PHYSICS, PAST AND PRESENT[1]

R. R. RAMSEY, Indiana University

During the brief time I have been associated with the subject of physics I have witnessed numerous changes. Scientific discoveries have been introduced which were unbelievable only a few years ago. I consider myself fortunate to have lived, and to be living, through such a period of scientific development.

My first acquaintance with physics was made in the Oxford, Ohio, High School about 1890, where I enrolled in Steele's "Fourteen Weeks in Physics." One impression which I gained from this course, and about the only clear recollection I have of it, was that the electric dynamo was a piece of apparatus, the functions of which were too complicated to understand. From the present day viewpoint this seems an impossible situation. However, one must take into consideration the fact that the teacher, who was one of the best I ever knew, had only within the last year found an opportunity to examine his first dynamo, when Oxford installed an electric lighting system.

Just a few years before, the county-seat of a neighboring county had lighted the entire town by placing arc lights on two high steel towers, probably 75 or 100 feet high—one by the courthouse and the other about eight squares away, near the railroad station.

According to the newspapers of the time, if a town had one of these mysterious arc lights the entire town would be as light as day. Why did we believe this to be true? you may ask. I could see, when the climatic conditions were right, the glow in the sky from the arc light of Eaton, which was thirteen miles distant from my home. I had seen the towers, but we never staid in Eaton after four p. m., due to the long journey of thirteen miles we made going home, therefore, I did not know just how effective these lights were.

During the "gay nineties" there were no automobiles, no hard roads, no rural mail deliveries, and no telephones. Even the appearance of the men and women was entirely different. Men wore cut-away frock coats and plug hats, especially in campaign years. Women wore yards and yards of material in their dresses. In order to increase the yardage women invented certain elevators or props called the bustle which was seen but not spoken of in polite society.

We hear that physics has undergone a complete change; that the old theories have been cast aside in favor of an entirely new type of physics. The physics of today is fundamentally the same as it was in the earlier days. The old is no more different from the new than men and women of today are different from those of 1895. It is evident that outward appearances have been altered in both cases, but the essential features of both have remained the same.

Certain aspects have been changed in order to accommodate the necessary additions which resulted from progress. The old turnpikes with toll gates were considered fine roads and served their purpose admirably in the early days, but the driver of the modern car or twenty-ton truck, tearing down the road at fifty to eighty miles per hour, does not care to come to a dead stop every four miles

[1] President's Address.

Proc. Ind. Acad. Sci. 40:33-44. (1930) 1931.

to hand the gate keeper three cents. He prefers to pay his toll when he must, of necessity, stop to take on gasoline.

The old high school teacher and the "Fourteen Weeks" high school physics text were up to the times and served their purposes as well as the modern specialist and texts serve our times. The professor of that time was a learned man, as was the text book writer—learned in the broad sense. The author of this "Fourteen Weeks" physics had become famous for his "Fourteen Weeks" series in all the then known sciences.

In the nineties we had Newton's laws of motion, and the laws of falling bodies, the same as we have now. We knew then as well as we know now that a stone thrown up will come down. Just why it comes down—the real reason why it falls—is as much of a mystery now as it was then. We called it gravitation then as now, and knew the laws governing falling bodies, but just why every particle in the universe attracts every other particle remains a mystery.

The same can be said about hydrostatics and perhaps about hydraulics. We have learned some of the experimental laws of wind pressure, and of fluids in motion since that time. These are discoveries which have come about due to necessity since man has learned to fly. Aeronautics in the nineties could perhaps be summed up by repeating "Jarius Green and His Flying Machine."

The fundamental laws of electricity were stated in Ohm's law, the same then as now. Perhaps there was some haziness about alternating currents due to the fact that the electromotive force in coils due to induction, was not as clearly understood then as now. Our hazy conception of alternating currents explains our ignorance of high frequency currents or radio currents. Electromagnetic radiation of electromagnetic waves then were a set of mathematical equations which had been given to us by Maxwell. These mathematical laws had no material meaning until the celebrated experiments of Hertz, in 1887-90. It was some four or five years later that these experiments began to soak into the mind of the average physicist of that time. The high perfection of Radio today, with all its faults, is largely due to an almost endless amount of experimentation made between 1890 and 1922. The average man thinks of the beginnings of Radio as being about January or February, 1922, when the broadcast craze stuck the country.

The wave theory of light was firmly established and Newton's corpuscular theory was only mentioned in Histories of Physics or when an illustration of ancient loose thinking was stressed. The wave theory explained every known phenomena of light—Velocity of Light, Interference, Diffraction, Polarization, Reflection and Refraction were all accounted for by the wave theory. Radiation formulae were somewhat emperical and unsatisfactory. Balmer's formula for the hydrogen spectrum had been worked out, but attempts to correlate the formula with the wave theory involved several assumptions which did not exactly fit with the wave theory.

The age old problem of "What is Matter?" received some attention and produced such theories as that of Sir William Thomson (Lord Kelvin) in which he postulated that the atom or the ultimate division of matter was composed of ether whirls something like the smoke rings or vortex produced by the expert smoker. These vortices could be shown to attract and repel one another under certain conditions, the same as well behaved atoms are supposed to do.

Physicists, as well as chemists, had proved to their satisfaction that the atom was the ultimate division of matter, that the exact number of atoms in the universe was fixed, and that an atom of iron or of any other element was doomed to everlasting fixation, in that it was absolutely impossible to change one element into another element.

At that time all the natural laws of any consequence had been discovered and the laws were also absolutely fixed. Professor Michelson, of Chicago University, is credited with the assertion that the future discoveries in physics would be made in the fourth decimal place. The physicist of the nineties knew all the laws of physics and he knew that the laws were exact, but as yet he had not discovered just how exact they were.

Michelson had been busying himself with measuring the exact length of the meter in terms of the wave length of light as represented in one of the green lines in the spectrum of cadmium—the argument being, we might lose the platinum bar which is kept in Paris and which is known as the standard meter, but we would always have cadmium, and since cadmium is an element we could not lose nor change it in any way. Therefore it was well to know the exact length of the meter in terms of the wave length of cadmium light.

The ink on the Chicago University catalog was scarcely dry when Röentgen, of Wurzberg, Germany, anncunced that he was able to photograph the bones in the hand, or the money in one's purse. In fact, according to the newspapers, you could look right through most opaque objects. This was a new discovery entirely new and foreign to any of the old ideas of Michelson and other physicists. Röentgen's discovery was made in 1895, but it did not become newspaper material until the early months of 1896. In 1896, Lorentz put forth a theory that matter or atoms were made up of smaller divisions called corpuscles or electrons, as he called them. During the next year Becquerel discovered that uranium gave off some sort of radiation which would fog a photographic plate through opaque material, much as X-rays, as the Röentgen radiation was called, did. Thus the electron theory of matter may be said to have originated in 1896 or 1897, a short time after Michelson had made his statement to the effect that all the laws of physics were known.

Some time before, in 1879, Sir William Crookes pointed out that in a highly evacuated glass tube with terminals, there was a peculiar something given off from the negative terminal when the tube was connected to an induction coil. This something, or radiation, could be deflected by means of a magnet and also caused certain substances to glow. Crookes called this peculiar substance or state, the fourth state of matter—solid, liquid, and gaseous being the first three states of matter.

This phenomena discovered by Crookes prehaps would have received little notice if it had not been for the ingenuity of the glass blower, who, possibly at Crookes' suggestion, made up tubes containing chunks of certain stones and ores so placed that when this fourth state of matter stuck, the ore was made to glow like a ball of fire. Some chunks glowed red, some blue, some green, or almost any color wished. The ingenious glass blower was able to make up bunches of glass which would glow and resemble a bouquet of actual flowers when the induction coil was operated. Due to this spectacular feature every laboratory in the country possessed these tubes which, together with the noise of the induction coil, were a great help in waking up the average student in physics.

The discovery of the X-rays was a great impetus to the study of the Crookes' tubes and the fourth state of matter. The result was that it was proven that Crookes' fourth state of matter was a stream of negatively charged particles, or a stream of negative particles of electricity, which were forced out of the negative terminal, or cathode, of the tube, and which proceeded in a straight line until they hit some material body and were stopped and absorbed.

The body on which these particles impinged usually glowed with a brilliant color and became hot. It was also noticed that Röentgen's X-rays seemed to emanate from the surface which stopped these electrons. This showed that these moving charges of electricity had something to do with the X-rays. At first these X-rays were explained by the casual observer by saying they were the same as ordinary light, but of shorter wave length—an ultra violet radiation. This explanation was given up when it gradually became known that Röentgen had failed to reflect, refract, or polarize these rays. They absolutely failed to respond to the tests to which ordinary well behaved wave motion, such as light, is supposed to respond.

Later these rays were explained by saying that they were a disturbance in the ether, but instead of being a train of waves they were a single pulse or wave, the analogy being that of a report of a gun in contrast to that of a sustained sound such as that from a tuning fork.

Later, about 1912, it was found that the first explanation was perhaps more to the point. The reason that the reflection experiments of Röentgen had failed, was due to the roughness or lack of polish of the mirror. Ordinary mirrors, which are polished so that the bumps on the mirror are not higher than a fraction of a wave length of light, become very rough when compared to the wave length of the X-rays. The hills on the mirror are hundreds, perhaps thousands of X-ray waves high. To illustrate: certain cliffs will produce excellent echoes; that is, they are good mirrors for sound. When compared to waves of sound, which are several feet long, they are smooth, the elevations being a fraction of a wave higher than the depressions. But no one would, on account of the excellent echo produced, expect to use the bluff as a shaving mirror.

Due to the work of Becquerel, Madame Curie, Rutherford and others, it was proven that the blackening of the photographic plate discovered by Becquerel was due to certain radiations given off spontaneously from the piece of uranium. These radiations were very much the same as the cathode rays in the Crookes tube, and the X-rays from the Röentgen tube. There was also a radiation which seemed to be moving charges of positive electricity. The radiations are: the alpha rays, or comparatively heavy moving atoms which carry positive charges; beta rays, which are lighter moving bodies carrying negative electricity (moving electrons); and the gamma rays, or radiations which have all the characteristics of the X-rays.

It was proven that the electron was a mass 1/1800 part of the hydrogen atom whose mass is 1.61×10^{-24} grams. The diameter of the electron was found to be less than $.4 \times 10^{-12}$ cm. The alpha ray was found to have a mass four times that of the hydrogen atom, and that it weighed exactly as much as the helium atom. The gamma rays had all the characteristics of X-rays except that, as a general thing, they were more penetrating. This was found later to be due to the fact that the average gamma ray has a wave length much shorter than the average X-rays produced by the ordinary tube.

The fact that the mass of the electron was found to be much smaller than the mass of the hydrogen atom made it imperative that there must be some change in the theory of matter. The atom could not be the ultimate division of matter since these were small particles or electrons, thrown out of atoms which were much smaller than the atom. This caused the structure of matter, the old problem of what and how things are made, to come in for revision.

Since the electron is much smaller than the atom, theories were advanced by J. J. Thomson, Rutherford, and others, that the atom is a miniature solar system, like the sun and the various planets revolving about the sun as a central nucleus. From this analogy we have the Thomson atom with the electrons revolving about the positive nucleus.

Thomson had very little to say about the positive nucleus except that the positive charge was great enough to neutralize the negative charges of the electrons. Rutherford's atom was very much like that of Thomson except that instead of having a central positive nucleus a positive sphere of influence was proposed. According to this theory the electrons floated, as they revolved, in a sphere or space which held the electrons or kept them from repelling their neighboring electrons.

In order to settle the question as to the nature of the nucleus Rutherford and others performed certain experiments. These experiments justified Thomson's central nucleus theory and also showed that the diameter of the nucleus was about the same or a little less than the diameter of the electron. These experiments were made by determining the scattering of alpha particles when the atom is bombarded with alpha-rays. Since the atom is a solar system, a body from the outside comes into the solar system something like a comet swinging around the sun. However, in this case there is repulsion instead of attraction, causing the comet or alpha particle to swing away from the nucleus instead of around the nucleus. The amount of bending or the amount of scattering depends upon how close the alpha-ray comes to the positive nucleus. If the atom is bombarded with a large number of alpha rays, as when the atoms in very thin gold leaf is bombarded by a large number of alpha-rays by applying the laws of probability it can be determined how many alpha-rays on the average will be bent five degrees and how many will be bent ten degrees, etc. If the central nucleus has a large diameter comparable to that of the atom due to direct hits and otherwise, there will be a different distribution or scattering than if the nucleus is small. If the nucleus is a sphere of influence through which the electrons can be shot, the closer the electron comes to going through the exact center the less the amount of bending, while if the nucleus is a small central body the closer the electron comes to the exact center of the atom, barring direct hits, the greater will be the bending. By methods similar to the one outlined, it was proven that the nucleus was a central body and that its diameter was about the same or a little less than the diameter of the electron, the diameter of the nucleus of the gold atom being equal to or less than $.4 \times 10^{-12}$ centimeters. From other assumptions, namely, that the mass is electromagnetic in origin, the diameter of the nucleus is shown to be much smaller than that of the diameter of the electron. The mass of the nucleus is thousands of times greater than the mass of the electron, but the diameter of the nucleus is smaller than that of the electron.

It has been long known that when atoms are excited or disturbed that they radiate or give off light of some definite color. One method of exciting sodium atoms is to heat them in a colorless Bunsen flame. Just how these waves get started has been a question which has become more puzzling the more we know about the atom.

It was at one time assumed that the electron rotating in its orbit shakes or disturbs the ether, due to the simple harmonic motion or apparent simple harmonic motion of the electron. After the dimensions of the orbits and diameters of the electrons were known more exactly it became evident that the frequency of rotation of the electron in its orbit was not the right frequency to get the frequency of light, and this assumption could not be made.

In fact, radiation was a subject which seemed to defy the reasoning of the physicist. Using the usual or classical assumptions it was found that when the frequency was low the experimental and calculated results agreed, but when these formulae were applied to high frequency the experimental results failed to check with theory.

About 1910 Planck overcame the difficulty by a rather arbitrary assumption, this assumption being that the frequency of the radiation was related to the energy radiated by the simple equation, Energy $= h\nu$ where ν is the frequency of the energy radiated, and where h is a universal constant known as Planck's constant. $h = 6.545 \times 10^{-27}$ ergs/sec. This assumption says that when a radiator radiates, it radiates a definite amount of energy. This definite amount depends solely on the frequency. Thus if we are receiving energy from one or more radiators the amount received consists of one or more of these definite quantities of energy or quanta. Thus we receive energy in definite amounts.

The electron theory of electricity assumes that electricity is divided into chunks or electrons whose charge is $e = 4.774 \times 10^{-10}$ E.M. units of electricity. The electron theory of electricity is a quantum theory of electricity in that electricity is divided into elementary charges all of which are alike.

It has been said at times that energy is divided into quanta. It is true that according to the theory of quanta we receive energy in quanta or chunks, as it were, but the size of the chunks depends on the frequency of the radiator. The higher the frequency the larger the chunk.

The assumption that energy $= h\nu$ without any apparent justification was a rather radical assumption. The only justification for this assumption, according to Planck, was the fact that it worked*.

Bohr, in 1913, made use of this quanta assumption in what is known as Bohr's atom. He assumed that the atom like the Thomson atom, consisted of a positive nucleus with electrons revolving about the central nucleus in orbits much like the planets about the sun. These orbits are definite orbits, paths, grooves or levels, which bear certain relations, one to the other, the radii being to each other as the squares of the natural numbers. Thus the ratio of the radii are 1, 4, 9, 16, etc. When the electron is in one of these orbits or grooves it is stable. When it falls out of one orbit it descends to another. In a normal atom all the electrons are in their proper orbits rotating about the nucleus. In the normal condition electrons are found in the orbits nearest to the nucleus.

When the atom has been excited, one or more of the electrons has been lifted or knocked out of its normal orbit into an orbit of greater radius. This necessarily required work or energy to move the electron against the attraction of the nucleus. When the electron falls back to its normal orbit or level it radiates a certain amount of energy. This energy radiated is the difference in the potential energy of the electron in the two orbits or levels. The loss of potential energy is $W_1 - W_2$, and this is equal to $h\nu$. When the change of energy from one level to another is great the frequency of the radiation is great, and the light radiated is violet or ultraviolet light, while if the energy levels are not greatly different the light radiated has low frequency such as red or infra red light.

According to the Bohr theory the simplest atom—hydrogen—consists of a positive nucleus and one satelite or electron revolving about it. The normal

*Planck's Heat Radiation, Marius, p. 120,153.

position of the electron is necessarily in the inner ring or in the ring whose radius is proportional to unity.

If a mass of hydrogen gas is excited, as in a Plucker or Hittorf tube attached to an induction coil, the electrons in certain atoms are lifted from the orbit of radius one to the orbit of radius two. Others are lifted to orbit three, and others to higher levels if the discharge of the coil is sufficiently intense. If these electrons fall or jump to the home orbit, then the frequency is proportional to the difference of energy, or the frequency $\nu = Rz^2(1/n^2_1 - 1/n^2_2)$. If the electron falls from the second orbit to the first, the frequency is proportional to $(1/1 - 1/4)$, or to $3/4$. If it jumps or falls from the third to number one, the frequency is proportional to $(1/1 - 1/9)$, or to $8/9$. The frequency due to a jump from any orbit to the home orbit is proportional to $(1/1 - 1/n^2)$ where n is the number of the orbit from which it fell.

If the electrons fall from higher orbits to orbit number two, then the frequency is proportional to $(1/2^2 - 1/n^2)$ where n is a number greater than two; i.e., 3, 4, 5, etc.

$$\text{The frequency } \nu = \left(\frac{2\pi^2 e^2 m\ z^2}{h^3}\right)\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where e is the charge of the electron, m is the mass of the electron, h is Planck's constant, and z is the atomic number which is equal to the positive charge of the positive nucleus.

When the above formula is calculated the frequency of the lines in the Balmer spectrum of hydrogen is given exactly.

Years ago Balmer had noted that the wave length or frequency of certain lines in the hydrogen spectrum could be expressed in a formula like the above, in that it might be expressed in terms of the difference of terms proportional to the square of the natural numbers. Balmer developed his formula by a cut and try process from the measured values of the lines in the hydrogen spectrum.

When the electrons fall into orbit number three the calculations agree with the frequency of certain lines which Paschen had noted belonged to a certain series, known as the Paschen series.

When the end orbit is number one we have what is known as the Lyman series. When the electrons fall into orbit four from the higher orbits we have the Brackett series.

The frequencies of the Lyman series are necessarily greater than those of the Balmer series. The Lyman series is in the ultra violet spectrum of hydrogen. The Balmer series have frequencies which correspond to the frequencies of the visible spectrum. This accounts for the fact that the Balmer series was the first series worked out.

The Bohr atom model works very well for hydrogen and the more simple atoms. When the number of electrons or planets increases it will be seen that the theory becomes very complicated and hard to manipulate.

The Bohr theory does not attempt to tell how the atom radiates. It simply says that the potential energy of the atom in a certain orbit is a certain amount; that when it jumps to an inner orbit the energy in that orbit is a smaller amount and the difference of these two energies somehow is radiated into space and the frequency of the radiation or light is such that h times the frequency is equal to the change in energy.

The old classical or ordinary laws of mechanics such as: forces, proportional to the products of electric quantities and inversely proportional to the square of the distance; the kinetic energy of the moving electron equals $\frac{1}{2}mv^2$, and such laws apply while the electron is in an orbit.

The ordinary mechanics apply until the electron jumps to a new orbit then the energy appears as light of frequency ν. After we have transformed the energy of the jump into light by the $h\nu$ process, then the Maxwell classical equations of wave motion apply. The justification for the queer assumption is that in the case of the Balmer series and like cases, it works.

The hydrogen spectrum is comparatively a very simple spectrum. Spectra of certain other elements are very complicated. Certain lines in the spectrum when analyzed are found to consist of two or more lines. This is known as fine structure. In trying to account for fine structure, relativity, and many arbitrary assumptions are resorted to. After one has made so many of these assumptions that seem necessary, it is almost as difficult to remember the assumptions as it is to remember the structure of the lines, one by one.

Any theory or model is useful, if for nothing else, in helping us to make a card catalog, as it were, of our knowledge. When the card catalog becomes more complicated and confusing than the pile of objects or data to be catalogued, the system has lost its usefulness. In like manner the Bohr theory, when applied to the more complicated cases, becomes quite unsatisfactory.

In the early nineties we knew what an atom was. In the early part of this century we knew what an electron was. In like manner we knew what X-rays were. During the last few years we are not so sure of our knowledge.

Certain experiments indicate that light, X-rays and radiation in general is radiated in quanta. Not only is the energy radiated $h\nu$ but the waves, if waves they be, all tend to go from one point to a second definite point, instead of being radiated in all directions from the source of the radiation. Thus light seems to go and come in chunks, or bunches of waves, or in quants.

In a photoelectric cell we have a coating of sodium, potassium or some such metal. When light strikes the metal, electrons are given off. The velocity with which these electrons are shot off depends upon the frequency of the light, not on the intensity. A very feeble violet light will cause electrons to leave the surface of the cell with a greater velocity than the velocity imparted to electrons by a strong red light. If the intensity of the light is increased, the number of electrons given off is increased but the velocity of the electrons remains the same. The $h\nu$ relation holds for the feeblest light. The velocity of the electron depends on the frequency of the light and is independent of the intensity.

If in an atom such as a mercury atom a certain electron falls between two orbits so that the loss of energy is equal to h times the frequency of green mercury light, and if this light falls upon a photoelectric cell and liberates an electron with the proper velocity so that its kinetic energy is equal to h times the frequency of the green mercury light, then the energy of the electron shot from the coating of the photoelectric cell is just equal to the energy lost by the electron in the mercury atom. If this be true, then it seems to be unthinkable that this can happen unless all the energy from the electron in the mercury atom was used to shoot the electron out of the surface of the photoelectric cell. This seems to indicate that all the energy from the mercury atom went in a bunch to the surface of the photoelectric cell.

Light from any source apparently goes out in all directions. However, all known sources of light consist of millions of radiating atoms. If we could get light from a source consisting of a single atom, we presume that it would not spread through space but perhaps go in one direction as a group of waves, something like a small school of minnows moving in water—all the little wiggles stay together and move together in the same direction.

On the other hand, light from the faintest stars produces interference patterns. Light which traverses one side of the lens of a telescope interferes in such a manner with light from the other side of the lens as to indicate that light from the two sides of the telescope came from the same source or electron. Thus the diameters of a quant is equal to or greater than the diameter of the largest telescope lens. The size of the quant as this bunch of waves or radiation is called is perhaps comparable to the size of a barrel.

The quanta radiation of X-rays is borne out by the Compton effect in which a quantum of X-rays of known wave length or frequency is so directed that the X-ray lifts an electron out of the material target upon which the X-rays impinge. It is found that the reflected or scattered X-ray has a lower frequency than the frequency of the primary X-ray. The difference in frequency can be accounted for if we assume that the difference in energy of the X-ray bundles is equal to the energy given to the electron. The calculations are made in the same manner as if we were to assume that we were dealing with two balls which strike each other and bound off at different velocities. The striking ball is the quant of X-rays; the electron is the ball struck. The quant and the electron rebound from each other in such a way that there is conservation of energy and conservation of momentum, as is the case when two elastic balls strike.

In the above we have X-rays acting like material balls, the same as electrons.

On the other hand we have electrons acting like waves. In 1924 L. de Broglie showed that the dynamics of any particle could be expressed in terms of the propagation of a group of waves. Later Davisson and Germer were able to show experimentally that electrons gave diffraction or interference patterns when they were shot through thin gold foil in the same manner that X-ray diffraction patterns are obtained when the X-rays are passed through thin foil or crystals. Here we have electrons giving diffraction patterns like light should. In the Compton effect we have light acting much the same as moving particles should.

I believe Davisson and Germer stated the dilemma something like the following: "We all know a rabbit when we see it, and we all know a cat when we see it. When we see a cat with a cotton tail on the lawn chewing its cud we wonder, but when we see a rabbit with a long tail climbing a tree, we are seeing things."

When we light a lamp and all the light goes in one direction to a certain point exactly like bullets from a machine gun, and when we take an electron gun and shoot electrons through a crystal grating and these electron bullets arrange themselves in orderly lines on a photographic plate, like light from an arc lamp which has been passed through a grating, we begin to wonder if we really know what wave motion or electrons are.

In an atom such as that of the Bohr atom we have an electron which is moving with a velocity V and obeys all the laws of the planets and other moving bodies. We may place rather more or less of a boundary for this electron, a boundary in which the electron must obey the classic theories of moving bodies. Suddenly there is a change and we have light or X-rays. We may perhaps place a boundary on this condition in which Maxwell's electrodynamic wave theory holds. We had energy in one box or boundary and this was $\frac{1}{2}mv^2$. The same energy is suddenly found in the other box or boundary and now it is $h\nu$. The only connection we have between the two is the two short horizontal lines in the equality sign in the equation $\frac{1}{2}mv^2 = h\nu$.

This dilemma can perhaps be smoothed out if we assume that the electron is a wave and that wave motion has mass and some of the properties of material particles. After we have reached this state of mind we are ready for wave mechanics, a mechanics something like Schrodinger's Mechanics, a mechanics in which an electron has no real position but a more or less probable position, where position and velocity seem to be two contradictory states.

Eddington says "Schrodinger's wave mechanics is not a physical theory but a dodge," and Eddington adds, "A very good dodge too."

Mathematically it is quite easy to see that we can pass from material bodies to waves, or vice versa, if we make certain assumptions. As a simple case we need not make more assumptions than those made by Planck, that energy is radiated in quanta, and this, according to Planck, is equal to $h\nu$ and $h\nu$, the energy of a moving ball, is equal to $\frac{1}{2}mv^2$, which is supposed to apply to light or radiation.

If the energy of the ball is $\frac{1}{2}mv^2$, which is equal to $h\nu$, ν is the frequency of the ball. Mathematically it may be either the frequency of the ball or the frequency of the light, or we can let it alone without designating just what vibrates. If we are very mathematically minded we can say we have a frequency and do not need a model to picture something vibrating. We simply have a vibration. Why worry about what vibrates?

$2(\frac{1}{2}mv^2)$ is momentum $= h\nu/c$ where c is the velocity of light. Thus we can say waves have momentum and electrons have frequency.

Why is this so? Because Planck made a lucky guess. I can not help thinking that he made his guess intuitively, after he had consciously or unconsciously observed how things radiated. To my mind there is something in the inner mechanism which makes radiators radiate in such a manner as to make the radiation received act as Planck guessed.

Because Planck made a lucky guess several others have attempted to imitate this method. As it has been said, "You can fool some of the people all of the time and all of the people some of the time, but you cannot fool all the people all the time." Likewise, some of the people may "guess" right all of the time, and all the people may guess right some of the time, but all the people can not guess right all the time. In other words, those who guess right all the time do not do much guessing.

There has recently been an excessive amount of unsubstantiated guessing. The more absurd the guess, the more newspaper space it commands. As soon as the ink is dry these authors feel that their work has been completed. The most objectionable feature is that many will not even admit that they are guessing, but state their theories as substantial facts. Others, like Sommerfeldt, are willing to admit their theory is a bold guess made to fit conditions, in the hope that their information is complete enough to justify their assertions.

When you hear a man make the assertion that the new theory of whatever kind, quanta or otherwise, has overthrown all the old theories and absolutely explains the universe, you may put it down that this particular man does not know the theory of which he is talking. Perhaps this person may be like the relativity expert whose mind had become so mathematically profound, and had become so much divorced from all things physical, that he firmly expected to get measurable relativity effects with such small velocities and accelerations as those of the earth rotating on its axis.

CONCLUSION

I have traced physics from the time when everything was known and definite, to a time when some things in it are neither very well known nor very definite. Some of the best authorities say that it is impossible to have, or to imagine, a working model of the modern theories. It would seem that some of the theories of physics are not physical; that our imaginations have carried us away from the known into the unknown for our explanations.

There is danger in making an assumption which may not be borne out in experiment, even though it seems quite logical. To the average mind, it seems entirely plausible that a ten pound weight should fall ten times as rapidly as a one pound weight. At one time theory said such was the case. However, experiment failed to substantiate this theory.

What is the exact condition of physics, you may ask. The great majority of the theories of physics are the same today as they were twenty-five or thirty years ago. The great changes are in relation to things of which little or nothing was known a few years ago. The uncertainty is concerned with some things such as atoms and electrons and how they behave. No one has ever seen an atom or an electron. We have assumed that they are like balls or like rings, or like solar systems, or perhaps they are as Planck guessed, $h\nu$. So far, nothing has explained everything in detail. And, of course, we always have the privilege of making further investigations.

I have already mentioned the changes in the appearances of men and women. Sabine, the father of modern acoustics, found that the acoustics of a room or theater were often improved by filling the room with people. Echoes and reverberations are due to sound waves bounding and rebounding from the walls and objects in the room. This continues until all the sound is absorbed. In a room filled with people the reverberation does not last so long. Sabine found that an average man absorbed a certain amount of sound and an average women absorbed more. During the past few years the order has been reversed. Due to the modern clothing, men absorb more than women.

Our knowledge of electrons, atoms, X-rays, and light waves is about as meager as that obtained about men and women by reverberation experiments. We observe some more or less indirect effects and then draw our conclusions and make our models of the atom and try to picture to ourselves what a light wave looks like. Imagine a blind intelligent being from Mars coming to earth and making reverberation experiments on theaters filled with men and women and then taking his data back home and there drawing a picture of a man or of a woman. It is possible that he might omit some of the details. The dimple on the chin perhaps.

In the structure of the atom, electron, and wave motion we may have made some mistakes. Even if we have been on the wrong track in many instances, our efforts have revealed some worth while facts. We have been able to assemble our theories in such a manner that we have developed many important industries. The vacuum tube, in which we assume we have a stream of electrons, has revolutionized and quickened telegraphy and telephony, to say nothing of radio and other uses of the tube. Nowadays such prosaic occupations as picking or sorting beans may be accomplished with vacuum tubes, even if we do not know what is in the tube.

The physics of the nineties applies today to most things to which it applied then, and in the same manner. In some few cases our conceptions and the applications have changed, such as those regarding the structure and habits of the atom, the electron, and wave motion in the ether.

The cases where radical changes are noted are those in which we have made conjectures concerning structure and motion—surmises which have been based upon meager and indirect experimental evidence. We have guessed repeatedly. We have made assumptions until we have vibrations without anything vibrating. We have momentum and change of momentum without anything moving. We have come to the place where to quote some of the leaders of modern Physics "it is impossible for the human mind to conceive of a physical model which will act according to the theory." It is in cases of the unknown or of the unseen such as atoms and electrons where the classical physics has failed to explain.

I firmly believe that the fundamentals of physics have not changed in the last few years. We have broadened our knowledge and conceptions but as yet all is not known concerning atoms, electrons and wave motion.

At present there are several seeming conflicts in our theories. But the time is coming when our knowledge will be increased to the point where it will be shown that our seeming conflicts are particular cases of a broader general conception. A conception which will be as simple and as universal as the law of gravitation.