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SCIENCE AND TECHNOLOGY[1]

By Professor ERNEST O. LAWRENCE
UNIVERSITY OF CALIFORNIA

IT is appropriate on this occasion to draw your attention again to the great partnership of modern times —science and technology; for the mutual dependence of the pure and applied sciences in the development of our material welfare is nothing short of an absorbing romance.

The applied sciences are devoted to perfecting instruments and means already available, a procedure which in some quarters has been regarded as the best attack on practical problems. On the other hand, the pure scientist is guided by curiosity to learn more about the facts of nature—and it frequently has turned out that new knowledge thus gained has furnished the basis for doing something in a way incomparably better than any perfection of the methods that were already in use.

The following is an illustration: A hundred years ago if one had wanted to improve artificial illumination the direct practical procedure would have been to improve the candle or the oil lamp, and worthwhile progress could certainly have been made in this direction; but researchers in electricity, who studied the subject at that time entirely without regard to its practical application, furnished the basis for new means of lighting which turned out to be vastly superior to anything that could have been obtained by the further perfection of the old sources. It was then that Michael Faraday discovered that a current can be generated in a wire by a changing magnetic field. You all know how, from the tiny galvanometer deflection which first showed Faraday the principle of electromagnetic induction, there developed for the use and comfort of mankind the electric generator, the electric light and the hosts of modern inventions which have followed in their wake.

It is remarkable that Faraday, the man of science so

[1] Commencement address at the Stevens Institute of Technology, on June 12, 1937.

devoted to the patient search for the underlying principles of electricity, possessed at the same time a vivid appreciation of the practical implications of scientific discoveries. Gladstone, you will remember, on seeing one of Faraday's famous experiments terminate in an effect which to the non-scientific mind was very uninspiring, asked what possible use his discovery could be. "Why, Mr. Prime Minister," answered Faraday, "you will soon be able to tax it." On another occasion in reply to a similar question from an elderly lady, he quoted Benjamin Franklin, "Madam, of what use is a new-born child?"—a remark full of significance.

It might be argued that one should devote himself only to those subjects that can be immediately applied; but the development of some entirely new branch of science may give a means of benefiting humanity which could not have been foreseen had one been guided solely by practical considerations. Again let us take a hypothetical illustration. Suppose that in the nineties a surgeon had set himself the task of improving the methods of diagnosing and setting bone fractures. He would not have known that the greatest contribution to that problem—the discovery of x-rays—was soon to come from the quiet laboratory of a man curious about electrical phenomena in a vacuum tube.

Roentgen's discovery, closely followed by Becquerel's recognition of radioactivity, provide two of the prominent milestones of science. The benefits that have already been given to mankind through their application to medicine are familiar to all, but they were of much greater significance than in respect to their practical aspects alone. When these startling discoveries were made physical science was drifting in the doldrums. There was a wide-spread feeling that the great underlying laws of nature were fully comprehended and that the scientific developments of the future would be concerned with less interesting and important details. Michelson had just made his whimsical prognostication that the future of physics lies in the next decimal place, implying a not too exciting or brilliant prospect. But the discovery of x-rays and radioactivity abruptly altered all this by reviving science, and at the same time the proper humility of scientists.

These epoch-making discoveries suddenly disclosed a new world—the world of the atom. The chemist's conception of the atom as an indivisible entity was soon discarded and in its place came wide recognition that within the atom lie domains of inconceivable richness. It is needless to elaborate on the great strides made by atomic physics in the intervening years. The man in the street now knows that his radio is operated by innumerable tiny slaves called electrons; and over his radio comes information on other miracles of technological science which have to do with the scintillating world of atoms. This is only to remind you that all these things came in the wake of Roentgen's chance discovery.

Again history has repeated itself—there are scientific cycles just as there are business cycles. Thirty years after the discovery of x-rays, the atomic theory had acquired an unwarranted position. The great successes of the theory gave rise to a wide-spread feeling that scientists really understood the underlying principles of the atomic world and again that the future held forth only the unexciting prospect of elaborating the details. The arrogance and complacency of the atomic physicist of the last decade was a perfect repetition of the attitude of the classical physicists at the end of the last century.

This state of affairs was short-lived, for now we are on the threshold of a new era fraught with potentialities for the future, as in the days of Faraday and of Roentgen—the era of the atomic nucleus. The new frontier lies within the hearts of atoms, and we are in a position to attack the problem the ancient alchemists set for themselves. Indeed their dreams have already been surpassed, for they sought ways of turning base metal into gold, while the modern scientist is now making something vastly more precious and useful, the artificial radioactive substances. It is not possible here to adequately tell the exciting story of artificial radioactivity and the important contributions to medical science that are in prospect or to tell about those swiftly moving fragments of atoms, the neutron rays, that are often the result of explosions within the atomic nucleus, and which are more penetrating than x-rays and indeed are already known to have more interesting properties.

Even to give you a survey of the many advances in the domain of the atomic nucleus would exceed the limits of your patience, and I shall restrict myself to the discussion of one significant result that has recently emerged—the experimental proof of the equivalence of mass and energy.

One of the consequences of Einstein's theory of relativity, first enunciated in 1905, was that matter is one form of energy. This consequence of relativity that it might be possible to release energy by the annihilation of matter or that matter might be created by the absorption of energy was no more revolutionary than the fundamental postulates of the relativity theory, yet it rocked the very foundations of physical thought —for we all had been brought up on the principles of the conservation of energy and the indestructibility of matter.

As the Einstein theory grew in favor, the validity of the mass-energy relation became more apparent, but until direct experimental verification was forthcoming, Einstein's great deduction could not be regarded as an established law of nature. Cockcroft and Walton, of the Cavendish Laboratory, in their pioneering experiments about five years ago on the transmutation of lithium were the first to observe beyond any question the conversion of matter into energy. Subsequently, studies of many other examples of transformation of the elements have given an abundance of additional evidence and there is no longer any doubt about the truth of this principle.

Now that it is an established fact that matter can be converted into energy, let us consider for a moment what this means. At the outset one is impressed with the tremendous amount of energy tied up in the form of matter. For example, a simple calculation according to the relativity theory shows that a glass of water if completely destroyed and converted into useful energy would yield more than a billion kilowatt hours, enough energy to supply a city with light and power for quite a time. It is a highly practical question therefore to inquire whether it is possible to tap this inexhaustible supply of fuel.

The source of the sun's energy has long been a great mystery, for there is good evidence that it has been blazing at its present brilliance for billions of years, and as yet there is no sign of its going out. Fuel for this almost eternal fire could be of no ordinary sort; and astronomers and physicists now believe that conditions within the sun are such that nuclear reactions are taking place on an extensive scale with the destruction of matter and conversion into radiant energy. Thus, the sun is gradually through the ages losing its mass; slowly its very substance is radiating into space.

But whether it will be possible to release subatomic energy on a practical and profitable basis for industrial purposes, whether perhaps it will be possible to realize conditions on the earth similar to those in the sun, is the question which of course interests the engineer. Indeed, it is a question of interest to every one, and accordingly it has been the subject of much popular discussion and speculation. But speculation is hardly more than a game of fortune-telling, and this is out of place here. It is only of interest to indicate the present state of knowledge with proper humility, with recognition that what the future holds forth only the future can tell. In this spirit it may be said at this time that although we now know that matter can be converted into energy, there is no greater prospect of destroying nuclear matter for power purposes than of cooling the ocean to freezing temperatures and extracting the heat for profitable work. Certain considerations bearing on the second law of thermodynamics would appear to govern the availability of energy in the hearts of atoms as in the Atlantic Ocean itself.

While the view that some day power plants may be run by the release of subatomic energy and that nuclei of atoms may be used as fuel appears fantastic, nevertheless, proof of the equivalence of mass and energy is none the less of great practical importance. It is conceivable that in our lifetime this great principle will play a vital rôle in technical developments which at the moment are beyond our dreams—for such has been the history of science.

Thus far the essential rôle played by pure science in industrial development has been dwelt upon with the endeavor to bring into relief the fact that much of our technological progress can only be achieved by the methods of the investigator whose primary interest is that of unravelling the mysteries of nature—following the threads of logic and experimental revelation wherever they lead without restriction of practical goals. But to stop here would be giving only one side of the picture; for technology is just as important for science as science is for technology.

In making this assertion the thought in mind is not that in the long run the practical achievements of industrial science are responsible for the prosecution of pure science, although it is true in large measure. Rather it is that industrial developments, per se, have been of essential importance in scientific progress.

Two famous experiments, one devised by Galileo three centuries ago and the other in modern times by Michelson with the aid of his interferometer, illustrate the point. Galileo dropped heavy bodies from the top of the leaning tower of Pisa and demonstrated that those of different weights fall to the ground in the same time. As regards experimental skill and delicacy of apparatus, this experiment could have been made many centuries earlier. Moreover, the ideas involved merely concerned weight and speed of travel, ideas familiar to people of ancient times.

But Michelson's experiment could not have been made earlier than it was. It required the general advance of technology as well as Michelson's experimental genius. It concerns the earth's motion through the ether, the all-pervading medium of light waves. Michelson's ingenious apparatus required the finest of optical parts, the products of the contemporary optical glass workers. Accordingly, it may be said that the perfection of glass technology made possible the Michelson interferometer, which in turn resulted in an experiment that formed the basis of Einstein's theory, a theory which has revolutionized not only our understanding of physics, but also our entire philosophy! Indeed, two philosophers, Alfred Whitehead and Victor Lenzen, provided these illustrations which I have borrowed.

And so leaving in your minds the essential rôle of pure science in modern technological progress and the equal importance of modern technology for the advance of science, I shall close, acknowledging my obligation to these modern philosophers by quoting from one who was a contemporary of Galileo—for it was Sir Francis Bacon who said, "Nature to be commanded must first be obeyed. Knowledge is power."

THE NUTRITIVE SIGNIFICANCE OF THE AMINO ACIDS AND CERTAIN RELATED COMPOUNDS[1,2]

By Professor W. C. ROSE
UNIVERSITY OF ILLINOIS

THE relation of the amino acids to growth has been the subject of numerous investigations during the past thirty years. Until comparatively recently, however, only three of these compounds, namely, tryptophane, lysine and histidine, had been shown definitely to be indispensable components of the food. Evidence which appeared to demonstrate the essential nature of cystine was presented by Osborne and Mendel; while certain other protein components, notably the dibasic amino acids and the prolines, seemed to be dispensable.[3]

Progress in such investigations was hampered by reason of the fact that methods were not available for the quantitative removal of single protein components. It appeared that if further information was to be obtained, one must resort to the use of diets in which the proteins were replaced entirely by mixtures of highly purified amino acids. Such investigations have been under way in this laboratory since 1930.

It soon became apparent that the *known* amino acids, when incorporated in otherwise adequate diets, were incapable of supporting growth. Evidently, proteins supply something which was not present in our original mixtures. This led eventually to the isolation and identification of a new indispensable constituent, namely, α-amino-β-hydroxy-n-butyric acid.[4] This compound is widely distributed in nature, but appears to occur in greatest abundance in the blood proteins. It has been named d-threonine, inasmuch as its spatial configuration is exactly analogous to that of the sugar d-threose.[5] When threonine is added to suitable amino acid mixtures the resulting preparation is an excellent substitute for dietary proteins.

In all our investigations young albino rats from our own colony have served as the experimental animals. The diets have carried the usual components—carbohydrates, fats, inorganic salts and vitamins—and differed from the ordinary so-called "synthetic" rations only in that proteins were replaced by amino acids. Food and water were kept in the cages at all times, so that the animals ate and drank *ad libitum*. By such a procedure, the importance of the individual amino acids has been determined by omitting them from the food one or more at a time.

Data have already been presented elsewhere demonstrating the indispensable nature of phenylalanine,[6] leucine and isoleucine.[7] It has also been shown that hydroxyglutamic acid,[8] citrulline,[9] tyrosine,[6] norleucine,[7] glycine and serine[10] are non-essential. During the past eighteen months all the generally recognized amino acids present in proteins have been classified with respect to their growth importance. It is the purpose of this note to present these findings, together with an outline of the physiological behavior of certain optically isomeric amino acids and related compounds. The evidence upon which the following statements are based will be described in detail elsewhere.

Contrary to the usual belief, cystine is not an indispensable component of the food. On the other hand, methionine is indispensable. In the absence of the latter from the ration, animals rapidly lose weight and eventually die, even though an abundant amount of cystine is supplied. Of particular interest in this connection is the fact that if methionine is administered at a level which permits maintenance or slow increase in weight, the addition of cystine greatly improves the quality of the diet. Thus, cystine stimu-

1 Aided by a grant from the Rockefeller Foundation.

2 This paper is a summary of one presented before the joint session of the Federation of American Societies for Experimental Biology at Memphis, Tenn., April 22, 1937. The author is indebted to Drs. Madelyn Womack, S. H. Eppstein, C. E. Meyer and a number of graduate students for the actual conduct of the experiments.

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