SCIENCE

VOL. 75 | FRIDAY, APRIL 1, 1932 | No. 1944

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SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal

Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

THE PRESENT STATE OF THE NATURAL SCIENCES[1]

By Professor ALFRED STOCK

DIRECTOR OF THE CHEMICAL INSTITUTE, TECHNISCHE HOCHSCHULE, KARLSRUHE, NON-RESIDENT LECTURER IN CHEMISTRY AT CORNELL UNIVERSITY ON THE GEORGE FISHER BAKER FOUNDATION

IN inaugurating the series of lectures which I am to give at Ithaca during the following months, my first thought is to express to Cornell University and to my colleagues in the department of chemistry, at whose head stands my friend Dennis, my sincere appreciation of their invitation to come to the university for this term under the George Fisher Baker Foundation. It is a great pleasure and honor to me to have the privilege of spending a few months with my American colleagues and personally to become acquainted with the country which to-day plays a leading part in the world in technical and economic achievement, and in which scientific work has a more assured position than in any other land.

This residence in Ithaca will for me be quite a decided change from my usual habits of life and it will afford me a desired opportunity of making a quiet survey of the present state of natural sciences and technology which to-day is nothing but applied and utilized natural science.

Is one justified in saying that we are now confronted with a crisis in the progress of the exact sciences and technology, a statement that is often heard or read in these days at least in our disrupted Europe? Are the exact sciences really unable to penetrate to the depths of human understanding? Will technology become the scourge of mankind, will it lead to the destruction of our economic life, to the embitterment of the soul? Does salvation lie in recourse to metaphysics or to philosophy?

Natural science, in the modern meaning of the term,

1 Introductory public lecture.

is but a few hundred years old, although in ancient days there were some very significant technical achievements such as those wonders of the world, the pyramids of the Pharaohs, and a developed technology in ceramics, dyeing and tanning. Astronomy was studied zealously, although chiefly from the astrological side. The alchemy of the middle ages led to the discovery of no small number of chemical facts. But natural science, as we understand it to-day, in which research is carried out not only for practical ends but for its own sake in order to create a well-rounded concept of nature, was developed only on the threshold of modern times. A fresh strong breeze swept through the world and tore down the webs of the Scholastics. Humanism and reformation rendered men's minds receptive to new thoughts and new objectives. The natural sciences devised for their use the instruments without which it was impossible to carry on exact investigation—the clock, the barometer, the thermometer, the telescope, the microscope, the air-pump and many other devices. Men braved the dangers of the sea and gained a knowledge of our earth. Great minds solved the secrets of planetary motion and brought the earth to the modest position that it now occupies in the universe. The alchemical groping among the mysteries of nature was replaced by scientific study, and the invention of printing gave wings to the interchange of thought. Academies of science were founded, and one after another the fields of natural science rose from mere description and empiricism to the discovery and application of mathematically formulated laws. Astronomy and physics were the first to develop. Chemistry and biology followed more slowly. The miracle came to pass that mathematics, apparently the most abstract field of human meditation, proved to be an incomparable aid in the natural sciences and in technology.

The past century brought an astonishing development in scientific and technical methods. While in the past progress had been restricted to a few illustrious leaders, there now arose armies of scientific and technical pioneers equipped with elaborate experimental and theoretical aids. With almost the same methods all civilized countries are now carrying forward scientific research, and while at times there flashes forth the brilliant success of an individual, it is probable that the discovery might eventually have been achieved through the methodical, although slower progress of the many, as Professor Desch also pointed out in his recent lecture here. The leader shows the path and the scientific laborers and builders follow in his footsteps, and there quickly springs up a new settlement where a short time ago there was a trackless desert.

This mass production, however, gives rise to many a difficulty. Scientific and technical literature has increased at such a rate as to be terrifying, and it is difficult to keep in touch with all that has been written even within a limited field. It is almost impossible for scientific journals and works of reference to do justice to their subjects. We look forward to the future with anxiety. Things can not be allowed to go on at this pace. Greater restraint is needed, both in the scope of the work and in publishing. This applies also to the excessive number of conventions and congresses, where often the same questions are discussed over and over again.

On the other hand, however, this great activity and research since the beginning of the present century has led to most remarkable progress in science and technology, as has never before been the case in such a short period. In describing some of the fruits of this time, the present speaker can of course only give a few examples chosen at random.

Physics, through x-ray optics and the more recent electron optics, has greatly extended the earlier field that embraced only visible light and the immediately related field of radiation. The possibilities of these optical methods (in the widest sense of the word) are truly miraculous. They bring us information of what is going on in the most remote sections of the universe, as well as in the interior of the minute chemical atoms; they disclose to us the existence of chemical compounds so short-lived that we can not hope ever to be able to grasp and keep them; they enable us to determine magnitudes that at first seem to have nothing at all to do with optics, as, for example, the measurement of chemical forces.

Electricity has broadened its foundations through the investigation of electrons, which one may regard as the atoms of negative electricity. Every one who enjoys a radio apparatus has some realization of the significance of the discovery and utilization of long-wave electromagnetic rays. Somewhat less comprehensible to lay minds are the equally recent changes in the theoretical concepts of the physicists. Probably the greatest accomplishment in natural science since the days of Copernicus and Newton is the creation of the quantum theory, according to which energy is emitted and received in definite individual portions, or "quanta"-wise, just as the chemical elements occur "atom"-wise. The theory of relativity gave rise among laymen to an unnecessary and excited criticism of their traditional concept of time. Upon the new so-called "wave-mechanics" is based the latest theory of the nature of the atom. The former independence from each other of "mass" and "energy" has now been converted into a mutual relationship. The naïve mechanistic picture of the universe became a victim of these revolutions in our physical concepts, and physics was plunged into a battle of theories and interpretations that still rages. The old uncertainty as to the wave or corpuscular nature of radiant energy was revived. Since it has been shown in America that, even at the high translatory velocity of the earth, the "ether wind" has no effect on the velocity of light, the conflict concerning the nature and even the existence of the universal ether has broken out anew. In fact, one even hears doubts as to whether the law of causality, that rigid connection between cause and effect, extends to and rules the field of the atom's microcosm. Natural science lost one of its most important supports and methods of reasoning when the law of causality was revoked. The present speaker holds with those investigators who assume that the law of causality governs the field of the infinitely minute, and that only our methods of observation and measurement are still too coarse to enable us accurately to trace the causes and the effects of these phenomena. Even the skeptics hold that under all circumstances "statistical causality" continues to be, in the ordinary physical world at any rate, the average result of a statistical plurality.

Modern physics appears to withdraw more and more into the higher sphere of mathematics, and mathematics advances to meet it by devising new mathematical methods.

Nearly all the other branches of natural science have been swept along with the tempestuous developments in physics. At many points we see incisive progress and a breaking away from the older views.

Similar fundamental changes are also apparent in astronomy, the oldest of our sciences. It has greatly expanded its concepts of the universe, employing that much-abused term in its true sense. To-day it looks far beyond our own solar and galactic systems into the most distant realms of universal space. The fixed stars became the object of precise research concerning their chemical composition, magnitude, density, temperature and also their movements. We find many giant stars being assigned densities as low as that of the earth's atmosphere, while in the case of other stars a tremendous mass concentration must be assumed. For example, a dark companion of Sirius is supposed to possess a density of 50,000. Through modern ideas concerning atomic conversion and the transition between matter and energy the balance of astronomic energy has received a wholly new explanation. That slight shift in wave-length, due to the relative motion of light-source and observer which we call the Doppler effect, has revealed to us the relative movements in the universe. By its aid we have recognized centers of motion, and have determined some apparently fantastic velocities up to 12,000 kilometers per second. It can here be mentioned that through researches in the physics of electrons it has recently been possible to solve the problem of the earth's aurora borealis and to show that it is an electronic phenomenon caused by the earth's magnetism.

Chemical research has profited particularly from the progress of modern physics. Spectrum analysis, the quantum and the electron theories, together with "wave mechanics," have enabled the chemist to draw up such a picture of the chemical atom as was never dreamed of a few decades ago when it was considered to be a rigid, unchangeable object. Owing to our modern concepts of the atom with its positively charged nucleus surrounded by electrons, it is possible to explain a multitude of apparently unrelated phenomena, such as the spectra characteristic of the individual elements, "ionization" or the occurrence of electrically charged atoms, the possible "activation" of elements by light, electricity and the like, the chemical similarity of certain elements as expressed in the periodic system, atomic disintegration in the radioactive elements and the remarkable phenomena that accompany it, and the existence of isotopes which behave alike chemically, although having different atomic weights. In the "mass spectrograph" we have a surprisingly simple and accurate mean for determining the atomic weight of isotopes.

Reaction velocities, heretofore one of the least understood fields of chemistry, have been opened up for study by these new ideas. As Haber has expressed it, "We have now gained a first impression of the actual nature of the play staged by chemical processes, where before as Schönbein put it, we have known only what happens before the curtain rises and remains when it has fallen." Evidently here the leading parts are played by the activation of the atoms and the "chain reactions" induced by the energy developed in reactions between individual atoms. Band spectra have enabled us to detect the transitory existence of unusual compounds such as hydroxyl and have thus supplied us with an explanation of many hitherto obscure reactions. Great progress has also been made in our knowledge of the special forces acting on a particle on the surface of a substance, where, contrary to the conditions in its interior, there is no longer that uniform effect due to neighboring surrounding particles. This knowledge has illuminated the once dark and obscure fields of colloid chemistry, adsorption phenomena, contact effects and catalysts.

Nor has classic preparative chemistry been inactive. Among its many remarkable successes during recent years one may mention the preparation of substances of vital importance to the human organism, such as adrenaline from the suprarenal glands, insulin from the pancreatic gland, thyroxine from the thyroid and the vitamins C and D in crystallized form.

Mineralogy has gained a deeper insight of its subject, and to-day directs its attention more to the nature and the arrangement of the smallest structural elements of the crystal lattice than to the external form of the crystal. Our new knowledge concerning radioactivity and the tremendous energy developed by the disintegrating atom has helped geology to secure an essentially different and better founded idea of the nature of vulcanism. The distribution of the chemical elements throughout the various zones of the earth's interior is also much more clearly understood.

Biology is occupied less and less with morphological reasoning and treats biological phenomena as the results of physical and chemical processes. This has made it possible to explain the functioning of the muscles as being relatively simple chemical reactions. The investigation of the hormones, regulators of the most diverse functions of the organism, has made great progress. To mention but a single example: By the aid of the sex hormones, obtained from urine and other substances, it is now possible to direct the development of the individual at will, towards either the female or the male side. One almost shudders in contemplating the fearful power and responsibility thus placed in the hands of the chemist and of the physician.

Enzyme research has shown sound progress. These bodies which in such minute quantities play a wonderful part in the chemical economy of our bodies, in the assimilation of our food and the building up of the body material, have not as yet been isolated in the pure state nor even synthesized. Nevertheless, extensive progress has been made along this path. Methods of purification, concentration and separation have been further perfected by original adsorption methods avoiding chemical changes.

The theory of heredity has opened up a new chapter of great practical significance. Simple regularities, some of which were discovered long ago, have proved to be of fundamental importance for every kind of heredity, in plants, in animals and even in man, as shown, for instance, in the study of hereditary hemophilia. A tremendous amount of observational material about regular and disturbed heredity or mutations, such as can be induced by x-rays, for example, has been investigated. One species of fly, *Drosophila melanogaster,* has attained fame through the service rendered to science by many hundreds of its generations and 20 million of individual specimens. We have come to recognize that the so-called "chromosomes" are the bearers of heredity in the cell, and the study of their mutual effects has revealed the laws of heredity. Agriculture has already begun to profit from these achievements of biological science.

Progress in healing, due to the achievements of the natural sciences, has already brought marked lengthening of our span of life. In civilized countries this period has almost doubled during recent years. Whether this prolongation is an unmixed blessing for the inhabitants of this globe—under modern economic conditions at least—is an open question. Another wonderful biological discovery is that of the so-called "mitogenetic" rays, a radiation of an ultraviolet nature that arises during biological processes, as, for instance, the growth of onion roots or the development of tadpoles. Although these rays are as yet not wholly understood, they are expected to solve biological problems, such as those of cell division. Perhaps this discovery constitutes the first step into a field, so far scarcely considered, that may prove of special importance for human life: the influence of electron processes, the activation of molecules, the effect of radiations and electrical charges on the living organism.

Applied science—technology—at first followed pure science with halting steps, but to-day it frequently points out the way to new and valuable lines of research. When one recalls that the steam engine was invented hardly more than one hundred years ago, the railroad began its service, and cotton came into use as a textile fiber, we seem to be dreaming when we think of the modern achievements of technical science, such as the vast railroad net covering the face of the globe, the miracles of engineering, the progress in electricity, aviation and wireless telegraphy, and the multiplied yield of the soil. Science is tireless in its efforts to advance technology still further, to furnish it with the most suitable material for every purpose, to make it independent of natural raw materials, to open up new sources of power and to simplify and cheapen its work. To-day industry clearly understands the great value of scientific research, and it not only has given valuable aid to university investigation but has also established excellently equipped research laboratories of its own.

The same efforts towards unification that characterize science and technology are wiping out the boundaries between the different natural sciences. This fact strongly characterizes the more recent developments. Astronomy, physics, chemistry, mineralogy, geology and biology are all merging more and more into one science of nature which everywhere is working with similar experimental and theoretical mathematical means. Physics and chemistry have already become more or less identical.

Even "exact" science and "metaphysical" or mental science bear witness to this modern tendency toward amalgamation. Very significant of this fact was a recent meeting at Prague of physicists, philosophers and mathematicians for mutual interchange of ideas and for general discussions. This being a first attempt, it was not easy to find a common basis of understanding and agreement. But do the different philosophical schools understand one another? It is undeniable that philosophy has already been strongly influenced by modern research in natural science. This influence increases the more, the further the individual branches of natural science progress toward an all-embracing theory of nature. To-day wide circles of philosophers no longer consider their objective as "systems" and philosophical "images of the universe," but a gradual advance in knowledge confirmed by the natural sciences. Thus philosophy becomes the forerunner and the guide for natural science. Driesch has written: "The philosopher reflects upon what is possible in those fields not yet wholly understood, and that means almost all of them, and submits his results to the investigator for decision. In exchange he continually receives from the investigator new material needing reflection and discussion." According to Russell, philosophy, as well as every other line of research, strives first after knowledge; as soon as final knowledge has been secured in any field, then that is no longer called "philosophy" but becomes an individual science. Formerly the investigation of heavenly phenomena, now called astronomy, was treated as a part of philosophy. More recently the study of the human soul was separated from philosophy and became psychology. "In philosophy," writes Carnap, "we experience the drama, depressing to scientific minds, of seeing a plurality of incompatible philosophic systems being erected one after the other and side by side." Von Mises says: "In aim, subject and method there is only *one* science, namely, the reconstruction of the world through concepts. The division of this science into two parts, into 'mental' and 'natural' sciences is only of a practical and transitory significance, it is not systematic and final." According to Spengler, "the unconscious longing of every true science is directed towards understanding, penetrating and embracing the universe as a whole." Driesch says: "No man is possessed of the pure *will to know,* independent of any practical considerations, to such a degree as the student of nature." Here we have philosophers and mathematicians testifying how far the natural and mental sciences have progressed toward mutual understanding.

Technology also seeks to get into touch with the mental sciences, having wearied of "mechanism," "rationalism," "materialism," or whatever other, once highly esteemed but now much abused, names may be applied to the pursuit of the purely technical. It examines with a critical eye its position within the totality of life and tries to find its place in human culture and economics. An American industrial leader coined the term "human engineering": Technology has to consider the human dignity of labor and how to smooth out the conflict between capital and labor. In the future, successful industrial work will depend more on the handling of men than on the improvement of machines. Plank foresees the development of a "meta-technology" as "the totality of technical economic thought and work, surpassing the limits of that which is based merely on reason and which is expressible in formulas and symbols."

This picture of the present state of the natural sciences, which, on account of the magnitude of the subject and the short time at the speaker's disposal, can be no more than an incomplete sketch, will show the overwhelming life force animating pure and applied natural sciences. There is no hint of weakening, of stopping or of that resignation expressed in Du Bois-Reymond's "Ignorabimus." All along the line there is a strenuous, often a revolutionary struggle for progress, a tendency to clear up contradictions, to unify our ideas regarding nature and the universe, a complete belief in the "possibility of unveiling the truth" and in the existence of "an eternal order that rules the world" (Planck).

Much has been done in the past, more remains to be accomplished. The student of nature should still be as modest as Newton, who said of himself that he seemed to be like a child playing with pebbles on the shore while before him stretches the infinite ocean of the unknown. Although no field of natural science is lacking in vastly important unsolved problems, their outlines are recognizable; and no one knows what lies hidden in the obscurity of the future. If Archimedes escapes death by the rough hand of the soldier, the natural sciences may long continue their triumphant march.

In Ostwald's pyramid of the sciences, sociology stands on the apex. It may be counted as one of the natural sciences, but its subject is the most complicated and incomputable of all natural products. The highest problem for the scientific mind to solve will be—how to free mankind from political, economic and social limitations and how to give it a purer and broader-minded understanding of humanity and sympathetic mutual coöperation.