[PRESIDENT'S ADDRESS.]

Recent Developments in Physical Science.

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On this—the twenty-fifth—birthday of the Indiana Academy of Science, it is meet that we survey the progress made and take an inventory of stock on hand. Where were we? Where are we?

Comparing physical science of today with physical science of twenty-five years ago, I am forced to the conclusion that there has been a revolution.

In the first place there has been a revolution in the methods of teaching science. I would remind you that the physics laboratory of the University of Berlin was founded in 1863, the Cavendish laboratory of Cambridge in 1874. In 1871 Professor Trowbridge, of Harvard, was obliged to borrow some electrical measuring instruments, as the university had none of its own. It is not surprising, then, that a few years later—at the time the Indiana Academy of Science was founded—there were in the United States very few physics laboratories worthy of the name. Physics teaching in college and high school was chiefly from the text-book. Today a college which would offer work in physics without a laboratory would be considered a joke; and in order to be commissioned, a high school must have a certain minimum of laboratory equipment and the physics teacher must devote a part of his time to laboratory instruction.

In the second place there has been a complete change in the attitude of men of affairs toward the physics professor and his students. No longer do they consider us theoretical, and therefore impractical. No longer do they look with distrust or contempt on laboratory methods and data. No longer do they hold that apprenticeship and experience are sufficient for their needs. Today the large industrial concerns are establishing laboratories of their own and employing in them the best trained men they can command.

In the third place, there has been a revolution in some of our physical theories. By the term revolution I do not mean a destructive upheaval in which the work of the past has been repudiated and destroyed and a new order of things established. I mean that some of our ideas have undergone such a complete and rapid change that what some might term an evolution is really a revolution. Indeed, we have had two revolutionary periods within the life of this Academy.

The first came in 1887 with the epoch-making researches of Heinrich Hertz. Faraday had given us his theory of lines of force and the mathematicians had attacked it. Young and Fresnel had given us the undulatory theory of light and Laplace and Poisson had "befuddled us with their objections." Ampere had given a theory of magnetism, but Poisson and Weber had given two others. To explain an electric charge we could resort to the one-fluid theory, the two-fluid theory, the potential theory, the energy theory, the ether-strain theory. Maxwell had written a treatise on electricity which few could read and no one could fully understand. A distinguished French physicist said he understood everything in Maxwell's book except what was meant by a body charged with electricity. Maxwell had given us but a vague idea of electric displacements and displacement currents, because his ideas were bound up in equations without experimental verification, or even illustration.

Then came Hertz's researches, which confirmed the fundamental hypotheses of the Faraday-Maxwell theory and "annexed to the domain of electricity the territory of light and radiant heat." [1]"Many thinkers," said Lord Kelvin, "have helped to build up the nineteenth century school of *plenum*, one ether for light, heat, electricity and magnetism; and Hertz's electrical papers, given to the world in the last decade of the century, will be a permanent monument of the splendid consummation now realized." Some one has said that Hertz enthroned Maxwell in every chair of physics in Europe and America.

It appears that many of the ancient philosophers had a shadowy idea of a medium in space which they personified and called "Aether." According to Heriod, Aether was the son of Erebus and Night and the brother of Day. The Orphic hymns speak of Aether as the soul of the world, the animator of all things, the principle of life. The children of Aether and Day were the objects about us, the heavens with all their stars, the land, the sea. Aether was the lightest and most active form of matter and Day had the power of converting it into heavier matter. Plato speaks of the

[1]Kelvin. Introduction to Jones' translation of Hertz's "Electric Waves." Macmillan, 1893.

Aether as being a form of matter far purer and lighter than air, so light that its weight cannot be ascertained because distributed through infinite space.

During the fifteen years following the publication of Hertz's researches it is probable that greater homage was paid to Ether by modern physicists than was ever given it by the ancients. The ether was appealed to from every quarter. Light, radiant heat and electric waves were ether waves. An electric charge was an ether strain. An electric current was a phenomenon in the ether and not in the wire in which it appeared to flow. Magnetism and gravitation were phenomena of the ether. Matter itself became an aggregation of ether vortices. Ether and motion were expected to explain everything. Such terms as natural philosophy and physics were discarded by some of our text-book writers who adopted such titles as "Matter, Ether and Motion"; "Ether Physics"; "Ether Dynamics"; "The Mechanics of the Ether." Physics was defined as the science of motion.

The classical mechanics of LaGrange was built on what were considered fundamental concepts—mass, force, space and time. Hertz, in his treatise on mechanics published in 1894, endeavored to eliminate force and potential energy and reduce a universe to ether movement. Space and time were not fundamental ideas, but as Kant had said, were subjective notions. We measure time by a change of space relation; that is, a movement of a star, of the earth, of a clock hand. "In a world void of all kind of movement there would not be seen the slightest sequence in the internal state of substances. Hence the abolition of the relation of substances to one another carries with it the annihilation of sequence and of time." Thus everything was made to depend upon movement. The equations of motion became the chief instruments of physical research, and the criterion by which the results of experiments were interpreted. Galileo lost his professorship because he dared to dispute the authority of Aristotle. Daguerre was for a time placed in an asylum because he said he could take a picture on a tin plate. Galvani was ridiculed by his friends and dubbed "the frog's dancing master." Franklin's paper on lightning conductors was considered foolish, and refused publication by the Royal Society. Fifteen years ago it would have been almost as disastrous for a physicist to question the authority of LaGrange or Maxwell. Not only were the *results* of experiments subjected to mathematical analysis, the *direction* of scientific investigation was largely so determined. The question was first put to mechanics. If a positive answer was indicated the question was put to nature and the research went on. If the equations indicated a negative result the question was dropped and the research abandoned.

Physics was an *exact* science. Other sciences were not exact sciences because their theories and hypotheses could not be mathematically expressed—the relation between cause and effect was not expressible in algebraical symbols. Physics was an exact science whose fundamental principles had been discovered and its laws expressed by equations. All that remained to be done was to make more accurate measurements of physical quantities for use as coefficients and exponents.

Let me quote from the 1894 catalogue and later catalogues of one of the largest universities in the United States.

"While it is never safe to affirm that the future of physical science has no marvels in store. * * * it seems probable that most of the grand underlying principles have been firmly established and that further advances are to be sought chiefly in the rigorous application of these principles to all the phenomena which come under our notice. * * * An eminent scientist has remarked that the future truths of physical science are to be looked for in the sixth place of decimals." The foregoing is a verbatim quotation from the introductory statement preceding the list of courses in physics offered at one of our great universities, written, I think, in 1894. "Underlying principles firmly established," "Future truths in sixth decimal place," 1894. Then came the discovery of Roentgen rays, 1895; Becquerel rays, 1896; Zeeman effect, 1896; radium, 1898; atomic disintegration, the transformation of matter, the thermal effect of radioactivity, and intra atomic energy, 1903. I am unable to locate the sixth decimal idea in recent catalogues.

J. J. Thomson likens the discovery of Roentgen rays to the discovery of gold in a sparsely populated country. Workers come in large numbers to seek the gold, many of them finding that "the country has other products, other charms, perhaps even more valuable than the gold itself."

The chief value of Roentgen's discovery was not that it furnished us a new kind of light for the investigation of dark places, but in the fact that it led a host of workers to study vacuum tube discharges—the discharge of electricity in gases and the effects of such discharges on matter itself. The old dusty Crookes' tube was taken down from the far corner of the upper shelf and regarded with new interest. In a day it had ceased to be a forgotten, though curious, plaything, and had become a powerful instrument of research. It was before Roentgen's discovery that a well-known professor said to me that he considered it foolish for one to spend any part of his departmental appropriation for a vacuum; that when he paid out money he wanted something in return—not an empty space. And yet this man was familiar with the work of Faraday and of Crookes, both of whom with prophetic mind had foreseen and foretold. Let me quote from a lecture by Faraday on the significant subject "Radiant Matter."

[1] "I may now notice a peculiar progression in physical properties (of matter) accompanying changes of form, and which is perhaps sufficient to induce, in the inventive and sanguine philosopher, a considerable degree of belief in the association of the radiant form with the others in the set of changes I have mentioned.

"As we ascend from the solid to the fluid and gaseous states, physical properties diminish in number and variety, each state losing some of those which belong to the preceding state. * * * The varieties of density, hardness, opacity, color, elasticity and form, which render the number of solids and fluids almost infinite, are now supplied by a few slight variations in weight and some unimportant shades of color.

"To those, therefore, who admit the radiant form of matter, no difficulty exists in the simplicity of the properties it possesses * * * . They point out the greater exertions which nature makes at each step of the change and think that, consistently, it ought to be greatest in the passage from the gaseous to the radiant form." The lecture from which the foregoing is a quotation was delivered in 1816, when Faraday was but twenty-four years old.

Let me quote again, this time from a lecture by Sir William Crookes delivered sixty years later, more than thirty years ago, on the same subject—"Radiant Matter."

"In studying this fourth state of matter we seem at length to have within our grasp and obedient to our control the little indivisible particles which with good warrant are supposed to constitute the physical basis of the universe. We have seen that in some of its properties radiant matter is as material as this table, whilst in other properties it almost assumes the character of radiant energy. We have actually touched the borderland where matter and force seem to merge into one another, the shadowy realm

[1]Life and Letters of Faraday, Vol. 1, p. 308.

between known and unknown, which for me has always had peculiar temptations. I venture to think that the greatest scientific problems of the future will find their solution in this borderland, and even beyond; here, it seems to me, lie ultimate realities, subtle, far-reaching, wonderful."

The developments of the last few years have demonstrated that no truer prophecy was ever uttered, and the prophet Crookes has lived to witness and to take a part in its fulfillment.

The importance of the present rejuvenation of physical science does not consist alone in the abundance of the harvest. There have been abundant harvests in the past. Consider the decade which closed one hundred years ago. In 1798 Rumford boiled water by friction. In 1799 Davy melted ice by friction in a vacuum and Laplace published his work on mechanics. In 1800 Volta constructed the Voltaic pile, Nicholson and Carlisle decomposed water, Davy discovered the properties of laughing gas, and Herschel discovered dark heat rays. In 1801 Piazzi discovered the first asteroid, Ritter the chemical rays, and Young the interference of light. In 1802 Wedgewood and Davy made sun pictures by the action of light on silver chloride, and Wollaston discovered dark lines in the sun's spectrum. In 1808 Malus discovered polarization by reflection, Gay Lussac the combination of gases by multiple volumes, and Dalton the law of multiple proportions.

So great was the exhilaration and satisfaction produced by these discoveries that many scientists of that period appear to have become infected with something akin to the "sixth decimal" delusion. "Electricity," wrote the French scientist Haüy, "enriched by the labor of so many distinguished physicists, seems to have reached the term when a science has no more important steps before it, and only leaves to those who cultivate it the hope of confirming the discoveries of their predecessors and of casting a brighter light on the truths revealed." A statement which was almost immediately followed by the discoveries of Oersted, Ampere, Seebeck and Faraday. A statement which has been followed by the telegraph, the telephone, the dynamo, the motor, the electric light, the electric railway, the Roentgen rays, and the wireless telegraph and telephone.

If anyone today is disposed to criticise the men of science of other times because of their limited view, their complacent opinions and their intolerance of all that did not agree with theories they considered established, let him first read and ponder over what One spake about motes and beams.

The real significance of recent developments is in the fact that they change—in a way revolutionize—some of our ideas of things. And here let me say that proven facts and proposed theories should not be confused. A theory is simply a working hypothesis, invented for the purpose of explaining facts, to be discarded when facts are discovered with which the theory is not in harmony. A theory may explain many facts, it may be generally accepted, it may have survived for generations and be false. The phlogiston theory, the corpuscular theory are two examples. Shall we say that the theory of the indestructibility of matter and of the conservation of energy are two others?

The usual chemistry text-book would have us believe in the indestructibility of matter because the chemist can change the form of matter almost at will, and in all the chemical reactions there is no loss of weight. In replying to this argument I wish to make three points.

First. The balance, notwithstanding the statement of text-books, compares weights and not masses, and it is only because weight is assumed to be proportional to mass that we say we determine mass by the balance. What we really compare is the gravitational force which the earth exerts on two masses, and we have no a priori right to assume that this gravitational force is absolutely independent of the state or molecular arrangement of the attracted body. Why, for instance should we expect an absolutely uniform field of force about a crystal when that same crystal will, if placed in a proper solution, continue to grow symmetrically, and perhaps replace a broken-off corner before beginning its growth?

It is conceivable that there should be a loss of weight in chemical reactions and yet no destruction of matter. It is possible that mass and weight are not strictly proportional. If J. J. Thomson were not disposed to question the equation $w = m \cdot g$ he would not have experimented with a pendulum of radium, and he would not now be experimenting with a pendulum of uranium oxide.

In the second place there *is* an apparent change of weight in chemical reactions as has been shown by several experimenters, notably by Landolt,[1] who found a loss in forty-two out of fifty-four cases. The chemical reactions were brought about in sealed glass tubes which generally weighed less after the reactions than they weighed before. Later[2] it was found that some of these losses might be attributed to temperature and volume

[1] H. Landolt. Preuss. Akad. Wiss. Berlin, Sitz. Ber. 8, pp. 266-298, 1906.
[2] Landolt. Preuss. Akad. Wiss. Berlin, Sitz. Ber. 96, pp. 354-387, 1908.

changes. Whatever the testimony of the balance may have been, some of the reactions must have been accompanied by a loss of weight, for it has been proven by chemical means that such reactions are frequently attended by the escape of something through the walls of the glass tubes.[1] This loss is readily explained by the disintegration theory. If one wishes to explain it by assuming the diffusion of ordinary gases through the glass walls of the tube he must explain the fact that, in many cases, it was the heavy and least volatile substances that escaped fastest.

In the third place the element of time has been overlooked. Matter may be disintegrating, but at such a slow rate that in the limited time over which experiments have been extended the balance has failed to detect the change. As far as our experience goes the time of rotation of the earth is constant; but we know that it cannot be absolutely constant. The moon has slowed down until it takes a month to make one turn. To an ephemeral insect almost everything would appear to be eternal. With due respect for the balance and the wonderful work it has enabled chemists to do, it must be admitted that it is, comparatively, a very crude instrument. Let me prove it.

Suppose we fix the limit of sensibility of the balance at one one-thousandth of a milligram. Our books on chemistry tell us that 1 c c of gas, say hydrogen, at ordinary pressure contains 4×10^{19} molecules. The density of H being 896×10^{-7}, then 1 gm. of H would consist of $(4 \times 10^{19}) \div (896 \times 10^{-7})$ molecules. Taking 112 as the ratio of the molecular weights of radium and H, then 1 gm. of radium would consist of $[(4 \times 10^{19}) \div (896 \times 10^{-7})] \div 112 = 4 \times 10^{22}$ molecules. Therefore .001 mgm. of radium would consist of 4×10^{16} molecules, and this would be the smallest possible number that our most sensitive balance could detect. If the gram of radium were disintegrating and its molecules escaping at the rate of a million per second it would require 4×10^{10} seconds = 463,000 days = 1270 years for that gram of radium to lose in weight only the one-thousandth part of one milligram, all the while its molecules trooping away at the rate of a million per second.

The population of the earth is about 1,500 millions. The smallest number of molecules a balance will detect is 4×10^{16}, or about 26,600,000 times the population of the earth. We wonder if Mars is inhabited. If a Martian were to come to the earth to make an experiment to determine whether or not the earth is populated and he had no better instrument

[1]C. Zenghelis. Zeitschr. Phys. Chem. 65, 3, pp. 341–358, Jan. 5, 1909.

"for the detection of the existence of a man" than is the balance for a molecule, he would be obliged to go back and report the earth uninhabited. In fact his instrument for the man test would need to be 26,600,000 times as sensitive as the balance to give him even a hint of the probability of an earth population.

Thomson says that the smallest quantity of unelectrified matter ever detected is probably neon, and this was discovered by the spectroscope—not the balance. But the number of molecules of neon required to give a spectroscopic effect is about ten million million, or about 7,000 times the population of the earth. It has been shown that the presence of a single charged atom can be detected by electrical means. Thus the electroscope is millions of millions of times as sensitive as the spectroscope, which is itself in many cases far more sensitive than the balance. This explains, in part, why radium was discovered by physicists, and why physicists have been most active in all the work which has had to do with the theories of electricity and matter. If chemists wish to compete with physicists in this field of investigation they must adopt physical methods and apparatus or devise some of their own which shall be far more sensitive than the balance or spectroscope. Further, many of the great chemists of the world need to awake to the fact that there is something doing and that they are not doing it. Their indifference is surprising. Only three months ago one of them expressed the following sentiments in a paper read before the chemical section of the British Association. [1]* * * "Those who feel that the electron is possibly" (note the possibly) "but a figment of the imagination will remain satisfied with a symbolic system which has served us so long and so well as a means of giving expression to facts which we do not pretend to explain. * * * Until the credentials of the electron are placed on a higher plane of practical politics, until they are placed on a practical plane, we may well rest content with our present condition and admit frankly that our knowledge is insufficient to enable us even to venture on an explanation of valency." Think of it! We, the chemists, "remain content" in this day when, as the Hon. A. J. Balfour has said, the attempt to unify physical science and nature [2]"excites feelings of the most acute intellectual gratification. The satisfaction it gives is almost

[1]Scientific American Supplement. 63, No. 1761. P. 210, Oct. 2, 1909.

[2]"Reflections Suggested by the New Theory of Matter." Presidential Address, British Association for the advancement of Science, 1904. Science. 20 No. 504, pp. 257-266, Aug. 26, 1904.

aesthetic in its intensity and quality. We feel the same sort of pleasurable shock as when from the crest of some melancholy pass we first see far below the sudden glory of plain, river and mountain." "Rest content!" No wonder the Noebel prize in chemistry was awarded to Rutherford, a physicist.

As to the second principle, the conservation of energy, some have had misgivings. It was Kelvin, I believe, who said that radium placed the first question mark after this great principle. Many have refused to believe in the electron and disintegration theories because they saw, or thought they saw, in these theories a contradiction of the principle of energy conservation. Personally I do not see that there are necessarily any contradictions. But even if there were and we were therefore justified in rejecting the theories proposed to explain the facts, we certainly should not be justified in rejecting the facts themselves.

In this connection I am reminded of the story of a lawyer whose client was placed in jail for some very trivial offense. When the lawyer learned the nature of the charge he said to his client: "My friend, they cannot put you in jail on such a charge as that." "Yes, but they have," replied the prisoner. When our physicist says that radium cannot remain at a higher temperature than its surroundings and continue to radiate heat, as that would be contrary to the second law of thermodynamics, the answer is, Yes, but it does. When he says that it cannot continue to radiate energy without receiving energy from some other body, as that would be contrary to the principle of the conservation of energy, the answer is, Yes, but it does it.

When some one says that helium or carbon dioxide cannot appear in sealed tubes which contained no trace of these substances to begin with, the answer is, Yes, but they do.

Let us suppose that we have a mass of gunpowder and that it is possible to, and we do, cause it to explode, one grain at a time, each grain firing its neighbor as in the fuse of a firecracker. The temperature of the mass of gunpowder will be higher than its surroundings, and it will give off heat and other forms of energy and continue to do so as long as the powder lasts. No one would think of calling this an exception to the law of the conservation of energy or the second law of thermodynamics. The source of the energy is the atomic potential energy of the powder itself.

Let us suppose that we have a sphere with frictionless surface rotating at an enormous speed. Suppose that particles of matter are thrown off at frequent intervals. These particles, on account of their high speed. have considerable potential energy. Thus the sphere continues to give off energy without receiving any as long as any mass remains. The source of the energy is the kinetic energy stored in the sphere at the outset, of which energy we are conscious only when we have some method of detecting and slowing down the projected particles.

Thus the energy radiated by radium might be stored within the radium atom as potential energy and liberated by a sort of atomic—or subatomic—explosion. Or it might be stored as kinetic energy—of revolving electrons—and liberated gradually as these electrons escape from their orbits. It might be stored in both forms. In any case it is intra-atomic energy because stored *within* the atom itself and liberated only by atomic change—disintegration. In neither case would there be a violation of the principle of the conservation of energy or of the second law of thermodynamics. Sooner or later all the energy will have been radiated. The fact that the supply is destined to last so long is what appeals to us as wonderful. And so it is. The world is full of wonderful things to anyone who pauses long enough to think.

In this paper I have endeavored to give a general notion of the trend of thought and investigation in physical science rather than an enumeration and discussion of discoveries and theories. I might say, however, that there are strong reasons for believing in the molecular structure of electricity the electrical nature of matter, and the dependence of mass upon velocity. The theories of radioactivity and disintegration of matter are fairly well established. According to Ramsay, one of the most eminent chemists in the world, "we are on the brink of discovering the synthesis of atoms, which may lead to the discovery of the ordinary elements." Perhaps the dream of the alchemist is about to be realized. Certain it is that we are face to face with energies of which no one even dreamed a few years ago. Whether we call this energy intra-atomic, sub-atomic, interelemental or some other name, we know certainly that it exists, and that it exists in quantities far beyond the power of man's mind to comprehend. Man hopes some day, somewhere, somehow, to discover the means of unlocking this infinite storehouse. If this discovery is ever made, all the others which man has ever made will pale into insignificance beside it.

Lodge says of the one-pound shot and the one-hundred-pound shot which Galileo dropped from the top of the Leaning Tower, that "their simultaneous clang as they struck the ground together sounded the death knell of the old system of philosophy and heralded the birth of the new." The age of reverence for authority had passed away and the day of experimental investigation had dawned.

In a sense the discoveries of the past few years have resulted in a similar revolution. The revival of the experimental method has been complete. Accepted theories are being put to the test. What we have long regarded as proven facts are being questioned and, in many cases, challenged. There is no field of investigation which has not been cultivated anew.

In closing I wish to quote from the presidential address of J. J. Thomson[1] before the British Association at its last meeting. "The new discoveries made in physics the last few years, and the ideas and potentialities suggested by them, have had an effect upon the workers in that subject akin to that produced in literature by the Renaissance. Enthusiasm has been quickened and there is a hopeful, youthful, perhaps exuberant, spirit abroad which leads men to make with confidence experiments which would have been thought fantastic twenty years ago. It has quite dispelled the pessimistic feeling, not uncommon at that time, that all the interesting things had been discovered, and all that was left was to alter a decimal or two in some physical constant. There never was any justification for this feeling, there never were any signs of an approach to finality in science. The sum of knowledge is, at present at any rate, a diverging, not a converging series. As we conquer peak after peak we see regions in front of us full of interest and beauty, but we do not see our goal, we do not see the horizon; in the distance tower still higher peaks, which will yield to those who ascend them still wider prospects, and deepen the feeling, whose truth is emphasized by every advance in science, that 'Great are the works of the Lord.' "

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[1]Scientific Am. Sup. 63, Nos. 1757 and 1758, pp. 154, 155 and 174–176. Sept. 4 and Sept. 11, 1909.