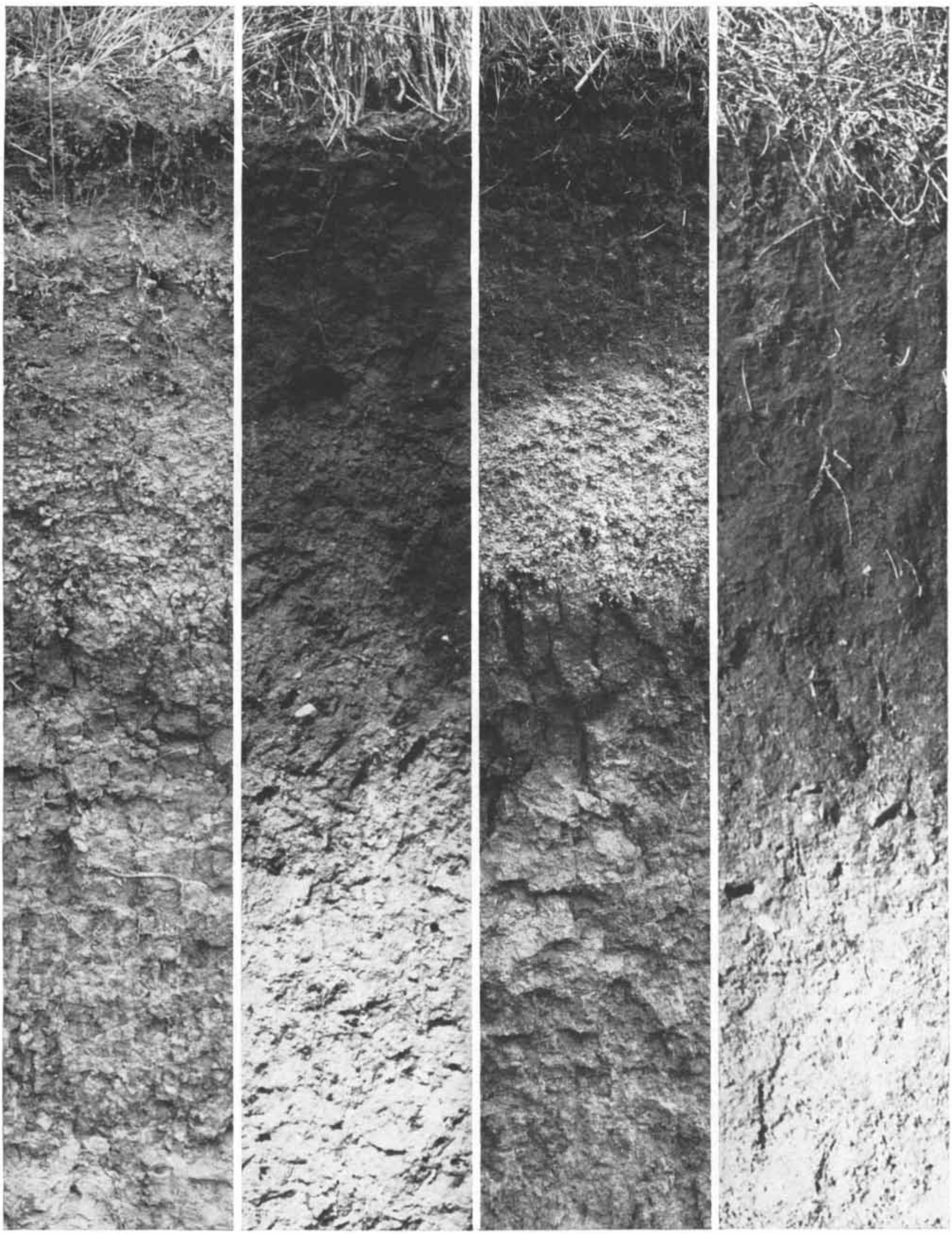
The Clarion

Suppose now we drive on west to another spot near Des Moines. Here the original native vegetation was tall grass rather than forest. The soils are nearly black. We shall cut our profile pit in a gently sloping place where the last great glaciers left a limy mixture of sand and boulder clay, along with some stones. We find that the surface A horizon, some eight to 14 inches thick, is a very dark brown to brownish-black fine granular loam. Below this the soil fades gradually into the other horizons; the boundaries are not so sharp and the differences are less prominent than in the Gray-Brown Podzolic. There is a transitional horizon some eight to 10 inches thick of a brownish-gray to dark yellowish-brown loam, with some streaks of the darker soil from above. These two upper layers are only slightly acid, while those beneath are neutral or calcareous. The top B layer under the transitional horizon is a yellowish-brown loam seven to 11 inches thick, and below this is another B of light yellowish-brown heavy loam or light clay loam about one foot thick. The A and B horizons together have a depth of some three feet. Below them lies a deep, pale yellow, mixed limy glacial till.

What we have been looking at is the Clarion soil—a Prairie soil representative of a group of nearly black soils that are dominant in the Corn Belt. Curiously, nowhere else in the world can one find another large area of soils exactly like these. The Clarion soil is in a transition zone between the forests of the more humid East and the grasses of the drier West. It has high fertility and nearly as wide a range of crops as the Gray-Brown Podzolic. Severe droughts are rare. The grasses of the region have been heavy feeders on minerals from the whole soil, and have concentrated them, along with abundant amounts of humus, in the A horizon—a great storehouse of mineral nutrients and nitrogen. The humus content of this soil can be maintained only under continuous grass. Any tillage and exposure of the soil to the sun is certain to reduce its humus, and no reasonable additions of manure or compost can maintain it at the original level. But a rotation of corn, small grains and mixed grasses and legumes can keep the humus at about 70 per cent of the natural level.



PHYSICAL AND BIOLOGICAL processes participate in the life of the soil. In the biological process plants remove water and various nutrients from the soil and combine them with carbon from the air. The various plant structures eventually return to the soil and decompose, releasing nutrients for a new cycle of plant growth.



FOUR IOWA SOIL TYPES are viewed in profile. At the left is the profile of the Weller silt loam, a Gray-Brown Podzolic soil. Second from the left is the profile of the Clarion loam, a dark brown Prairie soil. Third from the left is the profile of the Edina silt loam, a Planosol characterized by a gray, leached horizon over a dense claypan. Fourth from the left is the profile of the Webster silty clay loam, a Wiesenböden soil characteristic of regions with poor drainage. All four of these photographs show the soil to a depth of about four feet.

The Prairie soils usually need some phosphate fertilizers. Most of them also respond to extra nitrogen, especially for corn. Soil erosion should be controlled, for the loss of the surface horizons of this soil means serious depletion of organic matter, of nitrogen and of phosphorus. Generally, however, erosion of a Prairie soil does not expose an intractable B horizon, so the soil can be built back rather easily even after a great amount of erosion, short of deep gullying.

The Chernozem

A bit farther west and north—say west of Fargo, N. D.—we enter a region of subhumid grassland with another type of nearly black soil called Chernozem, from the Russian for "black earth." This soil is found over large areas of central Eurasia and North America. These great areas in the interior of continents were little cultivated before the age of modern science; not until railroads crossed the continents did the Chernozem soils become important in world commerce. Now a large proportion of the bread grains of the world come from them.

In contrast to the Gray-Brown Podzolic, the Chernozem soils have a limited number of adapted crops—mostly cereals. Lately breeders have developed some varieties of corn that also do fairly well in them. Unlike the Gray-Brown Podzolic soils, which need to be built up in productivity, the Chernozem soils have their maximum fertility when first plowed. Because there is relatively little natural leaching, these soils require little fertilizer unless the land is artificially irrigated; then both phosphorus and nitrogen are valuable. It has been found that under normal conditions soluble phosphates give worth-while returns on many of the Chernozems. These soils need no lime; one of their characteristics is a layer of accumulated lime just beneath the B horizon.

In the next drier belt beyond the Chernozem toward the Western desert are the Chestnut soils, somewhat like the Chernozem soils but lower in organic matter and even less leached of lime. The climate is still more uncertain; almost every year is drier or wetter than the "average." The uncertainty of climate and the rather limited range of crops that can be grown in the soil make its farming more hazardous. This has had an effect on the region's politics. In the areas of the Gray-Brown Podzolic soils, which are dependable and support a very wide range of crops, farmers developed a preference for individual effort and *laissez faire*. Farmers on the Chernozem-like soils, on the other hand, are forced to think more in terms of cooperation. They think more about controlled railroad rates, crop insurance, cooperative credit and the like. Many of the so-called radical ideas of government—that is, radical to believers in *laissez faire*—that have developed in the U. S. during the past 100 years originated in this area of grassland soils.

The Podzol

North of the Gray-Brown Podzolic region in the U. S., and over large areas in the northern part of the U.S.S.R. and northern Europe, is another type of soil known simply as Podzol. It is named for the ashlike, nearly white leached horizon that lies just under its organic mat. This soil is found in humid cool-temperate regions of coniferous forest or mixed conifers and broad-leafed trees. The soil is normally quite acid. In summers it is commonly fairly dry, for a while at least. But during part of the time leaching is severe—more so than in the Prairie or Chernozem.

In the woods the Podzol has a striking profile. Decomposition is slow in this cool climate, so a mat up to one foot thick of partly decomposed and matted leaves and twigs lies over the mineral soil. Beneath the organic mat, the A_1 horizon is less than half an inch thick. Directly under this is the nearly white A_2 horizon of maximum leaching; it is a loamy soil structured in thin fragile plates. Most of the roots are in the upper part of this horizon or just under the organic mat, although a few penetrate deeper. When the Podzol has been severely burned by forest fires, however, the vegetation often changes from the rather shallower-rooted pines to the more deeply rooted oaks until a new layer of organic matter has formed again. Ordinarily the white A_2 horizon is only two or three inches thick, but well-developed ones average more than a foot, and the Kauri Podzols of New Zealand have A_2 horizons up to 10 feet thick!

Below the white A_2, sometimes separated from it by a very thin transitional zone, lies a dark brown layer, the main B horizon. In this layer are accumulated iron and organic and mineral colloids leached down from above. When the soil is largely sandy, the B is cemented into a continuous but irregular hardpan. Many Podzols in Britain have a very thin, solidly cemented hardpan or "iron stone" just at the top of the B horizon. But the hardpan of the Podzol is not very impermeable to water, and strong roots also can get through it. Good management, liming, use of fertilizers and the growing of legume-grass meadows in time disintegrates the hardpan. The whole soil changes to something like a Prairie soil, only brown instead of brownish black, gradually lightening in color down to the C at some 15 to 30 inches.

Most of the Podzols are in geologically young landscapes. Many are stony. Usually swampy soils are mixed with them. In the Northern Lake States, for example, perhaps half of the land is swampy, not counting lakes. Only rarely do we find large areas of stone-free Podzols suitable for farming. The usual thing is to find relatively small areas of arable soils intricately mixed with others.

Nevertheless, Podzols are responsive to management and can be made economically productive. They can grow vegetables, especially potatoes and root crops, small grains, and good pasture feed and hays for dairy cattle. After clearing the land, the first step in the improvement of the soil is liming, so that legume-grass mixtures may be grown. Recent experience in Wisconsin suggests that liming also helps to release the native sources of phosphorus. It is necessary, however, to add phosphate fertilizers, especially at first, and potash as well; the native sources of potash in Podzols are only very slowly released.

Because a number of efforts to cultivate the very sandy Podzols in the Northern Lake States have failed, some say that this region "should all go back to forest." Some of it should. But it is equally important that the potentially arable Podzols in the region be used for farming in order to develop a good balance among forestry, mining, recreation and agriculture. With the recent improvement in the agricultural arts, farming on Podzols has a much better outlook than formerly.

The Tundra

Now let us look at some of the soils of the "frozen North." North of the Podzols, beyond the Brooks Range of Alaska, we come to a great treeless plain of Tundra soils. From a plane on a sunny day, the Tundra looks like a great grassy pasture. Most of the land is well covered with low plants—dwarf willow trees some three to six inches high, little arctic shrubs and flowering plants, grasslike sedges and reindeer moss. Little swamps and ponds dot the plain until near the Arctic Ocean there is nearly as much water as land.

Though the annual rainfall is light—no greater than that of the semi-arid West—the climate is humid, because of low temperatures and the consequent low evaporation. North of an average annual temperature of some three to five degrees Fahrenheit the subsoil is permanently frozen, except where the substratum is gravelly and drainage is very good. The soil lying on this permafrost has poor drainage in summer. As winter approaches again, the surface freezes, leaving a wet, squashy mass of soil between the two frozen layers. Pressures develop that force the viscous soil into mounds and blisters of many sizes, shapes and forms. Coarse sedges or other plants growing on the higher spots add to the mound-building with thick mats of roots.

If you dig into the Tundra soil near

Barrow in early July, you will find a surface layer some three to four inches thick of acid, brown, loamy soil, filled with fine roots and rich in humus. Beneath this is a grayer, mushy soil, also rich in humus. At nine to 12 inches you will strike the permafrost, here a rock-like, brown and grayish-brown loam, streaked and mottled with nearly white ice.

So far little beyond uncertain gardening and extensive grazing has been tried on the Tundra. No crop plants with the ability to grow at low temperatures such as the native plants can tolerate have been developed. Some day they may be.

Before we leave Alaska, we might take a quick look at the main productive soil of the Matanuska Valley. It is south of the permafrost line and developed under forest. During its formation strong winds from the northeast blew silt out of the bed of the Matanuska River—a glacier-fed stream. This gradual accumulation of fresh, fine mineral, still going on, gradually covers the soil, burying the roots, leaves and twigs. The result is a dark brown, silty soil, fairly rich in organic matter and some two to six feet deep. The soil is covered with a mat of moss, roots and other coarse material which, when plowed into the surface, adds to its stock of organic matter. This soil has good promise for vegetables and meadows, especially with improvements in plant varieties and culture practices.

Tropical Soils

It is in the tropics that we find the greatest variety of soils. Because of severe weathering there and a great diversity of seasonal combinations of rainfall, temperature and humidity, probably more soil types exist within the tropics than in all the land outside.

Suppose we look at a red soil a few miles north of Matadi near the Congo River in Central Africa. The annual rainfall is about 46 inches. Even during the dry season the sky is often cloudy and the air quite humid. Some 1,100 feet above sea level on a long gentle slope under a dense tropical rain forest we cut our pit. We do not find a thick mat of organic matter such as one might expect under trees. Although the annual fall of leaves is high, they decompose so rapidly that only a very thin litter rests on the surface at any time. The top inch of the soil itself is a highly granular, very dark, reddish-brown clay; below this the main A horizon to a depth of eight inches has the same color but a more irregular nut structure, well permeated with roots and insect holes. At 20 inches, below some transitional layers, we come to the main B horizon: red clay in a firm blocky structure that crushes easily in the hand. Below 40 inches this gradually fades in color and structure through a transitional horizon to the C at six or seven feet. The latter is a mottled mixture of red and yellowish-red clay with quartz pebbles and stones. The deep rocks underneath are chemically basic.

This general type of soil is known as Red Latosol. It has hundreds of variations. At varying depths there is often a heavy band of quartz pebbles and stones, marking an old stone line once uncovered by soil erosion and later covered by wash from higher land. Occasionally there are rocky hardpans, thought to have been formed in earlier geological ages under the influence of a fluctuating water table.

The clay in this soil is less sticky and more porous than that in the Gray-Brown Podzolic. Because water enters the Latosol more readily, it is less subject to erosion. In the place where we have dug our pit the lower soil is strongly acid (pH 5.3) and very low in plant nutrients, but the surface soil is neutral and fairly rich in mineral nutrients and organic matter released from the rotting plant remains. With clean cultivation, the soil rapidly loses its fertility. After it is abandoned, it first grows a cover of savanna grasses. Unless carefully protected, this cover will burn off each year and the soil will remain poor. But if it is protected the forest gradually returns and the soil becomes productive again.

Under cultivation this soil can be kept productive by the use of chemical fertilizers, shade and organic matter. Indeed, it can be cropped successfully even without fertilizers. The forest is cleared only in part, making space for rubber, cocoa, coffee, bananas and other crops that tolerate some shade. Then, as the crop-bearing trees grow larger, more forest trees can be removed. For food crops, the forest is cut in strips or corridors for plantings of mixtures of corn, bananas, cassava, rice, and so on; after four or five years the exhausted soil is allowed to return to forest. In another 10 to 15 years the soil will be ready for crops again. This corridor system is simply a scientific substitute for the method commonly practiced by natives of the tropics, who clear a patch, farm it until it is worn out, and move on to clear a fresh patch.

On these soils the rejuvenating effect of normal erosion is very important. The best soils in the tropics are the very young ones formed from basaltic lava, those renewed by showers of volcanic ash, those renewed by silty stream overflows and those on steep slopes where normal erosion removes the leached surface soil but leaves enough for good root growth and water storage. In these situations the soil often can be used for crops without fertilizers and even without lying fallow in forest, especially if organic matter is carefully conserved. The trouble is that a great deal of the organic matter is burned. Fire is the great enemy of soil productivity in the tropical areas.

While we are in Africa, we should inspect a peculiar soil that has a tendency to harden and form a substance called laterite, a word that comes from the Latin for brick. Near Elisabethville, for example, is a soil of this type that has developed from schist on an ancient, high, nearly level plateau. During the rainy season the water table is within a foot or two of the surface; in the dry season it drops to 30 feet or lower. At two feet or so below the surface there begins a thick mass of heavy clay which very gradually merges into the unweathered rock at 30 feet or deeper. When thoroughly dried from exposure, say in a ditch or deep pit or after removal of the upper soil by erosion, the clay hardens irreversibly. This hard, slaglike laterite is very resistant to weathering and reconversion to soil. People sometimes use the laterite clay to make bricks, building stones and even statues. It can be carved when fresh and then allowed to turn into hard stone. But in the present state of the agricultural arts, these Ground-Water Laterite soils are hardly usable as soil.

Desert Soils

The same is true, of course, of most desert soils. Most people would not consider the desert to be soil at all, and in extreme deserts, where almost no living matter exists, there can be little true soil. It is only near the margins, where widely spaced shrubs find a foothold and hold the soil material in place, that true soils form. Such soils can be seen in many parts of the U. S. Southwest. Often the surface has a pebbly or cobbly pavement, formed as the high winds swept away the finer materials until a protective covering accumulated. The surface soil coat is usually more or less crusted from beating rains and the hot sun, but the soil underneath is more loose and porous. Since there is little leaching, these soils are limy and often salty. Some have a concentration of clay in the B horizon. Deep down, old desert soils often have a hardpan, cemented with lime or silica.

In low places in the desert, which would be swamps in the Podzol region, the soil accumulates salts. Some of these salty soils, like the salt flats near Great Salt Lake, are practically sterile and useless. Others can be reclaimed.

It is not easy to make "the desert blossom as the rose" through irrigation. Water is usually scarce and not always itself free of salts. More often than not at least some drainage works are necessary. Salts are nearly always a problem; even if there is not altogether too much salt, its presence may upset the optimum balance of the various salts needed for plant nutrition.

Most true Desert soils are on relatively high plateaus and old river deltas—too high to irrigate. But in the same regions there are likely to be much younger and lower soils formed from recent alluvial deposits. These vary from coarse gravel to heavy clay. It is mainly these alluvial soils that are irrigated. For successful irrigation, soils must not be too sandy or gravelly, so that they may hold water at least fairly well; yet they must be well drained so some excess water can leach away. A soil that is well drained in the natural desert under four to five inches of rainfall may be swamped under irrigation with 30 to 40 inches. If drainage is poor, the soil is almost bound to accumulate enough salt to kill any cultivated plants.

Great successes and dramatic failures have attended irrigation projects since the dawn of history. Modern soil science and engineering now make possible much better predictions of the outcome of proposed projects and much better systems of water use and soil management. Yet even now enthusiastic promotion sometimes gets too far ahead of scientific prediction, to the sorrow of new settlers.

Prescriptions

We have looked at specimens of nine or so of a total of some 40 great soil groups found on our planet. Within each of these major groups are many local soil types, varying from one another in ways that affect their use. To make a detailed map of local soils for just one average Midwestern county of 500 square miles, a map sufficiently detailed so that results of research on the various soils can be applied effectively to individual fields, involves the identification of from 100 to 200 significantly distinct soil types and phases of soil types.

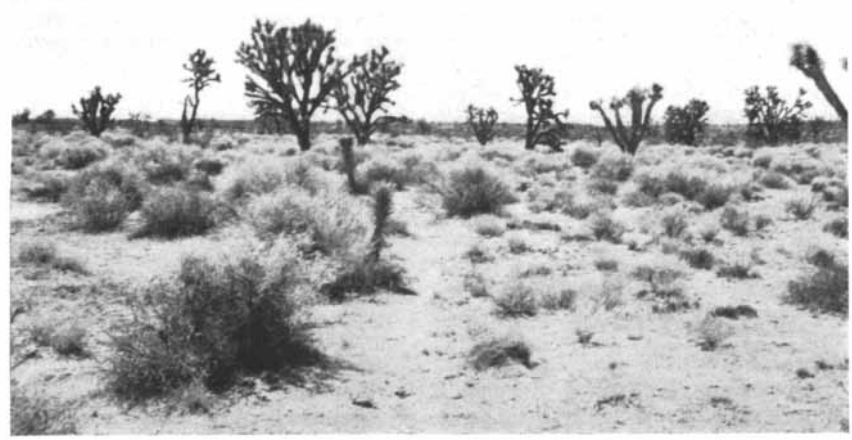
It is on the basis of these soil types and phases that detailed recommendations about crop varieties, fertilizers, rotations, erosion-control devices and the like are developed. Of course any single recommendation, such as a specific fertilizer, may apply to a large group of soil types, but for each recommendation the soils have to be grouped differently. A statement covering the essentials for a single county needs to be much longer than this article.

Gradually our knowledge about soils is being expanded and classified into a system. The system is still very imperfect, but ultimately all the local soil types of the world will be known and understood. Maps will give their location. Then every farmer, gardener and forester will have the benefit of what soil science has learned to enable him to use his own soil most effectively.

Charles E. Kellogg is Chief of the Division of Soil Survey in the U. S. Department of Agriculture.

GRAY-BROWN PODZOLIC SOILS have been intensively studied. On the similar soil of the Rothamsted Experimental Station in England wheat has been grown without fertilizer for 106 years (*left*). Manured plot is at right.

TROPICAL SOILS occur in great variety. On this tropical soil near the Congo River in Africa grow cultivated cassavas and bananas. If left uncultivated after exhaustion, the soil will be invaded by forest and renewed.



DESERT SOILS can sometimes be turned to agriculture by irrigation, but only with a detailed knowledge of their composition. On this soil in the Mohave Desert grow Joshua trees, which properly are not trees but yuccas.

COUNTERS

The devices that detect the ionizing radiations of the atom were invented some 40 years ago. Now they have become basic tools of the atomic age

by Serge A. Korff

WITH the advent of atomic energy, many devices of physics which long labored unostentatiously in laboratories have emerged as words on the front pages of newspapers. Among these are Geiger counters. One is led to believe that they were only recently invented, and that they were first constructed by scientists working on the atomic energy program in the U. S. Some nervous politicos have gone so far as to suggest that we have given the "secrets" of the construction of Geiger counters to other nations.

Actually the first experiment in which such counters were used was performed in 1909 at the Cavendish Laboratory of Cambridge University. The authors of the report describing them were Ernest Rutherford and H. Geiger. About 15 years later Geiger and W. Müller, a colleague assisting him in his studies of radioactivity in Germany, had occasion to make much larger counters than had been used before. Their designs were widely copied by other investigators and became known as Geiger-Müller counters. Present-day counters differ only in trivial details from those models. So the basic principle of this type of detecting device is at least 41 years old, and the instrument has been in general use by physicists on both sides of the Atlantic for nearly a quarter of a century.

For brevity's sake the devices are now referred to simply as counters. Their function is to detect and count atomic particles and radiations, or "rays." The word ray is a loosely used term that embraces all types of radiations, whether streams of charged particles, such as cathode rays and alpha rays, or beams of electromagnetic energy, such as visible light and X-rays. A counter does not record these radiations directly: it is in effect a track-examining device, like a hunting dog, which detects the presence of the quarry by its spoor.

Almost every type of radiation causes matter through which it passes to become "ionized," which means that the normal balance of positive and negative charges possessed by the atoms is disturbed. The positively-charged nucleus loses some of its neutralizing retinue of negatively-charged electrons and becomes a positive ion. The freed electrons may attach themselves to neutral atoms and thus produce negative ions. It is the amount of ionization produced that serves as the footprint and the measure of the responsible radiation.

There are several ways of recording this ionization; for example, a stream of alpha particles falling on a photographic plate will leave a developable trace in the emulsion; or, passing through a cloud chamber, it will leave enough ionization to cause cloud condensation when the chamber is expanded. In a Geiger counter the ions are made to initiate an electrical impulse which is translated into an easy-to-read visible or audible signal.

SUPPOSE we have a glass tube containing a gas (any gas will do, but some gases such as argon and neon do better) and two metallic electrodes by means of which a voltage can be applied to the gas. If the voltage is high enough, there will be a glow discharge in the gas—a phenomenon that has been made familiar to everyone by the neon sign. Now suppose that the voltage applied to the tube is almost but not quite high enough to cause a glow discharge. If an appreciable number of ions is suddenly created in the gas, a glow discharge may appear. This is the principle of the Geiger counter. It is an arrangement of electrodes in a gas, with an applied voltage almost sufficient to initiate a self-sustaining discharge in the gas, and some provision for "quenching" the discharge caused by ionization once it starts.

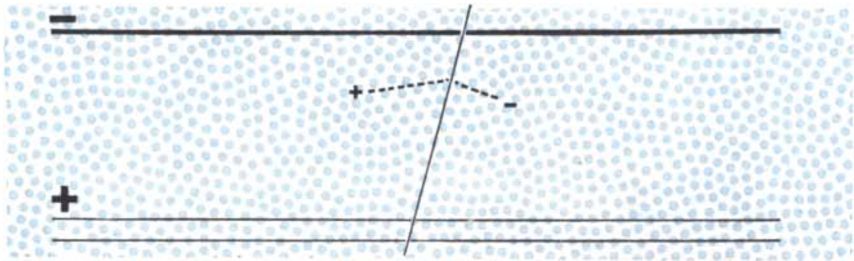
The two electrodes usually are in the form of (1) a cylinder and (2) a fine wire running through the center of the cylinder. The particles to be detected may be shot in through one end of the cylinder, through an aperture in the cylinder wall, or, if they are sufficiently penetrating (*e.g.*, X-rays), through the cylinder wall itself. As a particle passes through the gas inside the cylinder, it produces ionization. Any positive ion thus produced starts to drift, under the attractive force of the electrical field, toward the cylinder wall. The electron, or negative ion, similarly starts to drift toward the central wire. Since the field is very intense just around the central wire, the electron experiences a large acceleration when it reaches this region. It may gain enough energy to produce additional ionization by collision with other gas molecules. Each molecule thus ionized contributes more electrons, and each new electron may in turn produce further ionization. When the built-up "avalanche" of electrons finally arrives at the central wire, it produces an electrical impulse. This signal, amplified by vacuum tubes, is the counter's recording of the detected particle; it can be measured, or simply counted, or stored for a cumulative record.

Meanwhile the positive ions formed in the discharge of the electrons drift out to the cylinder, and when they arrive there they are neutralized. The counter is then ready for the next count. It is the travel time of the positive ions that determines the "resolving time" of the counter, or the fastest rate at which the counter will count particles passing through it. In most counters this travel time is between 100 and 200 microseconds, so that the counter can count between 5,000 to 10,000 particles per second.

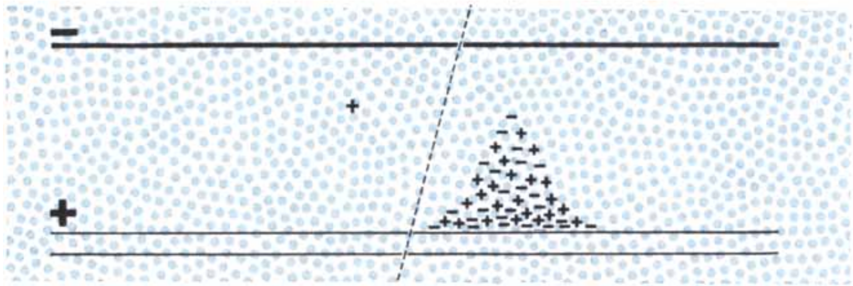
Each kind of atomic particle has its own "specific ionization," *i.e.*, it produces a certain number of ions per centimeter of path in a given gas at a given pressure. The number of ions produced also depends on the energy of the particle. This fortunate circumstance makes it possible to identify a particle as well as detect it. For example, a million-volt alpha particle will produce some 30,000 pairs of positive ions and negative electrons per centimeter of air at normal pressure; a deuteron of similar energy produces perhaps 10,000, a proton about 5,000, and an electron only 30 or 40. In order to distinguish between kinds of particles, the counter must be operated at a fairly low voltage. The size of the electron avalanche, *i.e.*, the size of the pulse, is then proportional to the number of ion-pairs produced by the particle, and the counter in this case is called a proportional counter. It is easy to design electronic circuits that will accept only pulses of a specified range of sizes. Thus the electronic circuits connected to a counter can be set to count the number of pulses produced by particles of any predetermined kind. A counter can be connected to two or more such circuits at once, so one circuit can count alpha particles while the second simultaneously counts beta particles entering the counter.

THE REASON the counter cannot differentiate particles at higher voltages is that the voltage produces a saturation of charge inside the counter, and the discharge pulse is the same whether it is triggered by one electron or 30,000. If we are interested only in counting the number of particles passing through the counter, without distinguishing the particles, operation of the counter in this voltage region serves perfectly well. In practice most counters are used in this way, because no pulse-size discriminating equipment or high-gain amplifier is required and the electronic circuitry is therefore simpler.

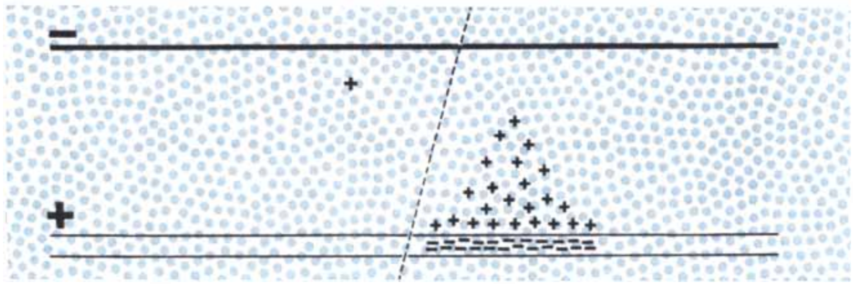
How does a counter detect X-rays? These rays do not ionize atoms as particles do. But we have seen that all that is needed to start the pulse-producing process is to set free at least one electron within the cylinder of the counter. There are two mechanisms by which X-rays can produce electrons: they can knock secondary electrons from the walls of the cylinder or other solid parts of the counter, and they can scatter electrons in the gas by the recoil process known as the Compton effect. Gamma rays produce electrons by the same mechanisms, so they too can be detected. Similarly ultraviolet light ejects elec-



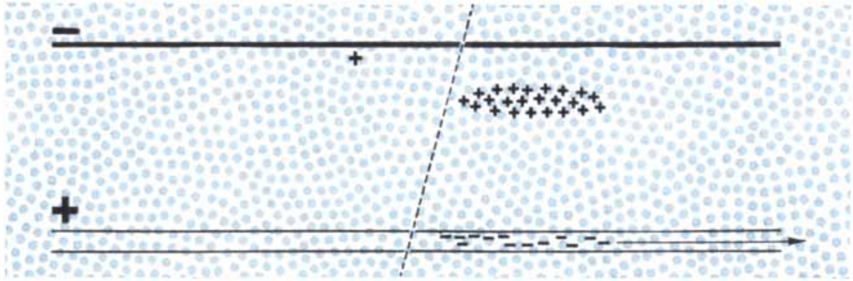
ELEMENTS of a counter in a highly schematic cross section are cylinder (*top*) and wire (*bottom*). A ray passing between them mutilates a gas atom.



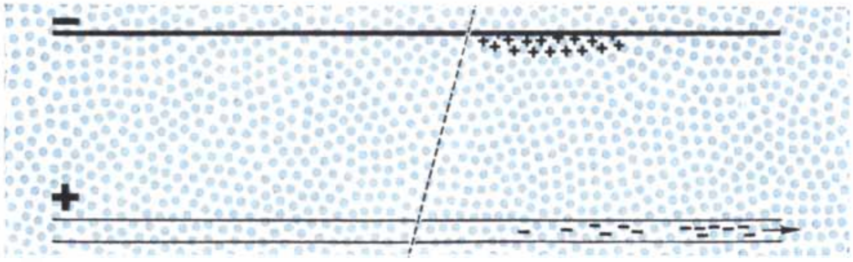
ELECTRON removed from gas atom by ray moves toward positive wire, colliding with other gas atoms. Result is an avalanche of electrons.



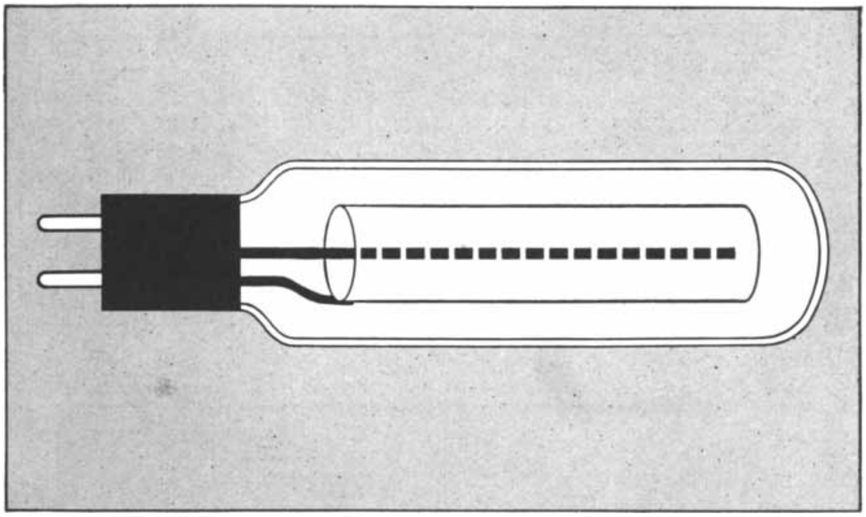
POSITIVE IONS are left behind as electrons collect in the wire. The positive ions move more slowly than the electrons because they are more massive.



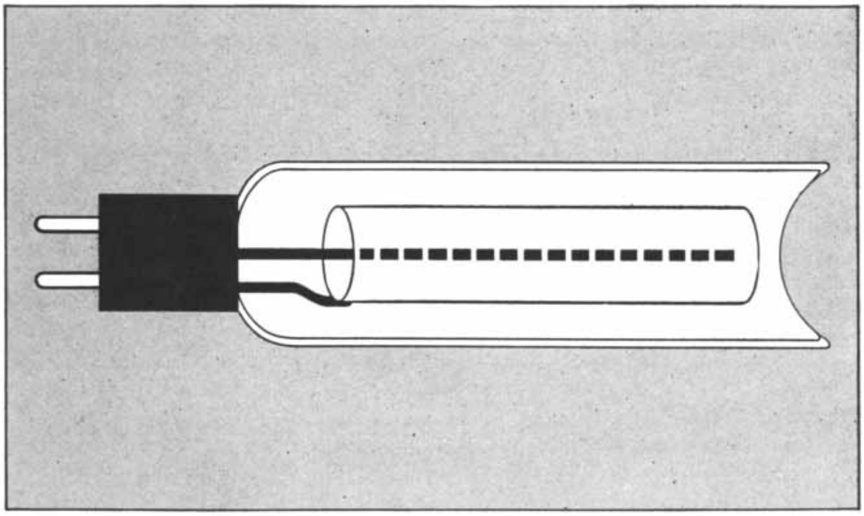
ION CLOUD drifts toward the negatively-charged cylinder. Electrons, still held in place by attraction of positive ions, begin to move along the wire.



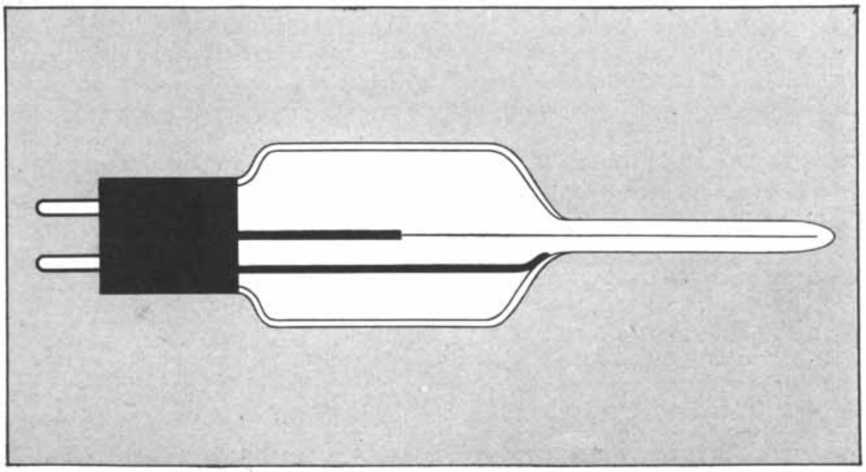
IMPULSE moves along wire as electrons are freed of attraction of positive ions. The positive ions are neutralized at the negatively-charged cylinder.



STANDARD COUNTER TUBE is basically a positively-charged wire surrounded by a negatively-charged cylinder. These parts are enclosed in a gas-filled glass envelope which may be mounted upon a standard tube base.



THIN-WINDOW COUNTER TUBE has a thin glass window at one end to admit those particles which cannot penetrate the glass envelope of the standard tube. Sometimes the radioactive material is placed within the counter.

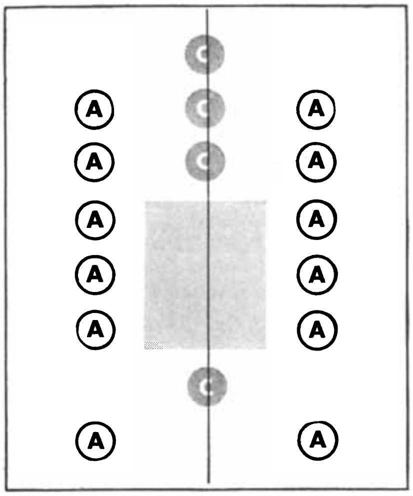


THIN-WALLED COUNTER TUBE is constructed with a needlelike end for insertion into radioactive liquids or tumors. Here cylinder is replaced by a thin metal coating that is deposited on the interior of the glass envelope.

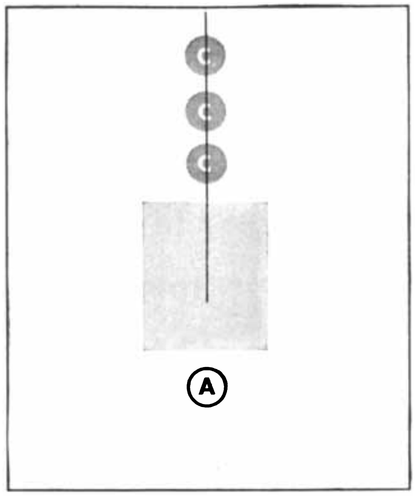
trons from the cylinder walls or gas atoms by the photoelectric effect; in this case the counter becomes a photoelectric cell and records a count each time a light-quantum produces a photoelectron. A counter can even be made to record the low-energy radiation of visible light. Visible light will produce no photoelectrons in the gas, but if the counter's cylinder is coated with a photosensitive substance, the light will knock photoelectrons from this surface, and the counter will therefore detect the light-flux falling upon it.

Designing a counter that will count neutrons is a little more difficult. Since neutrons are uncharged, they will not themselves produce ionization or electrons. Neutrons can, however, produce ionization indirectly by colliding with charged particles and causing them to ionize; in other words, a neutron is detected, loosely speaking, not from its own footprints but from the track of the charged particle to which it gives a push. The simplest situation of this kind occurs when high-energy neutrons knock electrons or nuclear particles out of the walls or gas molecules in an ordinary counter. But this is a very inefficient method of counting neutrons; at best the counter registers only one out of 50,000 of the fast neutrons that pass through it, and it does not record slow neutrons at all, for the impact of a neutron with less than 30 electron volts of energy is generally insufficient to separate an electron from its atom. For counting neutrons, therefore, the counter is modified by providing a material in which slow neutrons can cause a nuclear reaction. The most effective substance for this purpose is boron; another good one is lithium. When a neutron is captured by a boron atom, the result is the ejection of an alpha particle, which produces abundant ionization. The event can therefore be detected and recognized by a proportional counter. The probability of this capture reaction increases as the neutron energy decreases, so that very slow neutrons are the most easily counted. The probability for detection of neutrons by the boron nuclear reaction is more than a thousand times greater than by simple collision and recoil. The boron in the counter can be provided either as a lining for the walls or as a gas. Most neutron counters used today are simply conventional counters filled with boron trifluoride gas.

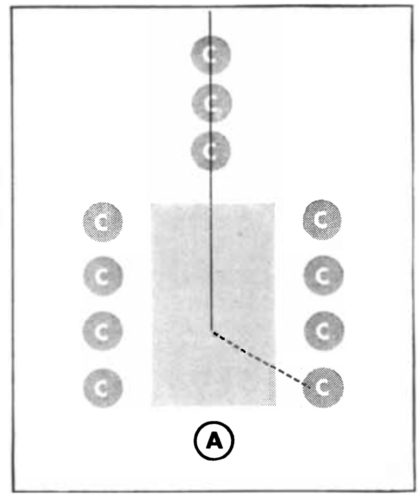
THERE now exist a remarkable variety of counters, in many sizes and shapes and for many special purposes. They range in size from tiny models about two millimeters in diameter and a few millimeters long to giant tubes eight inches in diameter and six feet long. Some have envelopes of glass, others of metal. Some have very thin windows to permit low-energy particles



PENETRATING cosmic-ray particles are counted to the exclusion of showers of particles by a special "anti-coincidence" arrangement of counters. Penetrating particle passing only through counters labeled C is counted; shower, passing also through counters labeled A, is not.



NON-PENETRATING cosmic-ray particles are counted by another anti-coincidence arrangement. Here the anti-coincidence counter is placed beneath the absorbing material. A particle passing through counters labeled C is counted; particle passing through four counters is not.



DECAYING cosmic-ray particles such as mesons might be counted by an arrangement of 12 counters, one of them an anti-coincidence counter. The counters are connected in such a way that they will count only a particle that fires the three counters at the top and one of side counters.

or ultraviolet light to enter; others are built so that the radioactive material to be counted can be placed inside the counter itself. For example, radioactive carbon 14, which gives off very weak radiation, is usually put inside the counter, either in the form of a gas such as methane (CH_4) made with the radiocarbon, or in a rod or plate. Some counters have jackets into which radioactive liquids can be poured. There are counters in the form of needles that can be inserted into biological specimens.

Counters can be arranged to give a great deal of information about radiations besides merely counting the particles. For example, several counters can be connected in such a way that a discharge is counted only when all the counters discharge simultaneously. This is called "coincidence counting." One obvious use for such an arrangement is to show the direction from which a stream of radiation is coming: when five counters are arranged in a straight line, the direction of any particle that discharges all five is clearly determined. Another use is to measure the effect of radiation-absorbing materials. Absorbers of various thicknesses are placed between the counters, and the change in the counting rate indicates the amount of absorption of the radiation by the material. In this way we not only can study the absorbing ability of various materials at various thicknesses, but when the properties of the absorber are known we can identify the kind of radiation or measure the energy of the particles. Coincidence counters are widely used, especially in research on high-energy particles. Very complicated combinations of coincidence and anti-coincidence counters have been employed in studying cosmic-ray phenomena. An anti-coincidence counter is operated in such a manner that a pulse is recorded only when the counter does *not* count; if a particle enters this counter and is detected by it, the circuit is desensitized and there is no pulse.

To reduce the labor of counting, a counter can be operated so that it records only every second pulse, or every tenth; the actual count is then determined by multiplying the reading by the scaling factor. Some counters have electronic circuits that store the counts and present the total arriving in a unit of time; such circuits are called counting-rate meters. They are frequently used in portable counters employed for radioactive survey work, such as geological prospecting for radioactive ores or exploration of areas contaminated by accidental spilling of radioactive compounds.

ASIDE from their many well-known uses in the atomic energy program and in laboratory research, counters are finding more and more applications in industry, medicine and other fields. They have become a remarkably useful tool in oil prospecting. For this purpose there is a special cylindrical device that has a piece of radium at one end and a counter at the other, with a lead shield between. When the device is lowered into a well, radiation from the radium, prevented by the lead shield from reaching the counter directly, is scattered back to the counter by the geological formation. The nature of this scattering depends on the kind of formation, and with a little experience in interpreting the record the prospector can identify the formation and thereby determine whether it is of a type likely to contain oil. A variation of this technique uses a neutron counter with a source of neutrons (radium and beryllium) at the other end. Since neutrons are preferentially scattered by hydrocarbons, this method can readily detect hydrocarbon-bearing formations.

Another commercial use of counters is as a particularly sensitive thickness-gauge. A source of radiation is placed over a table and a Geiger counter below it. As the material to be measured (*e.g.*, a sheet of metal) slides across the table, the response of the counter, controlled by the amount of particle absorption in the sheet, accurately measures its thickness. Other counters are used to monitor large X-ray machines or radioactive wastes for safety or to locate lost tubes of radium. In industrial and medical research counters are now in common use to follow radioactive tracers. Such tracers are employed to study the uptake of chemicals or fertilizers by plants, the effects of insect sprays, the migration of particular elements in melts of steel and a great number of other phenomena. In each case a Geiger counter is essential to tell where the radioactive compound has gone, and how much has gone there.

In an age of increasing interest in radioactivity, natural and artificial, it is clear that counters are destined to become one of mankind's most useful tools.

Serge A. Korff is professor of physics at New York University.

GENETICS AND CANCER

The patient inbreeding of mice has done much to support the view that malignant growth is powerfully influenced by heredity and other genetic phenomena such as mutation

by Leonell C. Strong

CANCER is a problem in chemistry, in physics, in experimental medicine. But above all it is a biological problem, and it is through biology that we shall arrive at an understanding of it. Conceivably by trying hundreds of thousands of drugs—the attack that is being pressed most aggressively at the present time—we may some day find an empirical cure for cancer. Yet it is at least equally conceivable that this approach may fail; in any case man cannot hope to gain complete mastery over the insidious affliction of cancer until he has unraveled its fundamental biological nature.

One way to investigate the nature of cancer is to study the biochemistry of the cell, and this subject is now engaging many investigators. There is another way which has received less attention; that is, to explore the inherent behavior of cells as living organisms. This study might be called the genetics of cancer. During the past half-century the science of genetics has revolutionized the whole of biology; to the specific study of cancer it has made incalculable contributions. It is now just 30 years since biologists began to apply genetics to cancer research by breeding special strains of mice for experimental studies of the disease. This seems a good occasion to consider what we have learned from genetics about the thorny cancer problem.

Thirty years ago cancer research was at a very low ebb. The few investigators of the problem were discouraged. Most of the experimental work in cancer up to that time had consisted in studying the growth of tumors transplanted from one mouse or rat into another. These investigations had produced a confusion of conflicting evidence; one investigator could not always confirm the findings of another—or even his own when he repeated an experiment.

To this impasse, as to biology in general, the then-infant science of genetics brought three great, revivifying contributions. One was the discovery of mutation—the sudden changes in genes that profoundly alter the development and behavior of cells. The second was the finding that the genes in the nucleus of a cell are arranged in certain definite patterns and relations; this discovery provided a means for studying the architecture of cells that went far beyond the range of the microscope. The third was the application to biology, through genetics, of quantitative methods of investigation such as had theretofore been reserved to physics, chemistry and the other so-called exact sciences. Now for the first time it became possible to standardize and evaluate the variables in a biological experiment.

UNDER the influence of the great Thomas Hunt Morgan at Columbia University, the author began 30 years ago to study the genetic aspects of the cancer problem. His interest was drawn to cancer by the fact that the disease had attacked a number of members of his own family—his grandmother, father and several cousins.

If quantitative methods were to be applied to cancer research, clearly the first step must be to standardize the experimental animals. This could be done by inbreeding, a process which, by narrowing the stock of genes through successive generations, eliminates many of the ancestral variations and produces more and more uniform offspring.

At the laboratory of the Carnegie Institution of Washington in Cold Spring Harbor, N. Y., the author began to produce inbred strains of mice by mating brother to sister. To reduce the possibility of contaminating the stocks with new genetic variations that might be introduced by spontaneous mutations, which are bound to occur in any large population, each strain was continued from only one selected pair of mice in each generation. From those original matings have come many of the inbred mice used in research in various laboratories of the U. S. and Europe today.

Over the past 30 years a number of pedigreed strains of remarkable uniformity have been bred. We now have mice that are biologically as alike as it is possible to make them. The acme of pedigreed inbreeding has been reached in a variety called the A strain, which has been continued for more than 100 generations. In this strain, whose offspring are extremely alike in all biological characteristics, a very high percentage of the females spontaneously develop a certain type of cancer of the mammary gland. That this tendency is inherited is abundantly proved by the fact that it has continued for more than 75 generations. There are other pedigreed strains that have a strong tendency to specific spontaneous cancers of the lung, the stomach, the liver and so on. Conversely, inbreeding has developed still other strains that show a high immunity to cancer.

With these pedigreed animals cancer investigators were able to proceed to conduct reproducible experiments under standard laboratory conditions. The investigation of the growth of transplanted tumors in mice was now placed on an accurate, scientific basis. It ultimately led to the finding that whether a transplanted tumor could be grown successfully in a mouse depended on the mouse's genetic constitution. Biologists soon found that inbred mice could be used for investigating not only hereditary susceptibility to cancer but many other biological characteristics. The various inbred strains differ in nutritional requirements and in their responses to hormones; they therefore serve as subjects for studying the biological effects of a great variety of experimental procedures. It was the use of inbred strains that made possible such advances in cancer research as the discovery of the milk factor by John J. Bittner of the University of Minnesota.

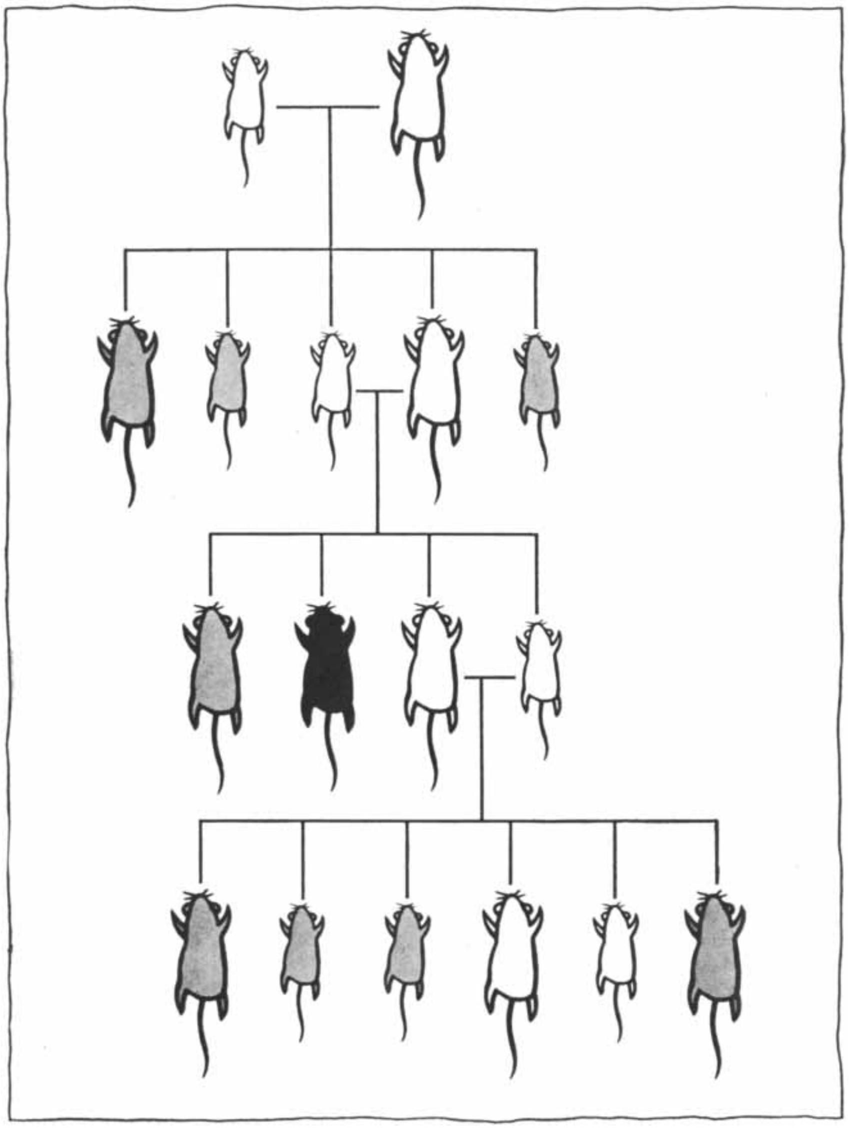
Then there sprang into view a hare that turned the cancer chase in a different direction. This was the discovery that certain chemicals, notably methylcholanthrene, are powerful cancer-causing agents. Injected into an animal, they quickly produce tumors, more malignant and more varied in type than any that occur spontaneously. These chemical carcinogens opened a large new field. As a research tool they are extraordinarily useful: instead of waiting months for a tumor to develop spontaneously, an experimenter can induce one in an animal in a relatively short time, and he can create unusual types of tumors for study. More than this, the carcinogens seemingly deflated the role of genetics in cancer. If cancer arises from the action of chemicals, why worry too much about the genetic influences? Was it not much more promising to concentrate on hunting down the agents directly responsible for producing cancer?

It turned out that the genes could not be dismissed so easily. We now know that an animal's susceptibility to induced cancer is controlled by its genetic constitution. This has been demonstrated by many experiments. They have shown that genes controlling susceptibility to induced tumors are linked on the same chromosomes with genes for known hereditary characteristics—proof that the former are also true hereditary genes.

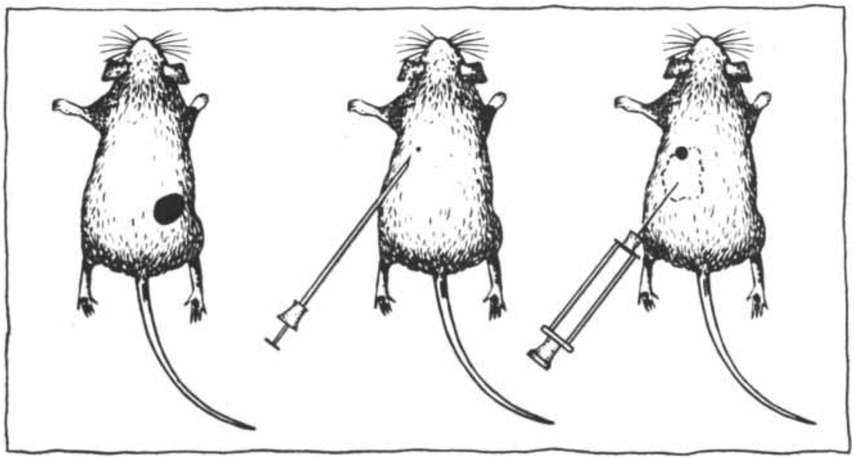
MEANWHILE certain unexpected and startling results emerged as by-products of the investigation. During the experiments several thousand mice were injected with methylcholanthrene. We found that many of these mice, although of very homogeneous, pedigreed stocks, began to produce peculiar offspring. Some of their offspring had curly tails; some were dwarf mice, others giants; some had hair of a different color from their forebears. Clearly the methylcholanthrene treatment had changed some of the genes of these mice. It had produced artificial mutations.

To account for this we must consider some facts about mutation rates. The spontaneous mutations in nature are known to be relatively rare. Extensive investigation of the fruit fly Drosophila and other animals has determined the spontaneous mutation rates for some genes. It has long been known that X-rays, ultraviolet rays and other types of radiation can increase mutation rates. The methylcholanthrene experiments showed that chemicals can do so also. This chemical increased the rate from one mutation in 26,000 mice to one in 550 mice. In some cases it caused mutations in genes that had not been known to mutate in nature.

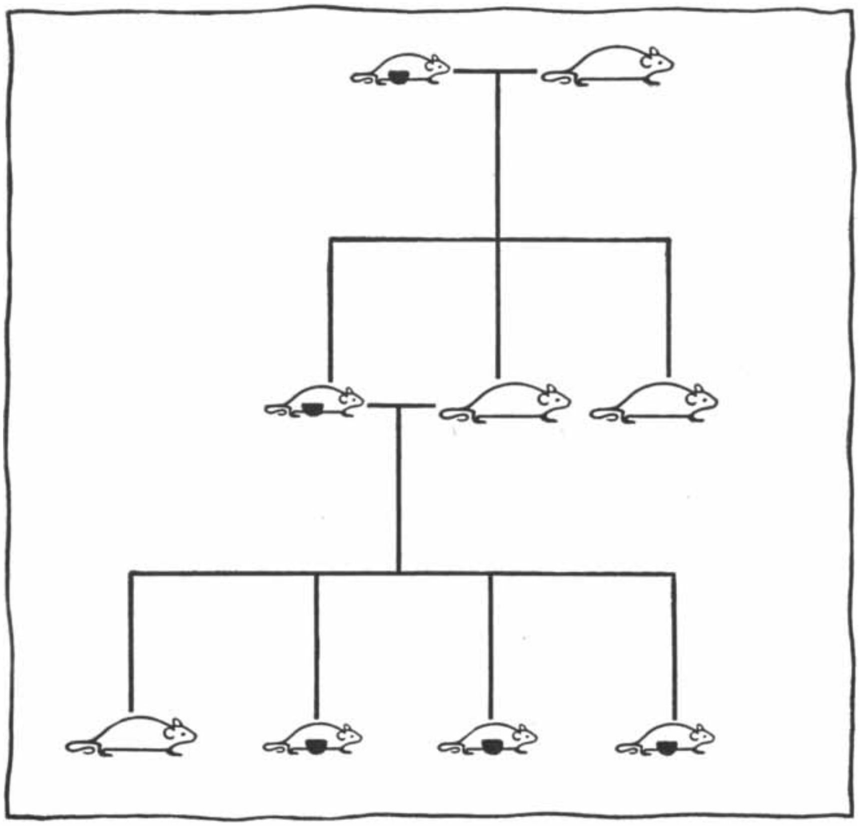
Now it is a curious and significant fact that almost every physical and chemical agent that can induce mutations can also induce cancer, and *vice versa*. This suggests that cancer may arise through some kind of mutation of normal body cells. Since in the case of cancer the change occurs not in germ cells but in somatic (body) cells, it would be a somatic mutation rather than a genetic one. That a carcinogen such as methylcholanthrene can produce nonhereditary changes, aside from cancer, in mouse cells has been amply proved in our experiments. Some of our mice, for example, are born with a mixture of characteristics: a single mouse may have a coat of hair that combines both the dominant and recessive color patterns of its line. Its offspring do not inherit this mosaic; they have either one color pattern or the other. Obviously the change in this mouse is not the result of any change in the germ plasm. It may occur through



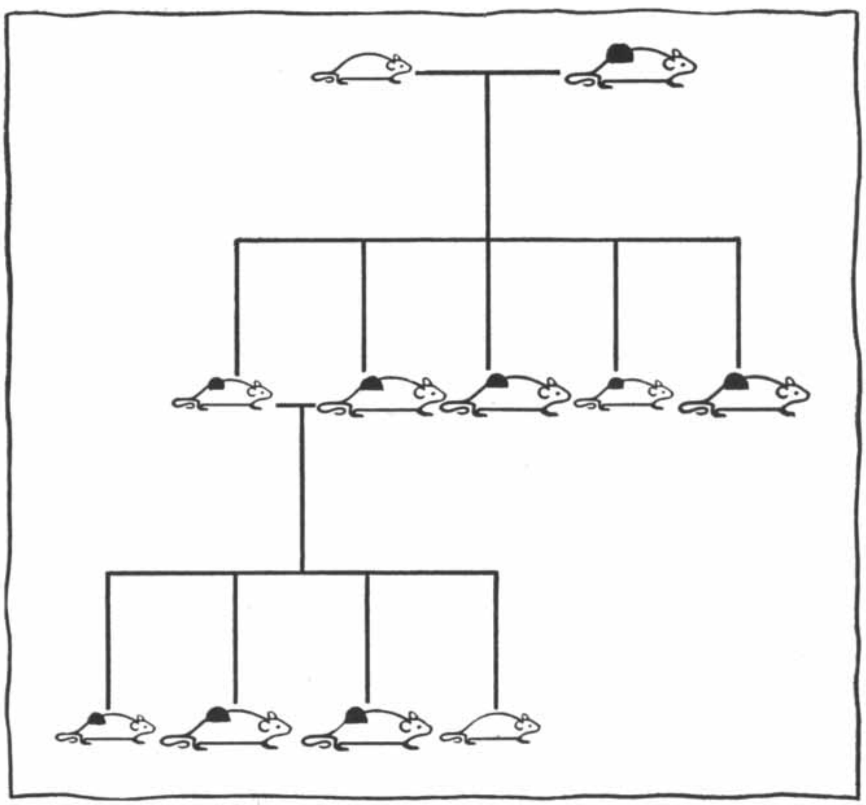
INBREEDING OF MICE produces a strain of great biological uniformity. Two mice in each litter (*white*) are bred, and the rest (*gray*) are used for experiment. A mutation (*black*) is eliminated from the line of descent.



TUMORS OF MICE which are studied in genetic experiments are spontaneous (*left*), transplanted (*center*) and chemically induced (*right*). All three types are influenced by the genetic constitution of the mouse.



SPONTANEOUS TUMORS of the mammary gland appear in nearly all the females of the author's A strain. In all these charts the slight difference in size between male and female mice has been exaggerated to distinguish them.



TRANSPLANTED TUMORS also show genetic influence. A susceptible mouse is crossed with a resistant one. Offspring are susceptible. Next generation shows that two dominant genes influenced susceptibility of first mouse.

some kind of alteration of the chromosomes or genes in the body cells during the mouse's embryonic period. Whatever the reason, the significant fact is that such mice or their close relatives almost invariably develop cancer. This seems to support the view that cancer, like the changes in color pattern, arises by somatic mutation.

Descendants of mice that have received methylcholanthrene injections for many generations show many other peculiarities: absence of one or both ovaries, long tufts of hair on the forehead, and so on. Experiments in the further breeding of these animals prove that these variations are usually not hereditary. Still another support for the somatic-mutation hypothesis of cancer is the fact that transplanted tumors in experimental animals sometimes change suddenly to other types; in this case the cancer itself, instead of normal tissue, undergoes a somatic mutation.

AT first thought this hypothesis may seem highly depressing. If cancer really does originate from the mutation of normal cells due to some natural cause, how can we ever hope to control the disease? To protect ourselves against the possibility of mutations by the action of ordinary radiations in nature, we would have to take refuge behind several feet of lead.

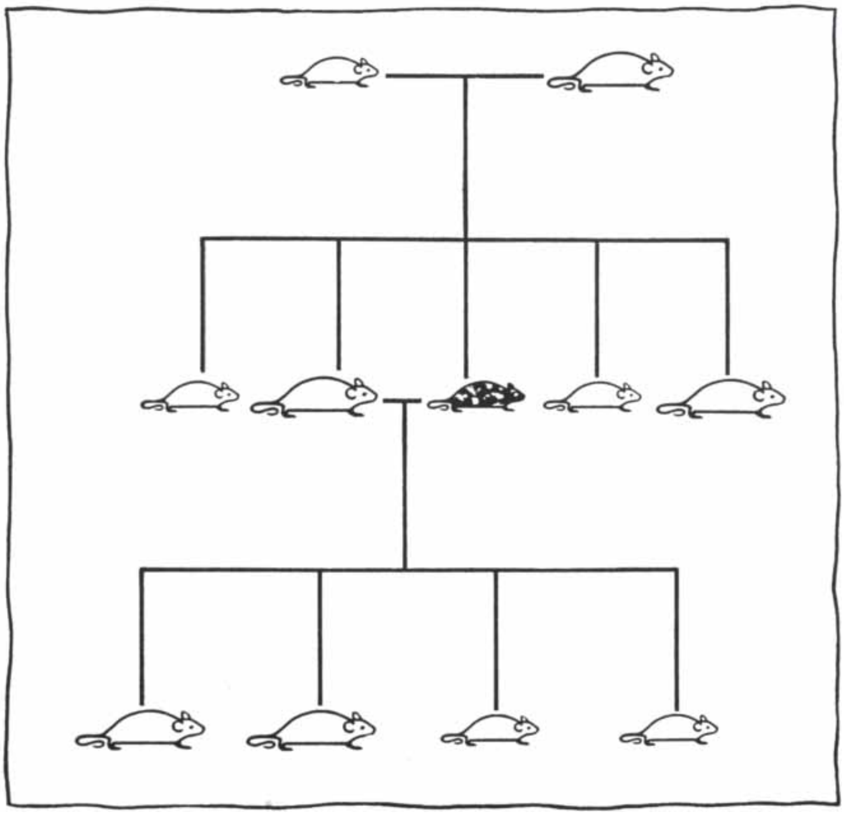
Actually there is no reason for such pessimism. We know that resistance to cancer can be developed by breeding. By selection we have bred strains of mice so resistant that they do not contract cancer no matter how great the insult. Admittedly the human race is not likely to adopt this basis of selection in its breeding. But at least, if the mutation theory proves correct, we are on the road toward finding out what the actual mechanism of resistance to cancer is. If we can determine just how this mechanism operates within the body, we may find a way to control it.

The application of genetics to this problem also offers the possibility of finding other means of preventing cancer. For example, we have recently found in our studies of inbred mice that their vulnerability to chemically induced cancer does not depend solely on their genetic constitution and the nature of the carcinogen. The order in which they are born also plays a part. Mice in the first litter of a given pair of parents are less susceptible to a certain chemically induced cancer than those in subsequent litters. Since all offspring of the same parents in these strains theoretically have the same genes, the increased vulnerability of the later litters must be due to the accumulation of some nongenetic factor or factors in the mother's body and perhaps the father's as well. On the other hand, mice in the first litter that do develop the cancer show a shorter survival time than victims in later litters; those in the eighth litter survive two and a half times as long as those in the first. In addition, in the mice of the later litters a smaller proportion of the tumors invade other tissues; although the mice are more susceptible to the cancer, their tumors have less ability to spread. These findings have opened up a new field of cancer research—perhaps an approach to the solution that we have been looking for. We are here on the threshold of determining a nongenetic cancer mechanism that may prove easy to control.

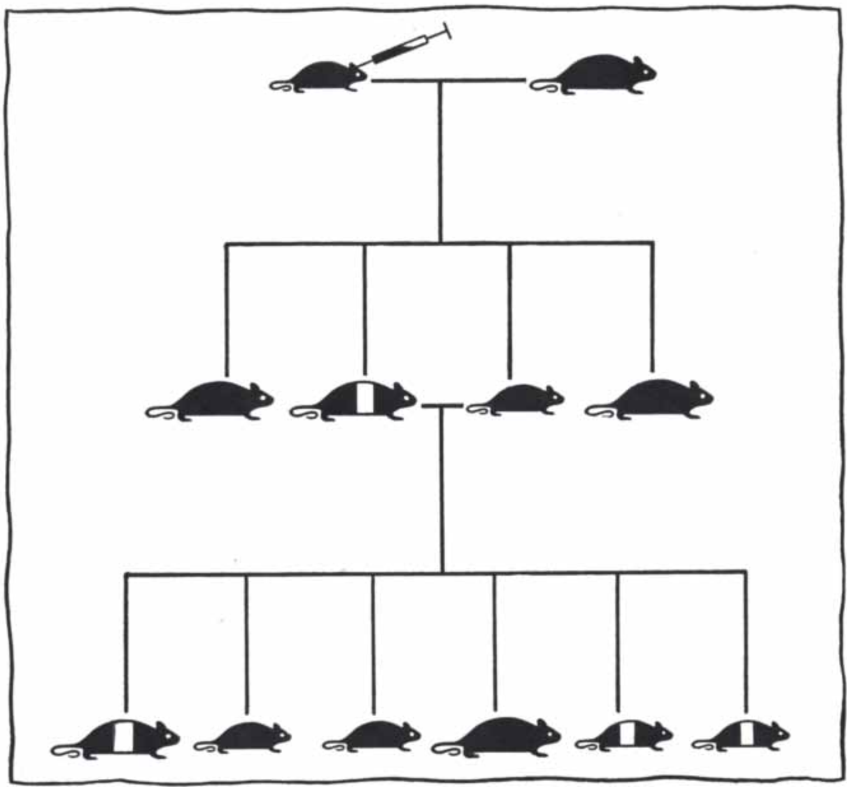
THE discovery that the same chemicals that induce cancer also induce mutations is of such basic importance that it should be further investigated by a whole group of scientists. Quite aside from the application of these facts to the problem of cancer, they raise questions of wide significance in biology. They may have a considerable bearing on biological evolution. The evolution of species, it is now generally agreed, is brought about by mutations. Somehow a gene suddenly changes and produces a new characteristic which thereafter, if it proves useful, is handed down from generation to generation of the organism. How these so-called spontaneous mutations occur in nature is quite unknown. It is unlikely that the responsible agent is X-rays, the favorite mutation-inducing tool of the laboratory experimenter, because as far as is known no species has ever been exposed to X-rays in nature. But there are many other types of radiation that do exist everywhere around us. Are mutations, and the consequent urge of all living things to evolution, generated by cosmic radiations, or by ultraviolet rays, or by the radiations from the radioactive rocks of the earth, or by all of them together? Each of these alternatives seems highly possible.

Yet the discovery that chemicals can induce mutations introduces still another possibility. May it not be that mutations and evolution have been engineered at least in part by the process of nutrition itself—by the food upon which all living things depend for life? In their diet there may well be chemical compounds that are capable of producing not only cancer but changes in the genes. It is true that both of these types of change are relatively infrequent, and this is very fortunate, for if the cells were more vulnerable to diet-induced alterations, the living world might soon eat itself to death. Be that as it may, these speculations illustrate some of the fascinating biological questions suggested by the transformations of our mice.

Leonell C. Strong is professor of anatomy at the Yale University School of Medicine.



MOSAIC pattern of a mouse's coat appears to be the result of a change in a gene of a body cell during the embryonic period. The phenomenon lends support to the theory that cancer may be the result of such somatic mutation.

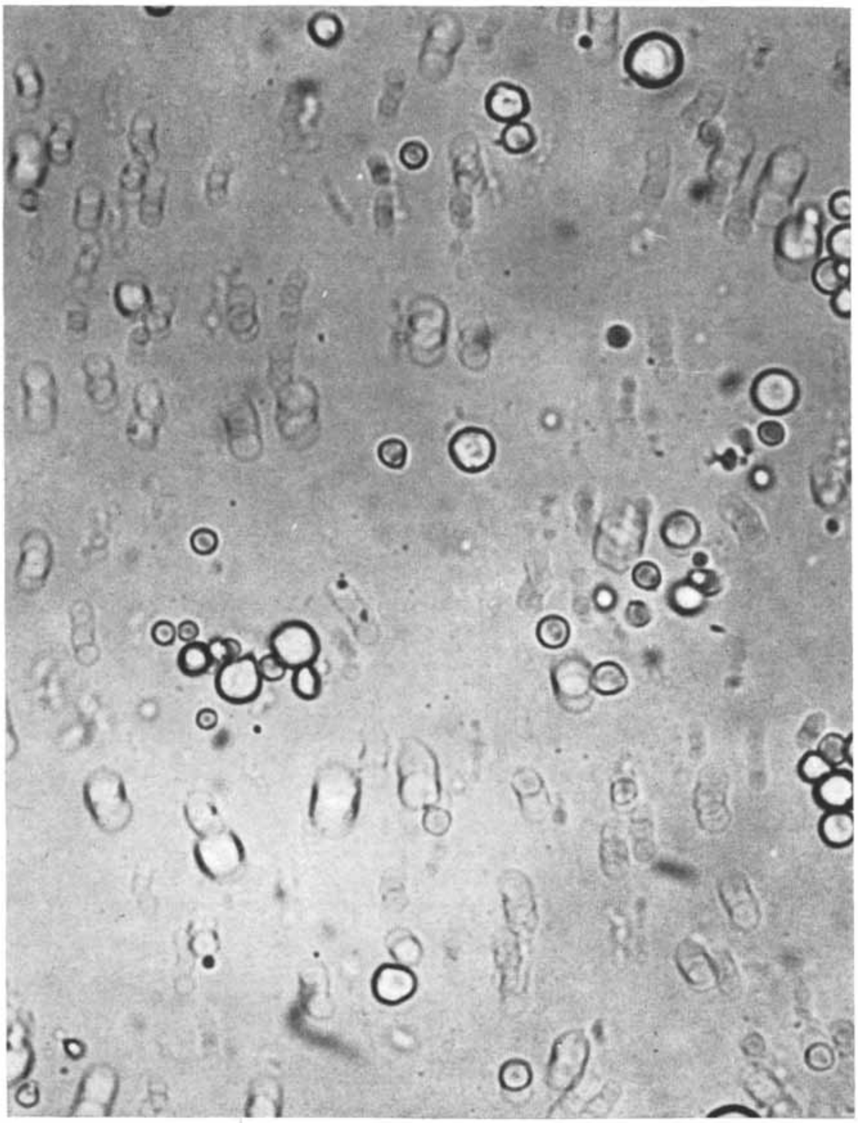


MUTATION may occur in a mouse injected with methylcholanthrene. Here an offspring of such a mouse has a banded coat. Band is passed along to half the members of next generation, indicating that mutation is dominant.

The Limits of Measurement

Can the accuracy of observation indefinitely be improved? What of the fundamental atomic and molecular uncertainties of the process?

by R. Furth



THE BROWNIAN MOVEMENT of small particles is illustrated by this photomicrograph of oil globules in water. The multiple images are particles that have moved discontinuously under the thermal molecular bombardment.

SEVENTY years ago, when the system of ideas that we now call "classical physics" had been established, most physicists believed that they had before them an essentially true and very beautiful picture of the physical world. To perfect the picture, they thought, it remained only to put in more detail and make some minor corrections of the physical laws. For this it was necessary to increase the accuracy of quantitative observations, on the one hand by the construction of more sensitive and more accurate measuring instruments, and on the other by a very careful analysis of possible errors. Thus the experimenters of that period became primarily craftsmen in measuring techniques, and a physicist who succeeded in measuring a physical "constant" with a new degree of precision could be sure of making his way in academic life.

Nobody then doubted that the process of increasing the accuracy of observation could be continued indefinitely, at least in principle. Wonderful progress had been made in the construction of precision instruments and there seemed no reason why this steady improvement should ever come to an end.

The classical physicists realized, of course, that the process of measuring necessarily involves a mutual interaction between the object to be measured and the measuring device, and that this must to a certain degree change the measured object. For instance, when one uses a wire gauge to measure the thickness of a wire, the instrument causes a very slight deformation of the wire; one can avoid this by measuring the thickness optically under a microscope, but now the wire must be illuminated with concentrated light, which heats it slightly and makes it expand. Similarly, to measure an electric current one has to send at least a fraction of it through the measuring galvanometer, and that alters the original value of the current. Yet it seemed that by increasing the sensitivity of the measuring devices one could reduce this interaction below any desired level, and that in any case corrections for the interaction could be calculated as long as the interaction was of a regular character and subject to known physical laws.

Around the turn of the century this and other basic problems in measurement began to become a great deal more involved, partly because of quite unexpected developments in experimental technique and partly as a result of new insight into the very nature of the laws of physics.

It is obvious that a physical quantity can be measured with accuracy only if it is precisely defined. Consider the measurement of the properties of a gas. According to the kinetic theory, the laws governing the "macroscopic" behavior of a gas hold strictly only for systems consisting of a theoretically infinite number of molecules. In other words, macroscopic quantities such as density, pressure and temperature are defined as statistical averages over infinitely large numbers of molecular events. But any device for measuring such a quantity can only record the outcome of a finite number of such events; for example, a pressure gauge records the net result of a large but finite number of molecular impacts on its sensitive surface. Hence even the most perfect instrument could not give the true value of the quantity to be measured, and repeated measurements will show irregular fluctuations, due to the irregular thermal movement of the molecules, which become more and more apparent with increasing sensitivity of the instrument.

THE CLASSICAL physicists did not believe that within the foreseeable future the sensitivity of instruments could be brought anywhere near the level where these tiny irregular fluctuations would need to be seriously considered in measurement. But around 1905 Albert Einstein and the Polish physicist M. Smoluchowski independently showed that such fluctuations should under certain circumstances be observable by methods already available. They calculated that the fluctuations in the number of impacts of molecules on the surface of a small particle suspended in a fluid should produce an irregular movement of the particle, large enough to be observable and measurable under an ordinary microscope. The particle, in other words, acts as an extremely sensitive pressure gauge, and its movements record the fluctuations of pressure in the fluid. This phenomenon had actually been observed by many scientists; it had first been described by the English botanist Robert Brown in 1827. But it was not until almost a century later that the phenomenon was generally recognized as a manifestation of the thermal movement of molecules and given the name "Brownian movement."

The discovery of this phenomenon made it clear that there was no point in trying to increase the accuracy of measurement of such statistical quantities beyond the inherent statistical error. Indeed, when we try to do so, we find that we encounter another difficulty; the internal movement of the particles in the measuring instrument itself produces an irregular fluctuation of the readings, which increases with increasing sensitivity and increasing temperature. Thus it is useless to try to improve very sensitive torsion balances or radiometers by further increasing their sensitivity, for this at the same time also increases the fluctuations.

The same limitation applies to electric devices. In the first place, since electric charge is always attached to particles of finite mass (ions and electrons) and an electric current is always connected with a flow of such particles, the current, charge density, voltage and so on must display irregular fluctuations when measured with sufficiently sensitive instruments. Secondly, the transfer of electricity through electronic tubes must be subject to fluctuations due to the "grainy" structure (*i.e.*, electrons) of the electric current. This is usually called the "shot effect," from a mechanical analogy: if you fill a funnel with small shot and let it pour out on a wooden plate, the flow of pellets will be more or less irregular, producing an irregular drumming noise. In communication systems using electronic tubes to amplify weak signals such fluctuations become apparent as background "noise." Clearly nothing can be gained in the performance of a receiver by increasing its sensitivity beyond the level at which the fluctuations, or noise, begin to exceed the strength of the signals themselves.

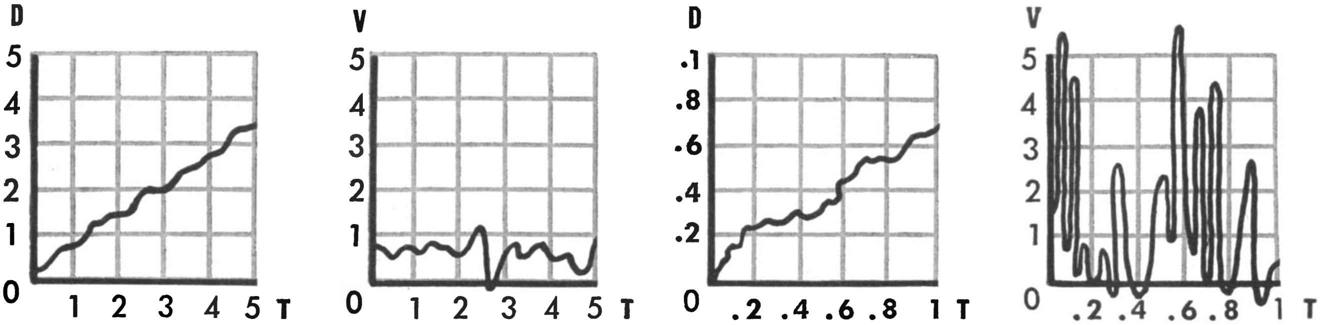
In view of these new facts the older ideas about the action of the measuring instrument on the measured object also had to be revised. Because of the Brownian motion of the measuring device this reaction has an irregular character, and therefore it cannot be completely corrected by compensatory calculations. For example, when a weak electric current is measured by means of a very sensitive coil galvanometer, inaccuracies arise from the inherent irregular fluctuations of the current itself, from the mechanical Brownian motion of the instrument, and from the motion of the coil within the magnetic field, which generates an irregularly varying current that is superposed on the current to be measured.

IN 1905 the Austrian physicist E. Schweidler called attention to another irregularity in nature. It had already been shown that the spontaneous decay of radioactive substances followed a very simple law: namely, that the number of atoms decaying per second is proportional to the number of undecayed atoms present. Schweidler interpreted this to mean that radioactive decay is a chance process; each atom has a definite probability for decaying within the next second, and this probability is independent of the atom's age, just as the probability for throwing a double six with a pair of dice is always one in 36 regardless of how long the game has been going on. Schweidler reasoned that if the decay of atoms does actually occur at random, the intensity of radioactivity from a piece of radioactive material should fluctuate irregularly in time. This was indeed proved experimentally soon afterward. It is now well known that the sequence of nuclear events is irregular in time. This holds not only for natural radioactive processes but also for nuclear processes produced artificially in the laboratory and for the mysterious processes responsible for cosmic radiation.

Thus it gradually became clear that nuclear processes were of a statistical nature and therefore incapable of being measured with infinite precision. In the meantime it had been found that the processes of emission and absorption of light could not be explained on the basis of classical physical laws, and quantum theory was introduced to overcome this difficulty. According to this theory, the emission and absorption of light by matter takes place in the form of finite quanta of energy or photons. It was Einstein who in 1917 suggested that the processes of emission and absorption were governed by probability laws like those governing radioactive decay, which implies that optical phenomena also are statistical in nature and cannot be measured with unlimited accuracy because of inherent fluctuations. This has been directly confirmed by experiment, for we now have devices of such extreme sensitivity that the statistical fluctuations of light intensity can be detected and even single light quanta can be counted.

All this makes one wonder if there are any physical quantities left which are not of a statistical nature. And what may be the origin of this chance character? To these questions Max Born in 1926 put forth a very radical answer which is now almost generally accepted. Briefly expressed, it states that the laws of quantum theory governing all atomic processes, and most probably all nuclear ones, are inherently statistical in character. They do not predict the fate of an individual atom or electron or photon but only give probabilities for the various events that may happen to it. This leads to the conclusion that all physical quantities, with the sole exception of the universal constants, are defined only statistically. Consequently they must exhibit fluctuations that will prevent precise measurements being taken beyond a certain limit.

SO FAR our argument on the limits of measurement has been more or less intuitive. Now let us analyze the problem a little more rigorously. It is very well known that the accuracy of measurement can be considerably improved by frequent repetitions of the measurement. Indeed, definite results may be obtained even from measurements that seem hopelessly erratic if only the number of observations is sufficiently large. The same result can be achieved by the use of recording instruments that measure the observed quantity continuously over a period of time, and by smoothing the graph obtained. Or the measuring device can be designed in such a way that it will automatically integrate the measurements over a certain time interval and



INCREASED RESOLUTION of the movement of a particle under the microscope produces effects shown in these two pairs of diagrams. In first diagram the horizontal coordinate is time; the vertical coordinate, distance. In second the vertical coordinate is velocity. In third and fourth the magnification of the particle has been increased five times. Its position is now known with greater accuracy, but its velocity fluctuates more.

so directly give the required time average. An example of one such procedure is the measurement of the mean intensity of a weak light source by long photographic exposure.

There is a very serious objection, however, to this kind of scheme: it presupposes that the observer already knows that the quantity to be measured is constant in time. But how is one to know this except by taking repeated measurements and comparing them to find out whether the value is maintained or not? And since the readings or records will vary in time because of the fluctuations, one will not be able to decide whether the quantity has really remained strictly constant or has varied within the limits of the recorded fluctuations.

Actually the principal task of the experimenter is to measure a certain physical quantity as a function of time. If he restricts himself to a short time interval, this becomes equivalent to the problem of determining, at one and the same time, a quantity and its rate of change as precisely as possible. The question to be answered is then: Is there a natural limit to this precision, imposed by the thermal fluctuations and by the statistical nature of the physical laws?

Let us first consider the effect of the fluctuations of the measuring instrument in this new light. Any measuring device can be characterized by its "relaxation time," that is, the time which must elapse between two successive observations to make them independent of each other. In the case of the human eye or ear, this relaxation time is about a twentieth of a second. In an ordinary mercury thermometer, it is of the order of several minutes; at the other extreme, in some electronic relays and counters, it is of the order of millionths of a second. Clearly when we use an instrument with a very long relaxation time for measuring a quantity, the accuracy of the measurement will be very great, because the instrument can integrate to even out the fluctuations, but no information will be obtainable about the rate of change of the quantity during this time interval. On the other hand, by using an instrument with a very short relaxation time we can repeat measurements at short intervals and so approximately measure the rate of change, but now the fluctuations will make themselves very strongly felt.

In 1933 the author showed that if one multiplies the mean error in the measurement of a quantity by the mean error of the simultaneous measurement of its rate of change in time, one obtains a constant, which is independent of the relaxation time. Thus an increase in the accuracy of the value for the quantity automatically diminishes the accuracy of the rate of change, and *vice versa*. Now this error constant depends on the construction of the instrument and is proportional to the absolute temperature. So the only way to reduce the error arising from the thermal fluctuations of a given type of instrument is to lower its temperature.

WE NOW TURN to the question of the statistical fluctuations of the observed quantity itself. It will suffice to analyze in this light the most fundamental type of measurement; namely, the simultaneous determination of the position and the velocity, or rate of change of position in time, of a small particle in a fluid. We shall make the measurements with the help of a measuring microscope. The particle moves downward in the fluid as a result of the action of gravity. If there were no Brownian motion, the particle would move against the frictional resistance of the fluid with a constant speed, and the record of its positions over the time interval would be represented on a coordinate graph as a straight line. But because of the superposed Brownian motion the actual position-time record is irregular (*see first diagram at the top of this page*). In order to determine the average velocity of the particle from this diagram one can construct the velocity diagram (*second diagram*). This exhibits the spread of observational accuracy in the determination of the mean velocity. If one tries to increase the precision of measurement of the particle's position by using a microscope of greater magnification, one will obtain a curve (*third diagram*) which represents the beginning of the curve in chart A at higher resolving power. But now when one constructs the corresponding velocity diagram (*fourth diagram*), one realizes at once that what is gained in the accuracy of measurement of the particle's position is lost by the apparent increase in the spread of observed velocities from this average. This reflects the well-known phenomenon that the path of a Brownian particle seems to become more and more complicated the more one increases the magnification of the observing microscope.

In practice the thermal fluctuations of both the observed and the observational systems and their mutual interaction have to be taken into account. It can be shown that the uncertainty of the measurement is again given by a relation of the same type as before; *i.e.*, the product of the errors in the measurement of a quantity and of its rate of change in time is again a constant. The over-all error is proportional to the average temperature of the three elements—the object, the measuring device and the coupling mechanism. In the simplest case, when the temperature is uniform throughout the three parts, they merge into one combined system, and it becomes impossible to attribute the observed fluctuations to any particular cause. For example, the fluctuations exhibited by a supersensitive galvanometer in measuring a current can be equally well attributed to its mechanical Brownian movement, to the electrical fluctuations in the connected circuit or to the fluctuating interaction between both.

To increase the accuracy as much as possible one will try to keep the average temperature as low as possible. But here again we soon reach a limit beyond which we cannot proceed without impairing the sensitivity of the method. Take again as an example the observation of the path of a small particle. Here the light scattered by the particle into the observing device (the eye or a camera) plays the role of the coupling mechanism. If we use strong light so we can see or photograph the particle under high magnification, we introduce a high-temperature radiation that increases the Brownian fluctuations. On the other hand, if we use a weaker light to reduce the temperature, we must go to lower magnification to see the particle and there is a loss of sensitivity.

SO FAR the analysis has been conducted along "classical" lines. We now have to revise it in the light of the theory of quanta. According to the classical conception, at the absolute zero point of temperature the thermal fluctuations should vanish. Quantum theory, however, implies that every physical system must retain a finite "zero-point energy," which means that however low the temperature, the system will continue to fluctuate about an equilibrium position. Now if the system is bound to the equilibrium by strong forces, the fluctuations of position will be small, but it follows from the theory that the fluctuations in velocity will be large. On the other hand, if the system is bound loosely, the velocity fluctuations will be reduced but the fluctuations of position will inevitably increase. Quantitatively the product of the uncertainty of position and the uncertainty of velocity is approximately equal to Planck's universal constant of "action" (h) divided by the inertial resistance of the system. This relation is strikingly analogous to the corresponding "classical" relation. It shows that if the inertia of the measuring instrument is reduced sufficiently, then the inaccuracy of the simultaneous measurement of a quantity and its rate of change can be made very small, but it can never be reduced to nothing, even at zero temperature.

It is to be expected that these "zero-point fluctuations" will affect the behavior of the quantity to be measured as well as that of the measuring instrument. We can again restrict ourselves to the discussion of the movement of a particle under the action of some external force, say gravity. The classical view was that in the absence of thermal fluctuations the path of the particle should be completely determined, and its position at any time should be strictly predictable. But quantum theory holds that owing to the zero-point fluctuations this is actually not the case. In the words of Erwin Schrödinger, we may say that the particle performs a kind of "wobbling motion" about its classical path. As a result the progress of an individual particle cannot be predicted strictly; we can only calculate probabilities.

ALL THIS is summed up in Werner Heisenberg's famous "uncertainty principle." Applied to the question of measurement, this principle can be expressed as follows: The product of the uncertainty of the position and the uncertainty of the velocity of a material particle at one and the same time is approximately equal to Planck's constant, h, divided by the mass, m, of the particle. This indeterminacy is inherent in the very nature of the quantum laws of motion. Thus no instrument can be designed that would make it possible to measure the position and speed of a particle simultaneously with a greater accuracy than h/m.

Plainly the quantum-mechanical uncertainty relation is of precisely the same type as the one imposed by thermal fluctuations, except that the former is independent of temperature and that no distinction can be made between zero-point fluctuations of the measured object and measuring device and the unpredictable interaction between them. Both processes affect all measurements, but the actual limit of accuracy in a particular case is determined by whether the Brownian movement or the zero-point fluctuations factor predominates: in measurements involving particles of large mass or high temperatures the limit of accuracy is fixed by the Brownian movement of the particle, while in those involving fundamental particles of very small mass, such as electrons, protons and neutrons, or very low temperatures, the quantum-mechanical limitation will be decisive.

Indeed, in the case of electrons the quantity h/m is of the order of magnitude unity, *i.e.*, about 1. On the other hand, the diameter of an atom is of the order of 10^{-8} centimeters, and the velocities of electrons within the atom are of the order of 10^{8} centimeters per second, so their product is also of the order of magnitude unity. In other words, the error involved in the simultaneous measurement of the position and velocity of the electron is of the same order as the quantity to be measured. It becomes clear at once that observation of the movement of the electron within the atom is out of the question; the observational method is so crude that it completely upsets what it endeavors to investigate. The same is true of the investigation of intranuclear processes by means of the bombardment of nuclei, and of the observation of the effects of this bombardment.

To summarize we may say that the aim of quantitative observation is the simultaneous measurement of physical quantities and their rate of change, and that the accuracy of this process has a natural limit. This limit is imposed both by the chance character of the thermal agitation within the instrument and the measured object, and by the statistical nature of the quantum-mechanical interaction processes among the fundamental particles.

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ANIMAL COURTSHIP

An account of some curious preliminaries to mating among birds, insects and spiders, with particular reference to the influence of vision

by Lorus J. and Margery J. Milne

MARRIAGE has been defined by cynics as a state of antagonistic cooperation between two human beings of opposite sex. But most of us think of the partnership as something entered into on a basis of mutual approval. The choice depends in great part on those aspects that are subject to visual inspection; each "likes the looks" of the other. Not only in the human instance but throughout the animal kingdom, courtship is linked closely to the possession of good eyes. It has been described scientifically as "an elaborate sexual response involving recognition, selection and pursuit."

A little reflection will show that it takes no small powers of discrimination merely to recognize a potential mate. First there is the question of kind. Although it is not always easy to distinguish one species from another, every animal learns to make the distinction instantly and at a distance. A robin, for example, responds very differently to the approach of a hawk, a pigeon, a cat or another robin. The hawk may induce a mad dash for a thicket; the pigeon may elicit no response beyond a cocking of the head to center the pigeon's image on the fovea of the eye; the cat causes a jerky flight from one limb to another while forceful calls spread the excitement and alarm. A robin, on the other hand, is identified by the robin not only as such, but also as to sex. If the newcomer is a male, the first male robin will streak arrowlike toward the intruder to drive him away from its invisibly fenced preserve; any ornithologist can recognize the angry shrieks and interpret the clash of feathered wings, even though the action may be hidden by a hedge. But a female entering these sacred boundaries is no trespasser. Everyone knows the sequence: the male struts and plumes himself; the female responds to his courtship with seeming indifference, manifested at one extreme by gentle avoidance and at the other by passive cooperation.

How does a robin recognize another robin's sex? The female is sometimes smaller than the male, but not always; it generally has a less brilliantly colored breast, but again the distinction is not invariable. Does a robin recognize sex by visible markings or by behavior?

These questions have been studied experimentally in birds other than robins. One of the kinds studied is the Maryland yellowthroat. The male of this warbler has a black mask of feathers which is lacking in the female. Male yellowthroats are just as insistent on territorial rights as robins. A male will attack and tear to pieces even a stuffed specimen of another male, mounted with wire on a bush. A taxidermy specimen of a female, on the other hand, receives full courtship attentions. But let the experimenter paint a black mask on the stuffed female, and the little male flies into a fury of pecking and ripping. Evidently the mask is his clue to the bird's sex. The same type of recognition has been demonstrated in the flicker. Adult female flickers lack the black mustache marks characteristic of males and juveniles. If mustaches are painted on a female flicker, she becomes a target for battery by every male around, but for courtship by none. Clearly appearance rather than behavior is responsible for the identification of sex in these species.

THIS dependence on the eyes in courtship may be awkward when, as in the insects, vision is not too acute. The compound eyes of insects form only a vague, coarse image of objects ("Insect Vision," SCIENTIFIC AMERICAN, July, 1948). The resulting confusion in courtship can be observed in the white cabbage butterfly. Flitting over a field, the insect zigzags in a seemingly aimless fashion until it is within about two yards of another cabbage butterfly; then it makes directly for the white object to investigate. But it is stimulated just as strongly when it comes near a white daisy or a dandelion head in the field. Only at a distance of a foot or less can the insect distinguish one attraction from the other. Perhaps it accomplishes this by smell.

Like human beings, the lower creatures often do their wooing with a flair. Bird courtship is notably elaborate. Most of the common birds strut and bow, displaying the bright plumage of the mating season. The male strives both to exclude competitors from his territory and to attract females into it. The male black-crowned night heron, a water bird, presents his chosen female with twigs, one at a time. Often she not only responds to these suggestions but also begins hunting twigs herself and builds a nest in which the pair can raise a brood of young. The male common tern catches a little fish, holds it crosswise in his beak and parades with it up and down the beach. The sex differences in this bird are too indistinct for human eyes to distinguish, but when another tern comes up to him and accepts the fish, bird watchers recognize that he has found a female. He bows and scrapes the beach before her and keeps alert for any signs of cooperation. If his suit is successful, he proceeds after mating to prepare a hole in the sand in which she makes the nest.

This instinct for gift-making extends far down into other areas of the animal kingdom. One example is a small Micropezid fly, a third of an inch in length, known from British Guiana to Mexico. The males swagger around on long legs on the surface of leaves, displaying their iridescent blue bodies. They have a distinctive courtship technique that gives them an aspect strongly suggestive of bubble-gum chewing: the male fly alternately extrudes from its mouth and sucks in again a large, shiny globule. This is a rich food, and when he regurgitates it before a female not too coy to respond to his charms, she hurries over to share it. The two are soon as busy as a pair of teenagers strawed to one ice-cream soda! There ensues a pattern of behavior not uncommon elsewhere in the animal kingdom: as long as the food holds out, the female fly offers no resistance to the male, but the moment it is gone she spurns him. Some males make the liquid supply last longer by depositing minute droplets on the sides of the female's head, which gains time while she retrieves the globules with her forefeet. In this way the male often spreads his mating over a 15-minute period. The female, after finishing her meal and casting her mate aside, may promptly accept another partner—perhaps actuated, according to the great entomologist William Morton Wheeler, "more by hunger than by lust."

THE MICROPEZID flies' courtship antics are not nearly as complex as those of certain small Empidid flies. The latter prey on still tinier insects, sucking their body juices. Sometimes the male only paralyzes his prey and flies about with it basketed in his legs until he locates a dancing swarm of females of his own kind. Then he selects a mate and presents his gift to her. While the female eats her gift, squeezing it to obtain every drop of liquid contents, the pair mate on a plant. When the nourishment gives out, the female discards the shell and her partner with a single gesture.

Some varieties of a closely related fly called *Hilara* have an even more elaborate courtship ritual. The male, in flight, spins a fluffy, balloonlike mass of silk. This he presents to a female, who toys with it and examines it while she lets him have his way. Even a second-hand "balloon" will serve; those that have been dropped, probably after pairing, are constantly picked up and used again by other males.

Construction of these nuptial balloons, which often are wrapped around morsels of food, may easily originate in the instinct for self-preservation. Among many of the predatory insects and arachnids the life of the male is precarious in his mate's vicinity, for she may seize and devour him for dessert. This aspect of courtship was described in detail by the patient 19th-century French entomologist Jean Henri Fabre; he wrote particularly about the praying mantis and the scorpion. Spiders also are supposed to eat their mates regularly, though our foremost student of the group, Alexander Petrunkevitch of Yale University, insists that this is far from true. Female spiders, in any case, are safe playmates only when fully fed, and even then they occasionally take an extra snack. Obviously a male spider must use his eyes for something more than merely identifying the female. It seems likely, for example, that the intricate dancing of a jumping male spider before a potential mate is designed more to elicit information as to the state of her nutrition than to charm her into accepting his attentions. If the female responds to his dance as though he were a fly, he goes elsewhere. The male of the variety of spiders known as orb weavers makes a similarly cautious approach. He stands at the side of the female's web and shakes it gently. If the female is hungry, she will rush out to seize the fly she is led to suspect is caught; if she is satiated, she will remain quiet and let the male advance. Often the two sexes live together in the same web throughout the season. The males that survive are those that keep out of the way when their mates become interested in a meal.

IN SOME of the wolf spiders the mere odor of a nearby female is sufficient stimulus to start a male hunting for a fly as a placating gift. Veteran spider-watchers report eyewitness cases in which the female recognized the presence of the empty-handed male and ate him; in which the female pounced on the male before he had wrapped his captured fly in silk, and took the fly away; and, more happily, in which the male had his swaddled fly ready, tendered it to his mate and succeeded both in pairing with her and escaping afterward. There is an authentic story, the sequel to which unfortunately is not told, of a male that gave the female the well-wrapped dried remnants of a fly he himself had eaten!

Courtship becomes quite a problem, of course, for animals with poor vision or nocturnal habits. Some of the large, hairy, tarantula-like spiders of our Western deserts see so poorly that even after a pair meet the male may easily lose contact with the female. If the leg that first touches her and tells him of her presence slips off and they part for even a fraction of an inch, they may walk away from each other, or continue almost parallel only slightly apart, unable to find each other again. The males of these and many related spiders have

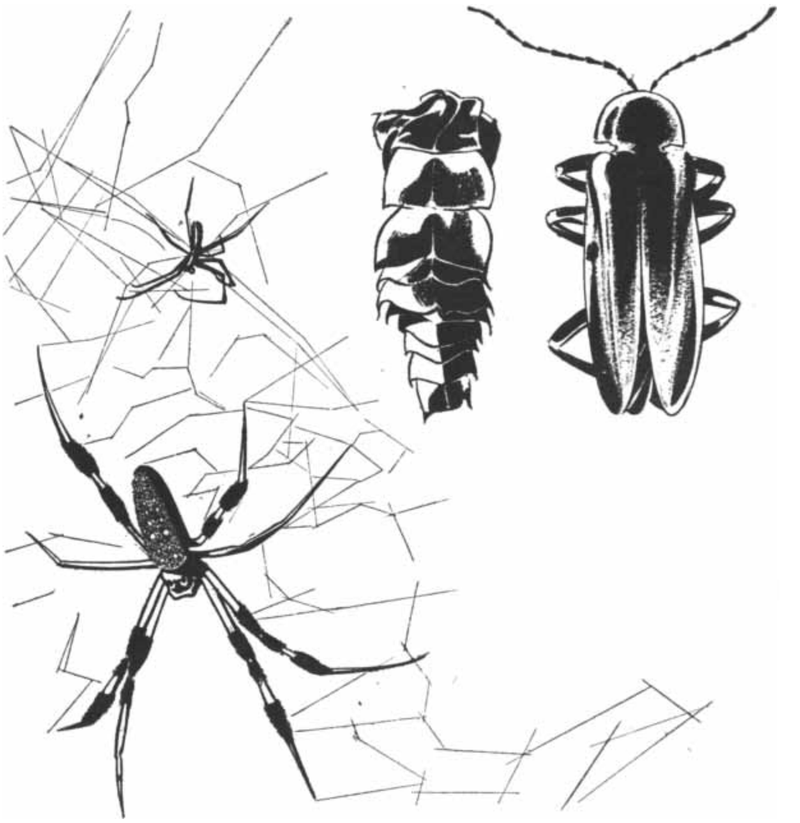
THE MALE FLICKER (*right*) **recognizes the female of the species** (*left*) **by the absence of a mustachelike marking behind the bill. If a mustache is painted on the female, the male will attack her as he would a rival.**

FEMALE PRAYING MANTIS (*lower left*) **may eat the male** (*upper left*) **during courtship if she is hungry. The cabbage butterfly** (*right*) **appears to have difficulty in distinguishing between a potential mate and clover.**

a self-protective habit that seems to be a regular part of their mating. Early in the preliminary posturing, when the male is facing his prospective mate, he reaches forward his foremost pair of legs and fits special horny cups over the closed tips of her poison fangs, thus disarming her. He retains this grasp on her all through mating. As in the case of man versus alligator, the battle is to keep the jaws closed. The female spider's muscles are chiefly arranged for clamping the fangs pincerwise on prey; only a relatively feeble mechanism is available for opening the jaws, and these muscles the male can successfully oppose. But when he leaves his mate he must be dexterous and quick. His plight is like that of the man with a bear by the tail.

In all the animal kingdom almost the only species equipped for courting by sight after dark are the fireflies. The twinkling lights familiar to everyone are beacons whereby the sexes find each other. They speak in code, and each kind of firefly has its own code language. The pattern is closely correlated with the specialized body structure of the particular variety of firefly. In many kinds both sexes are essentially alike, with feathery antennae, luminescent organs and eyes about equally well developed in the male and female. Such fireflies commonly assemble in small clusters and maintain a steady twinkling, attracting new recruits about as fast as mated pairs go off into the night. In other fireflies the male has relatively enormous eyes, occupying most of the head. Such males emit pulses of light at intervals as they fly. The females of the same type creep up grass-blades and ready themselves to respond with flashes of their own.

This behavior is characteristic of our common Eastern firefly, *Photinus pyralis*, whose mating habits have been studied intensively. The male has a peculiar flight that looks like a bright check mark in the dark: he turns on his light at the beginning of a sharp dip, reaches maximum brilliance and minimum altitude simultaneously, ascends on a gently rising upstroke for a little distance and then extinguishes the luminescence. This gesture is exciting only to a female firefly of the same variety. She responds by turning on her own glow so that it shines out from the grass-blade on which she is perched. Her light is less intense than that of the male, but lasts somewhat longer at its full brilliance. It also has another peculiarity that is the essence of the signaling code between them: she flashes her signal precisely two seconds after she sees the male's. To a properly timed signal he responds by changing his course in the dark to face her, and flashes again. If she replies after two seconds, he approaches. Ten to 15 such exchanges ultimately guide him to her



FEMALE TROPICAL SPIDER of the species Nephila (*lower left*) is much bigger than the male (*upper left*). Glowworm (*right center*) and firefly (*right*) are members of same species that can use lights as mating signals.

side. His is a beautiful example of insect navigation.

Any behavior as mechanical as this invites experiment, and various investigators have made tests with artificial signals. One found that a lighted match, waved in the check-mark form and promptly extinguished, induced female fireflies in the grass to glow in response. Another investigator placed a flashlight on the ground and winked it momentarily just two seconds after a male flying nearby had flashed his light. The male flew to the flashlight from a distance of several yards. The experiment was repeated with various sources of light, always with the same result. Even a captured male, induced to glow by gentle pinching two seconds after the flash from a flier, brought the free male to the observer's hand, where it attempted to mate with the captive.

The experiments showed clearly that the basic cue is the time interval, not the kind of light. If the flashed response comes too early or too late it is ignored. But so long as it occurs two seconds (plus or minus a fifth of a second) after the flying male has sent his visible call, it is unimportant whether the glow is from male, female or flashlight, whether it is a broadly lit area or a pin point of light, whether it is green, amber, orange, red or even infrared. (Fireflies are the only known insects that see in the infrared region of the spectrum.)

The glowworm of literature ("Shine, little glowworm, glimmer-glimmer") is the wingless female of *Lampyris noctiluca*, a member of the firefly family. The males of this variety have huge eyes but little or no ability to produce light. The females are grublike, scarcely differing in appearance from the larvae whence they grew. The female climbs to some grass-blade eminence and turns on her light; often she keeps the beacon burning continuously until a male arrives or she becomes exhausted. Here is a clear example in nature (rare or common, according to the point of view) of the female boldly inviting the male, showing none of the reticence so often claimed for the sex. It reminds one of the phalaropes, birds of the far North seen in the U. S. chiefly during their migrations. The female phalarope, larger and more brightly colored than the male, displays before him, badgering him into pairing with her. The male phalarope, incidentally, later incubates the eggs and rears the young, while the mother disports herself abroad.

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BOOKS

On the processes of intellectual change that led to the birth of modern science

by James R. Newman

THE ORIGINS OF MODERN SCIENCE, by Herbert Butterfield. The Macmillan Company ($2.50).

THE history of science has had a hard time capturing a seat in the academic senate. It has been charged that the animal is a hybrid and therefore sterile. Some critics have given currency to the sarcasm that, since historians know as little about science as scientists know about history, the historian of science can easily keep out of reach of experts in either camp.

These strictures are essentially unjust. The subject itself, properly conceived as the history of the part played by science and scientific thinking in the evolution of civilization, is surely of the first importance. Thus conceived, it is neither a hybrid nor sterile; much less is it a safe refuge for academic second-raters. Yet one may concede that much of the modern writing in this field is neither instructive nor entertaining. The dreary catalogues of minutiae, the chronicles of events and inventions, the superficial surveys and meretricious abridgements are familiar commodities. There are of course notable exceptions, and this book on the origins of modern science by Herbert Butterfield, professor of modern history in the University of Cambridge, is one of them.

The author, whose book is the result of a series of lectures delivered at the request of the Cambridge History of Science Committee, comes to the subject without bias or pretensions. A skilled general historian who, by choice and not as a professional duty, evidently read his way from top to bottom through the stacks of classical scientific literature, Butterfield brings new insights and gives new meaning and proportion to the great period of scientific advance from the 14th to the end of the 18th century. His study differs from more conventional approaches in concentrating on "lines of strategic change," on those nodes in the evolution of thought whence sprang the new branches of scientific investigation. He has sought to discover the "intellectual knots" which had to be untied at a given time before the fabric of science could be enlarged. It is the outstanding merit of his book that it is in the best sense a history and not a chronicle; that he has succeeded—not always but often—in bringing to life the complex process of intellectual advance without merely reading the past with the eyes of the 20th century; that he has shown the causes of the scientific revolution in terms of the changes that took place "inside the minds of the scientists themselves."

In some 200 pages he covers a tremendous epoch, examining from a fresh vantage point the development of astronomy and physics, the founding of modern physiology and chemistry, the birth of the idea of evolution, the relation between the scientific, industrial and agrarian revolutions. Everywhere he finds evidence to support his thesis that progress in science is determined less by great discoveries and inventions than by the gradual process of rearranging ideas, of "picking up the other end of the stick," of looking at familiar things in an unfamiliar way. The 19th-century German mathematician Karl Jacobi defined a formula for gaining new insights in mathematics: "Mann muss immer umkehren" ("One must always invert"): Butterfield suggests a similar key for advances in the other sciences.

One of his most effective case studies in the growth of ideas concerns the problem of motion. This he characterizes as the most amazing intellectual hurdle faced and overcome by the human mind in the last 1,500 years. The prerequisites of the achievement were at least two drastic steps: a complete reorientation of thought as to the working principle of the physical universe; and the overthrow of the authority of Aristotle, whose teachings had reigned absolute for almost 20 centuries. The consequences were "stupendous," including the emergence of modern science, especially astronomy and mechanics.

According to Aristotle, all heavy bodies had a "natural" motion toward the center of the universe, which for medieval thinkers was the center of the earth. All other motion was "violent" motion, because it required a constant motive force, and because it contravened the tendency of bodies to sink to their natural place. The acceleration of falling bodies was explained on the theory that they moved more "jubilantly"—somewhat like a horse—as they got nearer home. The planetary spheres, while exempt from the "natural" tendency, were kept wheeling in their great arcs by the labors of a sublime Intelligence or Prime Mover. As anyone could see, except for falling bodies things moved only when and as long as effort was expended to keep them moving. They moved fast when the mover worked hard; their motion was impeded by friction; they stopped when the mover stopped. For the motion of terrestrial objects it is clear that Aristotle had the example of the horse and cart in mind; in the celestial regions his mechanics left "the door halfway open for spirits already."

The clockwork universe in which marbles and planets rolled about as a result of the orderly interplay of gravitational forces, in which motion was as "natural" as rest, and in which God, once having wound the clock, had no further duties, was the supreme intellectual creation of the 17th century. How was the intellectual hurdle of Aristotle's teachings overcome, and the way opened for the "flood of change" culminating in the high-water mark of Newton's system? It was a slow process, in which the major and the minor thinkers, the plausible theories and the fantastic, the ideas of the ancients, the medievalists, the experimenters, the mathematicians and the philosophers all found a place. Among the first seeds of the subversive movement leading to the overthrow of accepted doctrines were the observed inconsistencies between experimental data and the dictates of Aristotelian theory. On the whole Aristotle's theory of motion squared pretty well with common experience; yet there was the anomaly of the misbehaving arrow which according to the horse and cart theory of motion should have fallen to earth the instant it lost contact with the bowstring. Nor was the traditional explanation of the acceleration of falling bodies swallowed without protest. In each case the paradox was met by an ingenious modification of the accepted system; yet every such synthesis, however brilliant, was a source of controversy, and raised suspicions concerning the validity of all Aristotle's teachings.

One of the major "generative factors" in the development of the scientific revolution, and, specifically, in the correct settlement of the problem of motion, was the discovery of the fact that Aristotle had not "reigned unchallenged" in the ancient days; that there were rival teachers to whose views the more independent medieval thinker might turn if the master seemed to be talking nonsense. To reject Aristotle was of course a step not without risk, whether one embraced one of his contemporaries or, worse still, spun one's own thoughts without the support of other authorities. When Harvey made his revolutionary discovery of the capacity of the heart he well expressed the dangers of nonconformism:

"What remains to be said upon the quantity and source of the blood which thus passes is of a character so novel and unheard of that I not only fear injury to myself from the envy of a few but tremble lest I have mankind at large for my enemies, so much doth wont and custom become a second nature."

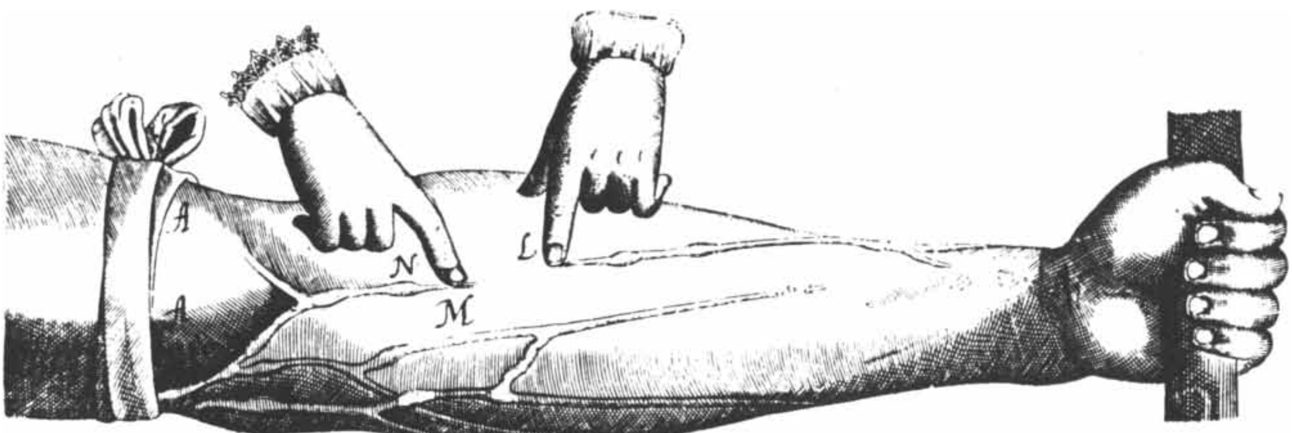
The theory of impetus was largely developed in the 14th century at the University of Paris by Jean Buridan and others. Although it was only a "first stage" in the history of the scientific revolution, it proved to be a major factor in dethroning the Aristotelian doctrine of motion. It was later picked up by Leonardo da Vinci, and some of the "remarkable strokes of modernity" in his notebooks were nothing more than transcriptions from 14th-century Parisian scholastic writers. This theory held that a projectile kept moving by virtue of "something" it had acquired in the course of getting underway, a thing "inside the body itself"; the acceleration of falling bodies was due to "impetus" continually being added to the constant fall produced by the original weight. The importance of the theory lay in the fact that men for the first time were presented with the idea of motion as a lingering aftereffect derived from an initial impulse. This was a "half-way house" to the modern view, fairly explicit in Galileo, that a body "continues its motion in a straight line until something intervenes to halt or slacken or deflect it."

What was needed to complete the journey was an extraordinary transposition of ideas from the real to an imaginary world. Modern mechanics describes quite well how real bodies behave in the real world; its principles and laws are derived, however, from a nonexistent conceptual world of pure, clean, empty, boundless Euclidean space, in which perfect geometric bodies execute perfect geometric figures. Until men—the great thinkers operating on the "margin of contemporary thought"—were able to establish the mathematical hypotheses of this ideal Platonic world, and to draw their mathematical consequences, it was impossible for them to construct a rational science of mechanics applicable to the physical world of experience. This was the transposition of mind required—the new look at nature in order to see what, in fact, there was to be seen rather than what some classical writer had said ought to be seen. Buridan, Nicholas of Oresme and Albert of Saxony with their theory of impetus; Galileo with his beautiful systematization of everyday mechanical occurrences and his ability to picture such situations as the behavior of perfectly spherical balls moving on perfectly smooth horizontal planes; Tycho Brahe with his immense and valuable observational labors in astronomy; Copernicus with the *De Revolutionibus Orbium* and heliocentric hypothesis; Kepler with his laws of planetary motion and his passionate search for harmony and "sphericity"; Descartes with his discourse on method, his determination to have all science as closely knit as mathematics, his wedding of algebra to geometry ("the greatest single step ever made in the progress of the exact sciences"); Huygens with his mathematical analysis of circular motion and centrifugal force; Gilbert with his *terella,* his theory of magnetism and gravitation; Viète, Stevin and Napier with their aids to simplicity of mathematical notation and operations: each took a part in the grand renovation not only of the physical sciences but of the whole manner of thinking about the furniture of the outside world.

In the development of modern physiology there was a similar slow unfolding of the presiding issues. The protagonists were compelled to unlearn false theories, to shift their angle of view, to sit down before fact "as a little child," to advance simpler and more satisfactory hypotheses, to make bold inductions, to confirm them, if possible, by sound experiment, to tinker with their conceptual engine until its parts of theory and fact fitted smoothly and the engine ran by itself. Medieval dissectionists and anatomists were not seeking fresh discoveries. They looked dutifully for the things Galen had told them to look for; they were demonstrators of established facts, not searchers for new truths. Even Vesalius, the founder of modern anatomy, admitted, when his findings differed from those of Galen, that "at first he could not believe his own eyes." Butterfield gives an amusing modern example of the same subservience to authority:

"I remember that on one occasion at school our physics master was giving a demonstration, and he was doing the mathematics on the blackboard while a boy called Booth was supposed to be watching the actual experiment. Booth, when called upon to report, said that nothing was happening, to which the master, Mr. Jones, replied: 'The liquid is rising in the tube'—but the boy persisted, 'No, sir, nothing is happening'; whereupon Mr. Jones grew red in the face, dashed across the little platform and boxed his ears. The liquid was certainly not rising in the tube, but we worried little. We knew that some Galileo or Galen had performed the experiment in the past, and if we could not make the answer come out correctly we were well aware that we ourselves were in the wrong."

Harvey, who demonstrated the function of veins and arteries, the true action of the heart and the circulation of the blood, had had his training at Padua, by paradox at once a great center of Aristotelian and Galenic learning and a focal point of the scientific revolution. Under



CIRCULATION OF THE BLOOD, in the discovery of William Harvey, was one of the great turning points in thought at the beginnings of modern science. Shown here is one of the illustrations from Harvey's anatomical exercises. If a finger is placed at L, and a second is slid upward toward N, the vein between will remain empty.

the rule of Venice, the "most successfully anti-clerical state in Europe," Padua enjoyed unusual freedom of thought. This attracted the ablest men of the time, who helped overthrow Aristotle by sharpening the process of criticism. Galen had posited only "a sort of ebb and flow" of the blood in the veins and arteries independently, a direct passage of air from the lungs to the heart, and a kind of seeping of the blood from the right side into the left ventricle through the thick dividing wall called the septum. As Butterfield points out, this was a complex doctrine of errors, not merely wrong in itself but a formidable barrier against physiological advance. Nonetheless Vesalius, da Vinci, Colombo, Cesalpino and Fabricius in their experiments and writings chipped away at the Galenic doctrines. Yet all this was "fumbling piecemeal progress," compared with Harvey's "masterly strategic strokes" which transformed the question forever. Harvey's work rested, as he said, not on books but on what he learned from dissection, observation and experiment. It had an "extraordinarily modern flavor as a result of the clearly mechanical nature of much of his inquiry and his argument; the importance that he gave to purely quantitative considerations; and the final cogency that he attributed to a piece of arithmetic." He spoke of the heart as "a piece of machinery in which though one wheel gives motion to another, yet all the wheels seem to move simultaneously." Here, then, even more than in contemporary progress toward the goal of reducing the universe to bare matter and motion, one touches upon "something like the genuine scientific revolution at last."

I can do no more than to mention a few of the other subjects considered by Butterfield. He discusses the linked roles of the experimental method and mathematics in furthering the evolution of scientific thought, the establishment of the theory of gravitation and of the clockwork universe. The works of Bacon and Descartes are viewed from a fresh and enlightening perspective; Bacon, it seems to me, comes off a little better than he deserves, though many modern historians undoubtedly have underestimated his influence. The *philosophe* movement, the work of Fontenelle in popularizing science, the transfer, in the time of Vauban and Sir William Petty, of the scientific method to politics, the proposal of the Abbé Saint-Pierre to establish a body of "scientific politicians" for planning purposes, the effects of John Locke's secularization of thought, the publication by Joseph Glanvill of the *Vanity of Dogmatizing*, with its insistence on the importance of skepticism in science and "the system of methodical doubt": all are among the topics considered in two of the most valuable chapters of Butterfield's excellent book.

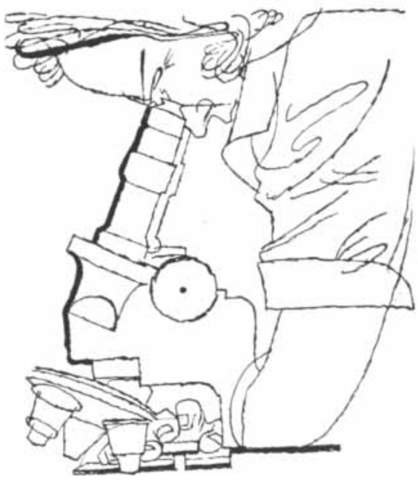
In his account of the effect of the scientific revolution on the nonmechanical sciences, *e.g.*, chemistry, he concedes there are difficulties in the way of discovering the actual state of things. One reason, among others, is that the historians of alchemy "seem to become tinctured with the kind of lunacy they set out to describe." A particularly sensitive passage concerns the many subtleties leading to "turns in the current of intellectual fashion." There are some who have tried to explain the scientific revolution as a "change in men's feeling for matter itself." The "scientific, the industrial and the agrarian revolutions," writes Butterfield, "form such a system of complex and interrelated changes, that in the lack of a microscopic examination we have to heap them all together as aspects of a general movement, which by the last quarter of the 17th century was palpably altering the face of the earth. The hazard consists not in putting all these things together and rolling them into one great bundle of complex change, but in thinking that we know how to disentangle them—what we see is the total intricate network of changes, and it is difficult to say that any one of these was the simple result of the scientific revolution itself."

There can be no question of the need for original thinking in this discipline, in order to furnish some glimpse at least of the forces at work in the growth of ideas. "Most people probably imagine," the English geneticist C. D. Darlington recently said, "that science advances like a steam roller, cracking its problems one by one with even and inexorable force. . . . Science [actually] advances as though by the pulling out of a drawer which gives on one side only to jam on the other." Butterfield's admirable book is the first, to my knowledge, to describe the peculiar, halting, complex, almost irrational dynamics of the evolution of rational scientific thought.

COURTSHIP AND MARRIAGE: A STUDY IN SOCIAL RELATIONSHIPS, by Francis E. Merrill. William Sloane Associates ($3.75). A sociological consideration of roles in marriage, dating and courtship. Dr. Merrill wrote his book primarily for the college student, and, although it contains no advice for the lovelorn, it analyzes the various social functions of courtship and marriage and stresses some of their consequences for the individual. Dr. Merrill believes that romantic love hinders marital adjustment, and the attitude of his book is well summarized in a remark made by La Rochefoucauld: "There are happy marriages, but there are no delicious ones."

CHILDREN IN CONFLICT, by Madeleine L. Rambert. International Universities Press, Inc. ($3.25). An unusually interesting and detailed account of child psychoanalysis: its goals, limitations and dynamics. Mlle. Rambert explains the process of reorganizing a child's inner life so that he may live in the complicated world of family, friends and school without terror and with the self-respect, spontaneity and satisfaction that is his birthright. She describes her use of puppets, stories, drawings and dreams in therapy. She defines the essential difference between child and adult analysis, the meaning of transference to the child, the role of re-education and the part the parent plays in the therapy. Her unique contribution is her therapeutic use of puppets and masks. Mlle. Rambert's realistic point of view, her creativeness, her sense of humor and her sincerity shine through the awkwardness of the translation.

THE LIFE OF GEORGE BERKELEY, BISHOP OF CLOYNE, by A. A. Luce. Thomas Nelson and Sons Ltd., Edinburgh ($4.00). An interesting and scholarly biography of the famous Irish philosopher whose doctrines are perhaps less well remembered than the attempt



of Samuel Johnson to refute them by kicking at a stone. The 18th-century Lord Bishop of Cloyne based his philosophy of immaterialism on the argument that the "absolute existence" of sensible things is a meaningless phrase, since the term existence when applied to sensible things necessarily implies a relation to perception. To critics and scoffers he replied: "My aim is truth; my reasons I have given. Confute them if you can; but think not to overbear me with either authorities or harsh words." Dr. Luce ably and devotedly describes the full life of this many-sided, practical and prophetic man: his work as a metaphysician, social philosopher, scientist and theologian; his ill-fated project to found a university in Bermuda; his two-and-a-half-year visit to America, during which he made generous gifts to Harvard and Yale; his patient maneuvers to find a patron and to win advancement; his Continental tours and his adventures with the London wits; his activities in Irish politics; his advocacy of tar-water as a universal medicament; his brilliant achievements as a critic and essayist. His only known serious poem contains the famous line: "Westward the course of empire takes its way," often ascribed to some such modern and militant poet as Rudyard Kipling.

FROM EUCLID TO EDDINGTON, by Sir Edmund Whittaker. Cambridge University Press ($3.75). Whatever comes from the pen of Sir Edmund Whittaker is distinguished for its clarity and elegance. His 1947 Tarner Lectures do not disappoint this expectation. He discusses with a minimum of mathematical paraphernalia—though he presupposes a good deal of background on the reader's part—various interpretations of the external world, including those of classical physics, relativity and quantum mechanics; he compares modern with earlier attempts to formulate a unified world view. One of the most absorbing and broadly accessible lectures is that which deals with the fascinating contributions to cosmology made by the late Sir Arthur Eddington. The one shortcoming of this survey is that Whittaker leaves many interpretive points undeveloped and fails to set out the philosophical standpoint from which his own appraisals have been made.

AN ECONOMIC GEOGRAPHY OF GREAT BRITAIN, by Wilfred Smith. E. P. Dutton and Co. ($7.75). A comprehensive handbook by the Senior Lecturer in Geography at the University of Liverpool, covering the agriculture, industry, transport and trade of England, Wales and Scotland. The first part deals with the transformation of the medieval into the modern economy; the second carries only to the beginning of the Second World War, although a few data from later years have been added. Useful for an understanding of the long-term trends of Britain's economy.

PHENOMENA, ATOMS AND MOLECULES, by Irving Langmuir. Philosophical Library ($10.00). Of the 436 pages of this book, 404 are devoted to 20 of Dr. Langmuir's research papers. The rest are given over to three brief essays of general interest, on the philosophy of science, on science legislation and on the international control of atomic energy. Dr. Langmuir is a noted experimenter, and beyond that a man of thoughtful and always independent social and philosophical opinions. A more representative sample of his views in the general category would have been particularly welcome; instead this collection of some of his technical reprints will have only a limited appeal, further curtailed by the preposterously high price the publishers ask.

INTRODUCTION TO MATHEMATICS, by H. R. Cooley, D. Gans, M. Kline and H. E. Wahlert. Houghton Mifflin Company ($4.25). This second edition deserves notice as a superior freshman college text, especially in its many-sided exposition of the relation of mathematical ideas to other fields of knowledge. The edition has been entirely rewritten but the attractive features of the original have been preserved and extended. Recommended no less for the common reader with a taste for mathematics and philosophy than for the college student interested in a one-year general survey of the subject.

A NEW DICTIONARY OF CHEMISTRY, by Stephen Miall and L. Mackenzie Miall. Longmans, Green and Company ($12.00). The second edition, with corrections and new materials added, of a handy reference work that explains chemical terms, gives clear, brief accounts of many chemical substances, and biographical notes about leading chemists of the past and present. A useful book not only for students of chemistry but for a wider circle of related professions.

THE GEOLOGY OF THE BRITISH EMPIRE, by F. R. C. Reed. Longmans, Green and Company ($14.00). The second edition of a scholarly survey, based on notes of the author's lectures at Cambridge, containing a wealth of geological information about various parts of the British Empire, including the Mediterranean area, the Sudan, East, West and South Africa, the West Indies, Canada, Burma, Ceylon, India, Australia and New Zealand (but not including the geology of the British Isles). Indispensable for advanced students and others engaged in economic, paleontological and petrographic research. Maps, tables and extensive bibliographies.

CLIMATOLOGY, by W. G. Kendrew. Oxford University Press ($7.50). The third edition of the well-known book *Climate*. This is a clearly written study of general purpose, dealing with the important features of climate, the regional distribution and the daily variations of the weather all over the world. Climatology differs from meteorology in its emphasis on the facts of the earth's climate and its effects on plants, animals and economic development rather than on the physical processes which go on in the atmosphere. Illustrated by excellent photographs.

LANDSCAPE, by C. A. Cotton. John Wiley & Sons, Inc. ($10.00). A second edition, enlarged and rewritten, of an authoritative work—the first volume of a trilogy—describing the effects of normal erosion in shaping the earth's contours. A book primarily for specialists but one that unfolds a remarkable story which the general reader, if sufficiently interested, should be able to follow. Numerous photographs and diagrams.

THE AMATEUR ASTRONOMER

Conducted by Albert G. Ingalls

At first glance the telescope shown on the opposite page might appear to have a Springfield mounting, a type invented by the late Russell W. Porter and named after his native Springfield, Vt. A closer inspection of the illustrations will reveal that the mounting is a simplification of the Springfield. To gain portability the Springfield's fixed eyepiece with its second reflection feature is omitted. The base casting is also reduced to about four inches in diameter and made to overhang the pedestal.

This compromise mounting was devised and built by A. D. Johnson of the Minneapolis Astronomy Club, who explains that "the base overhangs the north side of the pedestal in order to permit following a star through the zenith without the tube's encountering the post. This avoids the wearisome necessity of shifting it to the other side; it is the old and familiar bent pier.

"Much of this mounting," Johnson continues, "has been copied from the Springfield, but the declination screw rides on the tube saddle where it is always handy. The castings were made in my basement. With a crucible, a bucket of molding sand, a little parting sand from a foundry supplier and a book from the public library, I went to work on the adjunct hobby of making patterns and molds and melting scrap aluminum in the furnace. Casting parts, rather than sawing and filing them out of solid stock, proved to be not only very convenient but also a lot of fun."

The technique of molding and casting telescope parts is described in *Amateur Telescope Making—Advanced* and in a chapter by Roger Hayward, the Pasadena architect, amateur telescope maker and illustrator of this department, in *Procedures in Experimental Physics,* by John Strong and others.

"The saddle that fits the telescope tube was cast hollow," says Johnson, "with the ends straight across, and these ends were then cut to fit the tube. The counterweight arm has seven-inch horns that were welded to each other and to their extension by a blacksmith."

Asked whether his patterns are available for loan to other amateurs, Johnson replied that "they are pretty well beat up, since at least 50 amateurs in and around the Twin Cities have had castings made from them."

An uncoated piece of flat glass could be used as the diagonal mirror in a telescope, but only five per cent of the light would reach the eyepiece. However, in observing one star—the sun—it becomes necessary to throw out nearly all of a great excess of light. The piece of glass would accomplish this purpose, but it would produce a second image of the sun, not so bright as the main image and displaced from it due to back reflection from the inside of the rear surface of the glass. To solve this problem the younger Herschel, Sir John, tilted the rear face about 10 degrees to throw this back reflection out of the visual field. The result is called the Herschel wedge.

"My Herschel wedge," Johnson writes, "has proved to be a useful instrument for observing sunspots, the moon (except in its less dazzling first quarter) and Venus. The reduced light is easy on the eye, yet the reduction is accomplished without masking the outer parts of the mirror and reducing its resolving power or masking all except an outer ring and increasing diffraction. I altered the eyepiece adapter of my telescope to include a lateral outlet for insertion of the wedge unit (*cutaway drawing on page 62*) but found that on a refractor it was difficult in some positions to place the eye at the eyepiece." A better arrangement proved to be the one in the drawing on page 63.

Johnson has equipped both diagonals and wedges with holders having bayonet fastenings, and states with enthusiasm that these always go back to perfect adjustment when changed.

Probably all amateur telescope users carry about with them, often for years, unsolved puzzles in the bottomless science of optics. They read articles and optical books. They ponder, study, experiment, discuss their problems with a fellow-sufferer, if they are fortunate enough to have one available. They read the same book 20 times. They pin down its language word by word and compare it with related fragments in other books. They wish the books would not merely state facts but would also point out which "facts" are false.

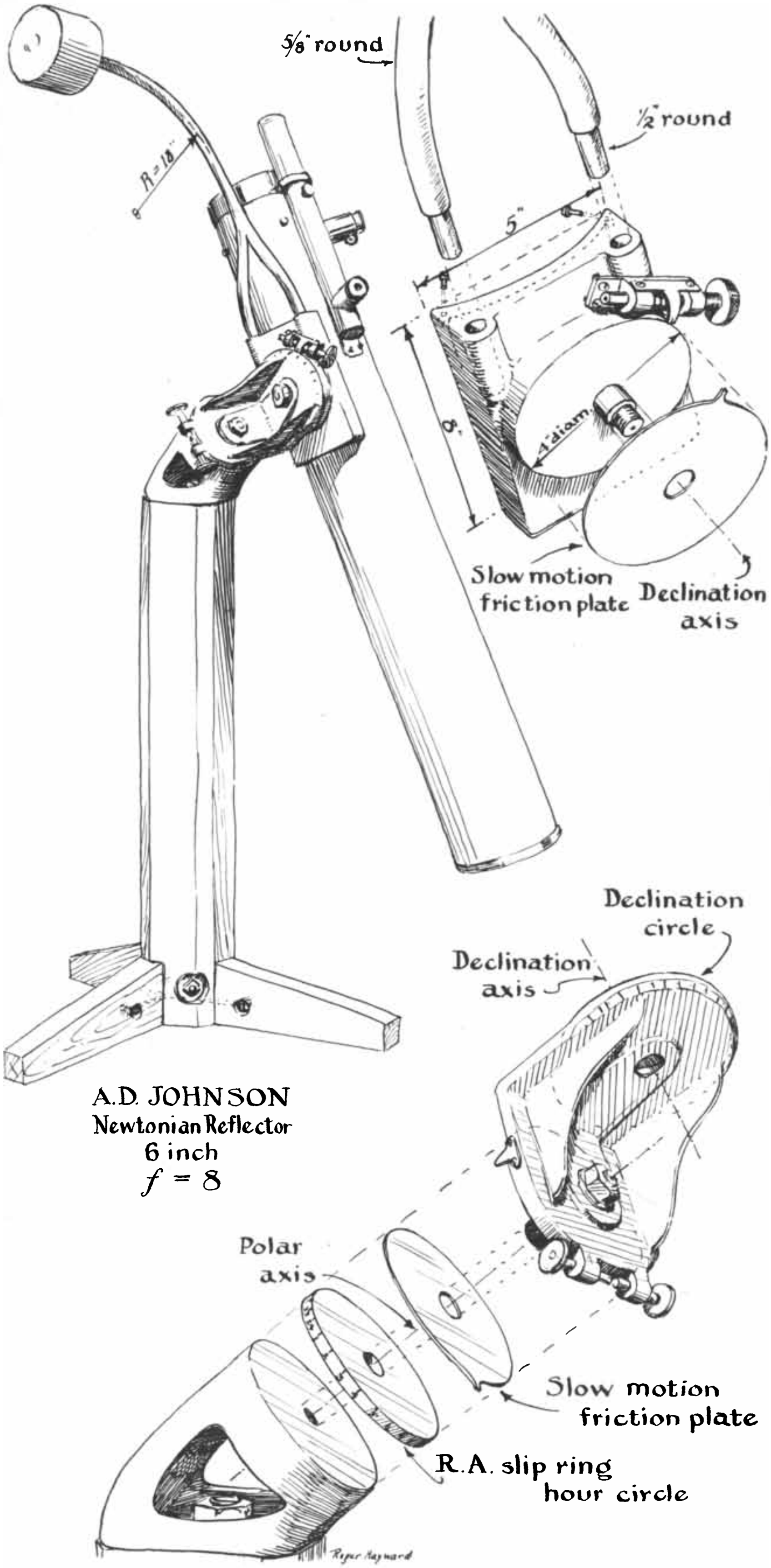
Yet persistently from time to time new insights arrive, often suddenly. Blank walls fall down, and one day that particular puzzle is put down as solved. Then is the time for the worker to write about it for the benefit of others—not years later when he has become expert and his recollection of the struggle has blurred. This is what David Rosebrugh of Waterbury, Conn., past president of the American Association of Variable Star Observers, has done by request after three years of groping with the language of standard treatises—specifically Louis Bell's *The Telescope* and H. Dennis Taylor's *The Adjustment and Testing of Telescope Objectives*—on the subject of testing refractor objectives while testing three such lenses. If what Rosebrugh has written fails to impress the expert as containing anything not already in these books, it may be that the expert unconsciously projects what he already knows into what he reads. Anyway, in commenting on his own note Rosebrugh rightly states that "if I had had it when I started studying in preparation for testing my objectives I would have found the whole subject vastly easier than I did." The note follows:

"Full instructions for testing a refractor objective assembled in a telescope can be found in standard works and, for those who are used to testing mirrors and complete reflecting telescopes, the reasons for most of the standard tests made on refracting telescopes are immediately apparent. For example, the necessity of aligning the optical axis of the objective with the mechanical axis of the telescope is obvious. Beyond a certain point, however, the testing of an objective diverges from that of a mirror. Once the reasons for this divergence are clear the reflector man will have no trouble in understanding the testing of an objective. This note will therefore be devoted to clarifying the one fundamental difference between testing a refractor and a reflector.

"A natural question that arises in the mind of the reflector expert is, 'Why cannot one test an objective by means of the Foucault knife-edge test?' The answer is that one could if one could secure parallel, monochromatic light (light of a single hue or wavelength).

"It is easy enough to secure parallel light, either from a reflector set up to act as a searchlight, or from a star, or by autocollimation with an optical flat. But it is difficult to secure monochromatic light, whether from a light source or from high-quality photographic filters. Light filters pass quite a mixture of light, as spectroscopic examination will show.

"Moreover, as an objective cannot be made fully achromatic like a mirror, even a test of an objective with parallel monochromatic light will not tell the full story, as it would with a paraboloidal mirror. In practice, for visual use, objectives are designed to focus the greenish-yellow



The Johnson portable semi-Springfield reflecting telescope light of about 5,500-6,000 Angstroms, which is what the eye sees best, but to throw away the red and blue rays, to which the eye is less sensitive, and which in any case cannot be focused if the greenish-yellow light is in focus.

"The method of throwing away the red and blue rays is to have them come to a focus farther away from the objective than the greenish-yellow rays. Thus if the telescope is correctly focused for greenish-yellow rays, the red and blue rays are thrown into the discard by being out of focus. In a well-designed $f/15$ refractor they will not come to a focus until the eyepiece is moved away from the objective a distance usually about 1/2,000 the focal length of the objective. At this point the greenish-yellow rays in turn are entirely out of focus.

"If the blue light is thrown away to the same distance as the red light, the objective is considered fully corrected. However, the skilled makers have found that it is better to overcorrect an objective, which means focusing the blue light at a point even farther than the red light.

"The fact that a mirror brings rays of all colors to the same focus, *i.e.*, is achromatic, while a visual objective brings only the greenish-yellow light to a usable focus, is the key to the one fundamental divergence between testing a mirror and an objective.

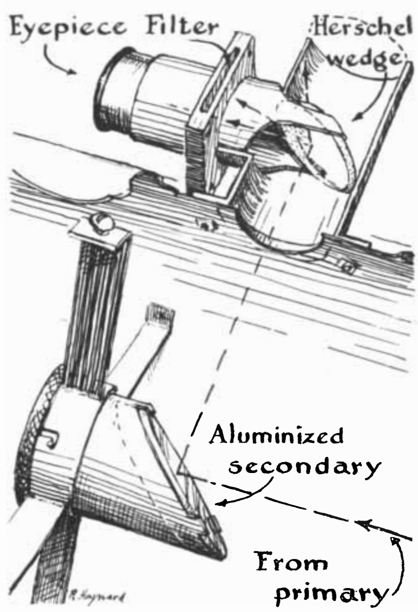
"In practice it is hardly worth while for the amateur to attempt to use the knife-edge test on an objective lens, though if a yellow-green filter is placed near the focus and Jupiter or a yellowish-white star is used as a source of parallel rays, one can make a knife-edge test on an objective which will show fairly well whether it dims equally all over, like a spherical mirror at center of curvature or a paraboloidal mirror when tested with parallel light. If the objective dims equally all over it is reasonably free from zones and has good spherical correction; that is, the rays that pass through its center focus at the same point as those that pass through the outer zone.

"However, a better test for zones and spherical correction is to look at a suitable star such as Polaris and use a high-power eyepiece covered with a yellow-green filter. Simply throw the image out of focus in both directions, and examine the resulting concentric rings by eye for irregularities that might indicate zones or spherical aberration. The interpretation is fully covered in standard works.

"This method of testing appears to be about as delicate as the knife-edge test is for a mirror, and on an objective it is more delicate because of the mixture of colors of varying focal length passed by even the best yellow-green photographic filter.

"This simple test still leaves the problem of whether the objective is properly corrected for color. The test for color correction can be made in the same manner as for spherical correction and zones, but omitting the filter. Focus on the star and then rack the eyepiece away from the objective, that is, outside the greenish-yellow focus. As the eyepiece is moved outward it is possible to detect the point at which the red rays come to a focus. This appears as a little red spot in the center of the out-of-focus image of Polaris. With less certainty the point still farther outside the yellow-green focus at which the blue rays come to a focus may be detected. If it is not detectable its location can be deduced from the appearance of the blended blue and red light in the middle zone of the star's out-of-focus image.

"The nature of these tests and the interpretation of what is seen are given in standard works, but the reasons why the



Herschel wedge: less desirable

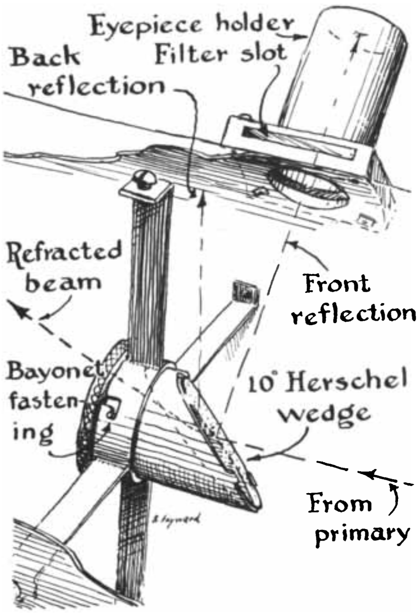
out-of-focus eyepiece tests are better in general than any attempt to make knife-edge tests on an objective are as stated above.

"The tests suggested in standard works for detecting striae and possible internal strains in the glass of an objective are easily understood and require no elaboration here."

The comprehensive testing of an objective lens would require tests for spherical aberration, both axial and lateral, axial and lateral achromatism, astigmatism, coma and perfection of workmanship, and would best be done on an optical bench. Statement of criteria would be included, and the tester would need enough experience to judge what he sees in comparison with a nearly perfect objective. However, in the preceding note by Rosebrugh the practical aim has been to help the average isolated worker to make a fairly good test, using the resources that he has. It is also aimed at destroying the widespread belief that a flat, shadowless cutoff in the autocollimation test is sufficient to attach a seal of quality to an objective lens, since this criterion applies to spherical aberration alone.

FEW faults of a telescope mirror are so injurious to image definition as the one called turned-down edge. Somehow during grinding or polishing a ring-shaped zone extending inward from the edge for a distance between a hair-width and almost an inch acquires a longer radius of curvature than the rest of the mirror. Enough has been written about detecting turned-down edge, or "TDE," but not enough about different methods of dealing with it.

An isolated amateur who appealed to this department for help in dealing with



Herschel wedge: more desirable

a compound case of TDE and overdeepened center was told that both ills might disappear if a hard lap were substituted for pitch that was possibly too soft. The appeal was then passed along to Albert H. Johns of Larchmont, N. Y., an advanced amateur and part-time professional, who added the following comments to the reply:

"Over a period of years I've seen hundreds of mirrors ultimately become first-class jobs simply through trial and error. There are so many variables that it is impossible to evaluate them one by one. For example, you can not precisely describe the quality of your lap under the exact conditions of operation. Your trouble most probably is too soft a lap, but maybe we couldn't be more wrong. The best I can do is to give you an outline of the way I would go about correcting your troubles.

"The most important factor is the hardness of the lap. Remember that the correct hardness for one day may be way off on a colder or hotter day. I do not use fancy mixtures of pitch with oil, wax and turpentine but only reasonably soft pitch mixed with rosin to bring it to the desired hardness for a 70- to 75-degree temperature, two parts pitch to one part rosin. Extra rosin gives greater hardness. Use rouge or cerium sparingly.

"Always keep the lap beveled to $\frac{1}{8}$- to $\frac{3}{8}$-inch less diameter than the mirror. In any rare instances when turned-up edge appears, allow the pitch to flow out to full diameter—but watch out lest the edge become turned down. Avoid short strokes such as you describe.

"All the above is for polishing. To correct the TDE lay waxed paper around the edges of the lap. Press for a few minutes in width slightly less than the TDE with mirror plus weights, remove the paper and calmly proceed to apply one-third strokes. Under no circumstances dunk or wash the mirror or tool after pressing and before working.

"Instead of using paper strips for depressing the edge of the lap one might scarify the edge with scratches, but these are too permanent and may cause turned-up edge through not filling in soon enough.

"Another way to arrange the paper for depressing the lap temporarily is to cut out a ring having the same internal diameter as the turned-down edge zone and serrate its inner edge with broad notches that leave teeth projecting from the mirror's edge into and just across the turned-down zone. Do not try to make these teeth uniform, since repetition may cause zones. Press this notched ring into the lap as described, remove it and go to work.

"The overdeepened center may be brought up with a paper star pressed into the center of the lap. In fact, the two zones, edge and center, may be treated as above simultaneously. After the zones have been raised, press for a longer period to eliminate the depressions in the pitch before resuming work.

"The most powerful method I have found for mirror correction in general is the zigzag stroke described for grinding by Everest in *Amateur Telescope Making—Advanced,* page 35, figure 30. This stroke blends out zones like nothing else on earth. By suitable distribution of the zigzag stroke one may continue right on up to full paraboloid, move the crest in or out as desired, and never be bothered with rings."

The editor of this department once learned a point by getting mad. After working interminably with tiny, fussy strokes to eliminate a hyperbola plus a TDE, a long deep scratch occurred. Since precision work would now not matter for many hours, the mirror was given an angry spell of longer-than-one-third strokes to teach it a lesson for getting itself scratched. Lo, the TDE and hyperbola both vanished. (P.S. The scratch didn't.)

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Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful. The lists are not intended as bibliographies of source material for the articles. The references selected will provide supplementary information.

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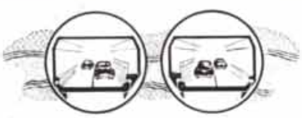

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