Some Notes on the Mechanism of Light and Heat Radiations.

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In all the realm of the natural sciences there has been no more fascinating and elusive problem than that relating to the mechanism involved in the transmission of light and heat. How energy may be transmitted at a distance; what action is involved at its source; what properties matter may possess that this may proceed over vast spaces; what atomic and molecular changes are involved in the emission and absorption of light and radiant heat, are all questions involving the ultimate structure of matter and are as yet incapable of complete solution.

Some of the familiar types of wave motion we observe in nature; for instance, wave motion in water; the transmission of sound waves through air, water and various solids are of such a character as to be easily reproduced under conditions whereby they can be accurately measured, their origin determined and their mode of propagation analyzed. In case of vibratory motion in matter capable of affecting the auditory nerve or in other words of producing sound, the mechanism is comparatively simple. As to source we have a material body, executing some form of simple harmonic motion; these vibrations being "handed on" to adjacent particles in a periodic disturbance or wave. This propagation stops, however, when the limit of matter has been reached, i. e., sound waves cannot traverse a vacuum. In all this process, matter has been concerned, both in the origin and the propagation of the wave motion. In light and heat waves, matter is concerned, also both in its production and absorption; but in its propagation they do not appear to depend in any way upon the presence of matter, as they pass readily through the best vacua and traverse the vast interstellar spaces with apparently the greatest ease.

Since we find that all radiations of light and heat energy originate in matter we must find the mechanism necessary for their production intimately involved in the constitution of matter itself. The kinetic theory served to give an incomplete mental picture of this mechanism and upon it was based many of the hypotheses of the past.

Various electrical and optical phenomena have been explained upon the ground of ether disturbances. These disturbances have been inter-

preted in different ways, but the consensus of opinion is to assign them to one of two kinds: first, magnetic and electro-static phenomena caused by strains in the ether and, second, based upon a dynamic disturbance; disturbances which can be propagated through the ether at the rate of three times ten to the tenth cm. per sec. (3×10^{10} cm.) These ether waves proceeding radially from the source carrying with them, not matter, in its old sense, but energy.

It is an established fact that all bodies emit radiant energy in some degree; the intensity of this radiation being dependent upon the character of the body, its surface peculiarities and upon its temperature. Kirchoff gave us a law which states a relation between the emissive and absorptive power of bodies, "that the ratio between the absorptive power and the emissive power is the same for all bodies at the same temperature and that the value of this ratio depends only on the temperature and the wave length." For a "black body" this ratio is considered unity in as much as it absorbs all the radiant energy which falls upon it. While we know of no substance which may be considered a "black body" in this sense, the radiations within a uniformly heated enclosure may be considered to approximate those emanating from a perfectly "black body."

Stefan's law takes us a step further and gives us a relative measure of the radiation of a black body emitted at different temperature. The law states that "the total energy radiated by a black body is directly proportional to the fourth power of the absolute temperature of the radiating body,"

$$\text{i. e. } E = C T^4 \text{ or } \frac{\Psi}{\Psi_\circ} = \left(\frac{\Theta}{\Theta_\circ}\right)^4 \text{ whence } \frac{\Theta}{\Theta_\circ} = \frac{\lambda_\circ}{\lambda} \text{ or } \Theta\lambda = \text{constant.}$$

Observation shows that the color of a "black body" is a function of its temperature; for instance at 530° C. it glows with a dull red; at 1000° C. the red gives place to a yellow and when 1200° C. to 1250° C. has been reached it has grown white hot or incandescent. In the spectrum of a black body we find the distribution of energy to be dependent upon its temperature. Wien has shown "that as the temperature of the body rises that the peak of the energy curve is displaced towards the shorter wave length." While Wien's law and his proposed revision stated in his second law satisfied the conditions obtaining in a limited area of the visible spectrum it was found not to hold true with respect to facts relating to wave lengths lying in the

region beyond the visible red. To satisfy these conditions Professor Max Planck proposed a modification as follows:

$$E = \frac{C\,\lambda^{-5}}{\varphi^{\frac{c}{\theta\lambda}} - 1}$$

C and c are constant.
where φ base of natural log.

As far as recent determinations have been carried out, this law holds true and gives practically a complete energy curve of a black body for desired temperatures. Not only did the statement of this law serve to reconcile purely theoretical conclusions with experimental determinations but paved the way for a more advanced step toward the explanation of the mechanism involved in radiation.

It is evident that we have yet to establish the connecting link between the thermal condition of a body and the radiant energy sent out into space by that body. If we go back to the theory developed by Maxwell we can easily see how this energy is propagated when once started in the ether. This theory clearly accounts for its speed, for interference and diffraction phenomena, but it apparently fails to closely associate thermal condition and the subsequent radiant energy. Planck found that this formula did not satisfactorily represent the relation existing between the frequency and the amount of energy involved, i. e. why, as a body grows hotter, does its color change from dull red to yellow and then white, unless there was some definite mathematical relation existing between the frequency and amount of energy given out by each vibratory particle. In an endeavor to determine this relation, Planck was led to advance the Quantum theory or hypothesis wherein he develops a type of function which apparently agrees with the facts better than any theories previously held. In doing this he has made a unique assumption, leaving the idea of the equi--partition of energy so necessary to the former theories, he has put forth the idea of the distribution of energy among the molecules of a substance through a mathematical consideration of probability. It is interesting to note in this connection that Planck states that the reason why no absolute proof of the second law of thermo-dynamics has ever been given is that it rests not on unchangeable mathematical relations, but upon mere probability or chance. Following out this idea he assumes that there may not be a steady, uniform flow of energy from a heated body, but that this may be propelled outward in quantities which

are integral multiples of some fundamental unit of energy. This implies that energy is emitted from a body in some definite, finite unit and is closely related to his idea that the entropy of a body is a function of the probability of its present state.

Conceiving the emission of radiant energy as explosive in type and not continuous, Planck concludes that these energy units may not be necessarily of the same magnitude. When a system is vibrating with high frequency, a large amount or large unit of energy is associated with it, whereas one of low frequency gives out smaller quantities or units of energy, thus giving us an explanation why so little energy is found in one end of the spectrum. The fact that some bodies have low thermal capacities at low temperatures and that these increase with rise in temperature is indicative of the value of this theory. In this connection it is interesting to note that an explanation of the hydrogen lines in the spectrum has been proposed, based on the idea that no radiations take place except when one electron vibrating changes the form of its orbit, at which instant the energy change of the system is the same. Take the case of the line spectra; it has been asserted that the lines in the spectrum of hydrogen are due to various electronic vibration frequencies in the hydrogen atom, when the equilibrium of this atom has been disturbed; but when this electron is vibrating about the so-called positive core of the atom that we have an entire system in equilibrium. As long as these vibrations are regular no energy can be sent forth, inasmuch as by this, the equilibrium of the system would be disturbed. With this disturbance there would be a change in its vibration frequency and assuming the radiation emission to be continuous it follows that the frequency change will likewise be continuous; but this at once results in the destruction of the lines in the spectrum. An ingenious explanation of these hydrogen lines has been proposed based on Planck's Quantum theory. The electron is conceived of as vibrating about the central core in some form of a stable orbit, probably ellipical in shape. At the instant that one of these orbits changes form radiation will take place. At this instant the radiation will be of one frequency and the energy change will be represented by $E = hn$ where n is frequency of vibrations and h is the universal constant of radiation and is termed by Planck the "operating quantity."

The problem is a very complex one and has been approached from many angles. The Zeeman effect produced when a light and heat center is placed in a magnetic field offers additional evidence relative to the shifting of line

spectra. It was found that the line spectra was materially changed when the center in question was placed in a strong magnetic field. Later this was shown to be related to the vibration of a negative charge of small magnitude, giving additional confirmation of the electron theory of radiation. We know that when a particle or particles of matter execute some form of simple harmonic motion with sufficient frequency that a note of definite pitch is produced. Why can not we carry the sound analogy over into the realm of electronic motion and conceive of one of these electrons executing some form of simple harmonic motion with, of course, some definite period, its frequency bearing some definite relation to its temperature, as proposed by Planck.

If the sound analogy referred to applies to combined waves of varying frequency and wave length so as to produce "spectral harmonics" to coin such a phrase, the center producing them must of necessity be very complex. Take for instance the fluorescent effects noted when the vapors of certain metals is examined; or the luminosity of a gas when a small portion of its molecular aggregate has been ionized. It has been found that when $\frac{1}{10,000,000}$ part of the molecules of a gas has been ionized that it becomes luminous. Likewise it has been observed that dissociation of some of the halogen group is accompanied by changes in its absorption spectrum. Many experiments also show that fluorescence and likewise phosphorescence are due to or accompanied by dissociation or ionization.

Considerable light has been shed upon this problem by the study of the emission of heat by radioactive substances. Curie and Laborde found in 1903 that the temperature of a radium compound was maintained by itself several degrees higher than its surroundings. It was found that radium emitted heat at a rate sufficient to more than melt its own weight of ice per hour. According to Rutherford the emission of heat from radioactive substances is a measure of energy of the radiation expelled from the active matter which are absorbed by itself and the surrounding envelope. This heating effect was supposed to be a measure of the kinetic energy of the expelled α particles; the heating effect was calculated by determining the kinetic energy of the α particles expelled from one gram of radium per second.

K.E. $= \frac{1}{2}$ mn ΣV^2 m = mass of particle.

n = no. emitted by each group per second.

v = the velocity of the different group of particles

considering the energy of the recoil as equal and opposite that of the α particle, the energy of recoil of mass M is $\frac{1}{2}\frac{m}{M}MV^2$, therefore total energy is $\frac{1}{2}$ mn$[1 + \frac{m}{M}]$ $\Sigma V^2 + E$ where E is the energy of the β and λ rays absorbed under these conditions.

1.38×10^3 ergs per second corresponds to heat emission of 118 grams calories per hour.

Heating effect of emanations 94.5 calories per hour.

Observed values 94 calories per hour; calculated 94.5 calories per hour.

Rutherford and Robertson made an experimental determination to see how accurately this theoretical value harmonized with the experimental value and found a very close correspondence between the two values. This agreement led Rutherford to say that "there thus appears to be no doubt that the heat emissions of radium can be accounted for by taking into consideration the energy of the radiations absorbed." (The heat emitted is 2.44×10^6 calories per gram).

He gives an interesting comparison as to the amount of energy set free in the action accompanying the expulsion of the rays, as follows: "the heat emitted during the combination of 1 cc. of H and O to form H_2O is about 2 gram calories; the emanation during its successive transformations thus gives out more than ten million times as much energy as the combination of an equal volume of H and O to form water although the latter reaction is accompanied by a larger release of energy than that of any other known to chemistry."

Further, "the energy emitted by radioactive substances is manifest during the transformation of the atom and is derived from the initial energy of the atoms themselves. The enormous quantity of energy released during the transformation of active matter shows unmistakeably that the atoms themselves must contain a great store of internal energy;" "undoubtedly this is true of all but it is only perceived in the case of those which undergo atomic transformation."

Experiments conducted within the past three years at Munich in determining the interference effects produced by the passage of X-rays through crystalline substances have shown that X-rays possess many of the properties

of light waves except in regard to their wave length, these being approximately 1/10000 the length of ultra-violet waves; these and the foregoing phenomena accompanying the ionization and dissociation of various gases; the disintegration of radioactive substances have given the champions of the undulatory theory of light some reason for alarm; the phenomena of interference was formerly considered as explainable only in the light of the wave theory, but the behavior of the X-rays when examined for interference effects in crystals seems to pave the way for a revision of this. Not only can the wave lengths of X-rays be measured by the method suggested but the atomic structure of the crystal itself is revealed and the motion of the atoms outlined. The imporatnce of this discovery in relation to thermal effects and heat emissions accompanying chemical reactions and rearrangements can hardly be overestimated.

As to the seriousness of the attempts to get at the ultimate constitution of light and heat centers and thereby gain a clearer knowledge of the mechanism of radiation, we have but to note the trend of thought as presented in recent papers read before the British Association for the Advancement of Science. At the recent Birmingham meeting of this association, a vigorous discussion arose as to the fundamentals involved in this question of radiation. At the meeting, J. H. Jeans, F. R. S., gave a very interesting and comprehensive summary of the facts relating to this fruitful topic; while he sets forth the new idea involved he retains faith in the truth of Maxwell's equations, but suggests that these equations can be made of more general application by the addition of the expression representing the unit quantities employed by Planck in his development. These quantities being respectively E and h. The magnitude of H has been determined to be 6.415×10^{-27} gm. cm./sec., an exceedingly small quantity. We might quote from Einstein in support of the quantum theory; he approached the problem from the standpoint of the theory of relativity. It may be necessary to revise our ideas of an all-pervading ether so essential to the working of the undulatory theory. We are just beginning to realize that we may have arrived at a point in our knowledge of light and heat centers where the wave theory fails to carry us any farther and that whereas it serves us well in explaining difficulties of elementary problems it does not carry us to an ultimate solution. We may conclude that as there are unmistakeable evidences derived from different sources that the undulatory theory fails to give satisfactory solution to many of the newer problems that have

arisen. The additions which it must receive are in the region of photo-magnetic or photo-electric manifestations as evidenced by the Zeeman effect and the connection existing between ionization and light centers.

Perhaps some investigator in the field of electro-magnetic oscillations will be able some day to devise an oscillator of such frequency that not only will he be able to produce radiant heat but run the gamut of a photo-chromatic scale not of sounds and their overtones and harmonics but create for us the gorgeous colors of a sunrise or a sunset; or perhaps there may arise a counterpart of modern orchestral music executed not in a concord of harmonious sounds but of color, with shades and tints more marvelously beautiful than any the human mind has yet conceived.