

Seven Great Discoveries in Twentieth Century Physics

Extracts from the Terry Foundation Lectures, Yale University, given by Prof. Robert A. Millikan, director of the Norman Bridge Laboratory of Physics, Pasadena, Calif.

Modern science has no one consistent scheme of interpretation of physical phenomena, and has become wise enough to see and admit that it has none. The stupendous blunder of 19th century physics lay in supposing that it had, in a certain sense, reached finality, that it had found a fairly consistent and universally applicable scheme of interpretation of the physical world—a set of laws in conformity with which all phenomena must everywhere take place—a scheme too, which made it unlikely that qualitatively new physical phenomena still remained to be discovered.

There are seven different categories of fundamentally new experimental facts in physics, all of which have been discovered within this single generation—the last thirty years—and the majority of which are inexplicable in terms of nineteenth century modes of thought in physics.

The first of these was the spectacular discovery of X-rays by Roentgen in 1895, a discovery which not only showed how little man knew at that time about ether physics, but which furnished the technique with the aid of which a whole new sub-atomic world—the world of the electron—was brought to light within the next few years.

The second discovery—that of the electron—is probably the most far-reaching one ever made thus far in the history of science though it is not particularly destructive of nineteenth century points of view.

The third new phenomenon was that of radio-activity, which changed man's whole conception of the nature and potentialities of matter. It shattered the nineteenth century notion of a world made up of eternal unchangeable elements, and revealed a dynamic in place of a static universe—a universe living, changing, evolving continuously, even in its chemical elements. Radioactive change is still a mystery inexplicable in terms of the mechanical pictures upon which we set such store in the nineteenth century.

The fourth revolutionary discovery was that of the invalidity of the great nineteenth century principle of the conservation of matter; for not only are there the best of theoretical reasons, due to Einstein, but excellent experimental grounds as well, for now believing that the mass of the stars

is actually being transformed into light and heat and radiated away into the outer reaches of space, where who knows but that it may be continually giving birth to new worlds. This last, however, is not yet a discovery—merely an inevitable speculation, stimulated by the discovery of the inter-convertibility of matter and radiation.

The fifth new phenomenon is that ether-waves can communicate to electrons which absorb them an energy which is proportional to their frequency, and quite independent of their intensity. This is a phenomenon of exceeding importance and of wide generality but as yet, and probably forever, completely inexplicable in terms of nineteenth century ether physics. It, added to another new set of facts known as the Compton Effect, named from Professor A. H. Compton of the University of Chicago, seems to require that radiant energy, at least when it is of sufficiently short wave length, shoots through space in the form of discrete entities sometimes called "eight-darts." We are in the strange position of having to retain all our ether physics—our wave theory—to explain, or describe, all the old phenomena, but to add to it an entirely unlike theory—a kind of corpuscular theory—to explain the new phenomena.

The sixth discovery has to do with the mechanism of emission of ether waves which we thought in the nineteenth century that we knew quite as much about as we know of the mechanism of emission of sound waves by a tuning fork. Indeed we thought the two mechanisms were essentially the same. Now we know that in some completely mysterious way, in simple atoms like hydrogen the jumping or falling of an electron from one energy level to another gives rise to an emitted ray the frequency of which is proportional to the change of energy which the electron underwent in its jump. We have simply given up the hope of getting any mechanical picture of how it happens. Not only that, but we have recently found that two electrons may jump simultaneously to two new positions inside an atom and integrate the combined energy of the two jumps into a single monochromatic light wave. Indeed, an atom seems to be endowed with the strange power of integrating the energy of an atomic shudder of whatever sort into a monochromatic ether wave. The birth of

a light ray as well as its transmission through space is still an event of intense interest to the physicist for the very reason that he knows so little about it—that it baffles description in terms of any sort of a mechanical picture that he can devise.

The seventh discovery constituting twentieth century physics is perhaps the most strikingly revolutionary of them all. It is the discovery that the very foundations of mechanics when looked at microscopically are unsound—the discovery that apparently all periodic motions are resolvable into circular and linear coordinates which cannot progress continuously as demanded by Newtonian laws, but which are built up out of definite unitary elements.

We had not come quite as near sounding the depths of the universe in 1900, even in the matter of fundamental physical principles as we thought we had. Today we can still look out with a sense of wonder and reverence upon the fundamental elements of the physical world as they have been revealed to us in the twentieth century. We know now that the childish mechanical conceptions of the nineteenth century are grotesquely inadequate. We have now no one consistent scheme of interpretation of physical phenomena and we have become wise enough to see and to admit that we have none. We have learned to work with new enthusiasm and new hope and new joy because there is still so much we do not understand and because we have actually succeeded in our life-time in finding more new relations in physics than had come to light in all preceding ages put together, and because the stream of discovery as yet shows no sign of abatement.

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On Fundamentalism

If there be some babblers who, though ignorant of all mathematics, take upon them to judge of these things, and dare to blame and cavil at my work, because of some passage of Scripture which they have wrested to their own purpose, I regard them not, and will not scruple to hold their judgment in contempt.—Copernicus: *De Revolutionibus (Dedication to the Pope)*.

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