A QUANTUM THEORY OF THE IMPULSE RADIATION

By Frank W. Bubb

Abstract

A quantum theory of the impulse radiation.—Evidence is presented which indicates that the quantum ejects the photo-electron by a sideways impulsive action in the direction of the "electric force." It is therefore assumed that a similar sideways reaction perpendicular to the direction of emission of the quantum acts on the cathode electron during the creation of the quantum. From this it follows that the frequency of the radiation emitted at an angle ϕ with the cathode beam cannot exceed the value $v_0 = m\beta^2c^2 \sin^2\phi/[2h\sqrt{1-\beta^2}(1-\beta\cos\phi)]$ where βc is the velocity of the cathode electron; hence the forward radiation exceeds the backward in hardness, in agreement with observation. Assuming the "electric force" of the quantum is determined by the sideways impulse acting in the creation of the quantum, results for polarization are obtained which agree with those of the wave theory and hence with observation. The problem of intensity distribution of the radiation from a target is a statistical one which will be treated later; but it is shown that the results of Stark and Loebe are in accord with this theory. The quantum is supposed to be a tiny corpuscle which undergoes a sideways cyclic vibration as it proceeds. This theory is seen to include a momentum relation as well as the Einstein photo-electric relation. It agrees in most formal results with Sommerfeld's wave theory.

Introduction

THE corpuscular theories of radiation which have been so far proposed, have all lacked the essential feature of a momentum relation. The chief support for these theories has been the phenomena covered generally by the Einstein photo-electric equation. This equation gives us information on frequency and energy phenomena, but we cannot expect a relation concerned only with energy to supply a complete dynamical basis for a corpuscular theory of radiation.

One of the most outstanding defects of corpuscular theories is their failure to explain polarization phenomena. In addition to this they do not account in as definite a manner as the wave theory for the fact that the x-radiation emitted from the forward side of a thin target bombarded normally by cathode rays, exceeds the backward radiation both in frequency and intensity. While corpuscular theories might suggest a maximum intensity in the forward direction, they have not so far required a maximum at about 60°, as Stark finds to be the case.

In striking contrast to this lack of success of the corpuscular theories, the wave theory in the hands of Sommerfeld[1] has given a rather complete

[1] A. Sommerfeld, Phys. Zeitschr. **10**, 969 (1909)

description of these various effects. It is true that the pulse theory, on which Sommerfeld based his explanations, has for excellent reasons been abandoned by most physicists. Nevertheless a critical examination of Sommerfeld's theory (or in fact almost any of the classical wave theories, for example, J. J. Thomson's theory of the scattering of radiation) cannot fail to impress upon one the remarkable power of the wave conception of the "electric force." It is by aid of this "electric force" that wave theorists are able to explain polarization phenomena, and to supply a dynamical basis for their theories.

Now there is no fundamental reason why corpuscular theories may not make use of this very potent conception of the "electric force." We might assign a sideways vector property to a corpuscle of radiant energy. If the properties of this sideways vector are judiciously defined, we may hope to explain polarization phenomena and even to make an attack on interference phenomena. A number of formal reasons might be urged for this view but certain new physical evidence may be cited which points in a very definite manner to the quantum as possessing a sideways vector property.

By the cloud expansion method the writer has recently photographed the tracks of photo-electrons ejected from air by plane polarized x-rays. These photographs show[2] that most of the photo-electrons are ejected nearly parallel to the electric vector of the polarized beam. If we choose to regard the quantum as a corpuscle, evidently, in view of this effect, we cannot regard it as a scalar bundle of energy. The writer has proposed[3] instead a theory based on the postulate that the quantum imparts its energy to the photo-electron by agency of a sideways impulse which acts in the direction of the electric vector of the radiation. By taking into account the forward momentum $h\nu/c$ of the quantum and also the initial momentum of the electron in its atomic orbit, formulas were set up which explain in a simple way both this effect and the Mackenzie[4] effect.

This view of the "vector quantum" is further confirmed by photographs published recently by C. T. R. Wilson.[5] These photographs show strange pairs of associated photo-electron tracks, both starting near the same point in the beam of x-rays and having about the same range. Now if the photo-electron is ejected by a sideways impulse it seems natural to look

[2] F. W. Bubb, Phys. Rev. **23**, 137 (1924)

[3] F. W. Bubb, Washington Univ. Stud. **11**, Scientific Series, p. 161

[4] Mackenzie, Phil. Mag. **14**, 176 (1907). This effect consists in the fact that the forward photo-electric current from a thin film traversed normally by high frequency radiation exceeds the backward current.

[5] C. T. R. Wilson, Proc. Roy. Soc. **104**, Fig. 22, Pl. 12, (1923)

for evidence of an equal and opposite reaction impulse. We might suppose the quantum to exert its sideways impulse upon one electron and its equal and opposite reaction impulse upon another electron[6] and consequently divide its energy about equally between the two. In this way we should get just such pairs as Wilson finds. Wilson states that there is a great tendency for the line joining the points of origins of the two members of a pair to be nearly perpendicular to the primary x-ray beam. This observation is in accord with the present view.

The shift recently discovered by A. H. Compton[7] in the spectral lines due to the scattering process and his explanation of this effect on the basis of the scattering of one quantum by one electron, furnishes a firm foundation for a corpuscular theory of radiation. Compton's "quantum scattered by a single electron" cannot without a most uneconomical stretch of the imagination, be conceived as having anything whatever to do with a spreading wave. The "quantum hypothesis of scattering" points directly to the quantum as being confined within very tiny boundaries which do not widen as the quantum proceeds. Surely this can have nothing to do with a homogeneous luminiferous aether, but on the contrary points to the quantum as a corpuscle. On this basis Compton,[7] Davis[8] and Ross[9] have measured in the most direct dynamically conceivable fashion the momentum $h\nu/c$ of this corpuscle.

Finally the arguments of Thomson, Einstein, Bragg and others for a corpuscular (or semi-corpuscular string) theory of radiation are well known. While most of the actual theories proposed have been abandoned even by their inventors, it is pertinent in the present connection to point out that in general the arguments presented by these theorists are still valid in almost all respects. The phenomena underlying these arguments have never been explained by the wave theory and in fact some of the phenomena have been judged to be incapable of explanation on a wave theory.[10]

In view of this evidence and these arguments and in the hope of supplying a corpuscular analogue for the very useful "electric force" of the wave

[6] On the other hand, if an atomic nucleus suffers the reaction impulse, since its mass is of the order of 2000 times that of the electron, it should receive a kinetic energy of the order of 1/2000 of that of the photo-electron. In this case we should expect to observe only one track—the ordinary case.

[7] A. H. Compton, Phys. Rev. **21**, 484 (1923)

[8] Bergen Davis, Paper before the A. A. A. S. and Am. Phys. Soc., Dec. 28, 1923

[9] P. A. Ross, Nat. Acad. Sci. Proc. **9**, 246 (July 1923)

[10] Thus R. A. Millikan remarks in effect ("The Electron" p. 230) that Einstein's photo-electric equation (deduced from a corpuscular point of view) now stands a perfect structure without visible means of support (from the wave theory).

theories, the following hypothesis is proposed. *The quantum of radiant energy $h\nu$ is a "vector quantum" or concentrated corpuscle, proceeding with the velocity of light, possessing the forward momentum $h\nu/c$, and possessing the vector property, which it maintains constant in direction as it proceeds, of imparting its energy by a sideways impulse. We suppose this vector property to be imparted to the quantum during the process of its creation (emission).*

By aid of these ideas we may set up a quantum theory of the impulse radiation which agrees in essential particulars with observation and in most formal results with the wave theory.

Outline of the Theory

Suppose that high speed electrons proceed in the direction OX (see Fig. 1) and impinge upon a thin target at O. We know from observation that high frequency radiation is emitted from the target in all directions (with certain asymmetries to be discussed later). From the observation that the highest frequency quantum emitted under these circumstances has an energy content equal to that of a single cathode electron, we infer that in this case the quantum is produced by a single cathode electron.

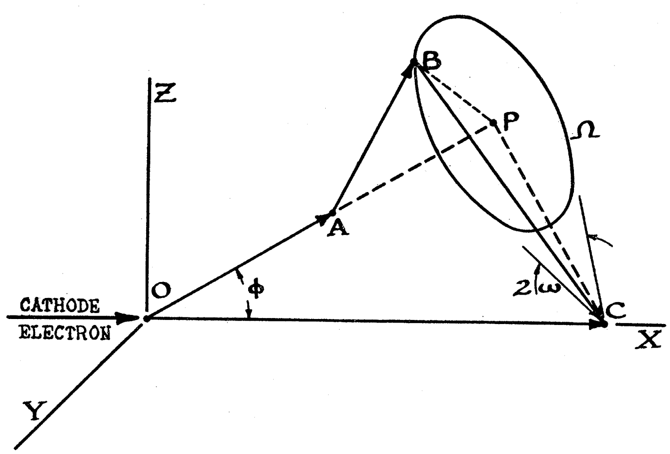

Fig. 1. The momentum relations involved in the emission of a single quantum of radiant energy.

We extend this inference and assume that each individual quantum, whether it be an "end quantum" or one of lower frequency, is produced by a single cathode electron.

Observation shows that in some cases cathode rays go right on through a thin target without producing radiation. Since the target consists entirely of atomic nuclei and electrons, we infer that those cathode electrons which do produce radiation act in conjunction with either an atomic nucleus or another electron. We shall regard the coupling between the cathode electron and atomic nucleus (or another electron) as subject to the laws of dynamics and shall make clear the present view of this coupling action by use of Fig. 1.

Let O be the point at which the cathode electron and the nucleus or electron cooperate to produce a quantum of radiant energy. Let OC be the initial momentum of the cathode electron. Let OP be the direction of emission of the quantum and OA its forward momentum $h\nu/c$. Let AB be the final momentum of the cathode electron after emission of the quantum. Finally in view of the evidence which has been previously presented to show that a quantum which ejects a photo-electron imparts its energy to the photo-electron by means of a sideways impulse, we now assume that *in the process of the emission of a single quantum of radiant energy an impulse CB whose direction is perpendicular to the direction of propagation of the quantum acts upon the cathode electron producing the quantum.* By the principle of the conservation of momentum we write the vector equation

$$OC = OA + AB + BC. \tag{1}$$

It should be noted in Fig. 1 that we require the impulse BC only to be perpendicular to OA; hence BC lies in a plane (call it Ω) through C perpendicular to OA, which intersects OA at P. In general then the point B and the vectors BC and AB do not lie in the XOZ plane.

Eq. (1) concerns only the cathode electron and does not involve directly the cooperating nucleus or electron. The sideways impulse we suppose to be the coupling action between these, or more definitely, we suppose the impulse CB to have its equal and opposite reaction upon the cooperating nucleus or electron. If this be the case, then part of the energy of the cathode electron is delivered to the nucleus or electron by the impulse. We therefore propose the following modification of Einstein's photoelectric equation.

$$mc^2\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right) = h\nu + mc^2\left(\frac{1}{\sqrt{1-\beta_0{}^2}} - 1\right) + E\,. \tag{2}$$

In this equation the left side represents the initial energy of the cathode electron where m is its rest mass and βc its velocity. The right side has three terms; the first gives the energy of the quantum, where h is Planck's constant and ν is the frequency of the quantum; the second term gives the energy remaining in the cathode electron after emission of the quantum, where $\beta_0 c$ is its final velocity; and the third term gives the energy E delivered to the cooperating nucleus or electron.

This energy E needs some discussion. In the first place if the nucleus acts with the cathode electron to produce the quantum we should expect E to be very small. For, although the momentum of the nucleus may very well be of the order of magnitude of the momentum of the cathode electron, since its mass is comparatively so much greater, its velocity and kinetic energy can only be of the order of 1/2000 of that of the cathode electron. On the other hand if an electron suffer the reaction impulse, the case is quite different. For, since the masses of this electron and the cathode electron are equal (neglecting relativity corrections),we should expect the kinetic energy of this electron to be of the same order as that of the cathode electron.

Let us assume for the present that the reaction to the impulse CB has its seat upon a heavy nucleus and that E, the energy delivered to the nucleus, is negligible. Eq. (2) above then becomes

$$\frac{mc^2}{\sqrt{1-\beta^2}} = h\nu + \frac{mc^2}{\sqrt{1-\beta_0{}^2}} . \tag{3}$$

Let $h\nu$ be assigned. This fixes the length of the vector OA which represents the momentum $h\nu/c$ of the quantum. If the speed of the cathode electron be given, it is easy to show by Eq. (3) that the momentum AB of the cathode electron after emission of the quantum is

$$AB = \frac{m\beta_0 c}{\sqrt{1-\beta_0{}^2}} = \sqrt{\frac{m^2\beta^2c^2}{1-\beta^2} - \frac{2mh\nu}{\sqrt{1-\beta^2}} + \frac{h^2\nu^2}{c^2}} . \tag{4}$$

We have already postulated that the impulse BC is in plane Ω through C perpendicular to OP. Consequently, since A is an assigned point, AB a determined length and Ω a fixed plane, it follows that the locus of B is a circle on plane Ω of center P. The radius PB of this circle is given by

$$\overline{PB}^2 = \frac{m^2\beta^2c^2}{1-\beta^2}\sin^2\phi - \frac{2mh\nu}{\sqrt{1-\beta^2}}(1-\beta\cos\phi) . \tag{5}$$

By aid of these equations we may now consider the frequency phenomena.

Frequency Phenomena

The radius PB, see Eq. (5), varies as we assign different values to ν. The maximum value which PB may have is PC, corresponding to which ν is zero. The minimum value which PB may have is zero, corresponding to which ν is given by

$$\nu_0 = \frac{m\beta^2c^2}{2h\sqrt{1-\beta^2}} \; \frac{\sin^2\phi}{1-\beta\cos\phi} \tag{6}$$

As the frequency of the radiation increases from zero to ν_0, the radius PB decreases from PC to zero. Corresponding to $PB=0$ it is easy to see that, in general, $OA \neq OP$ and that $AB=AP$, since B coincides with P (which means that the electron after emitting this frequency quantum, proceeds either exactly in the direction of the quantum or exactly opposite thereto). It we attempt to assume a larger quantum than that given by Eq. (6), it turns out that the momentum vector AB is less than AP and consequently the momentum relations cannot be satisfied. We therefore assert that the radiation emitted at the angle ϕ must have its frequency within the range zero to ν_0.

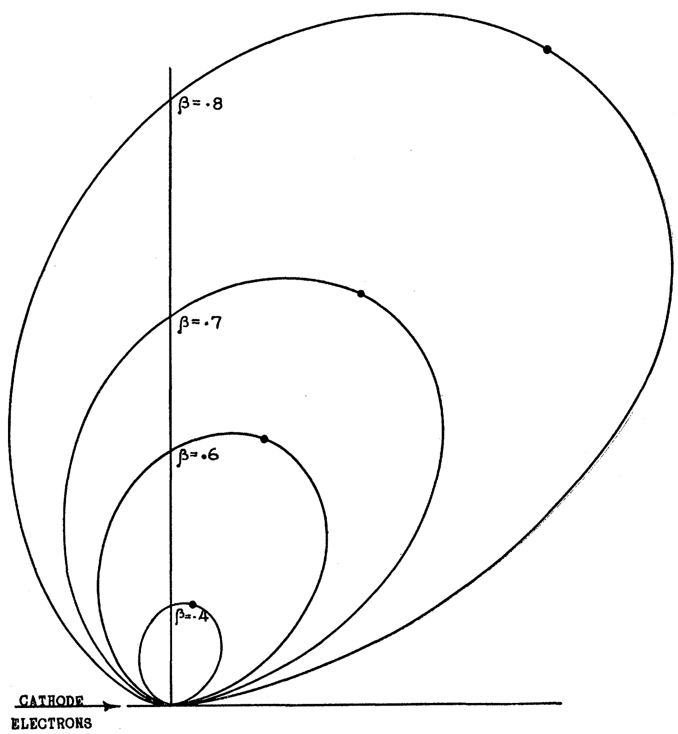

Fig. 2. Polar graph of the frequency range. The radius vector gives the maximum frequency of the radiation emitted at the corresponding angle.

Fig. 2 shows a polar graph of Eq. (6). The length of the radius vector at the angle ϕ represents the frequency range (0 to ν_0) which may be emitted at the angle ϕ. Several curves are shown corresponding to different speeds of cathode electron.

These curves bring out several results worthy of note. In the first place, the curves are not symmetrical on the forward and backward sides of the target. If we compare the maximum frequency emitted at the forward angle ϕ with the maximum frequency emitted at the symmetrical backward angle $180° - \phi$, we find the forward radiation harder than the backward in the ratio $(1+\beta \cos \phi)/(1-\beta \cos \phi)$. Furthermore, as the speed of the cathode electrons increase, the asymmetry becomes greater. These results agree with the observations of Stark,[11] Loebe, [12] Wagner,[13] Friedrich[14] and others.

The "end radiation," corresponding to the maximum possible frequency where $h\nu_e = mc^2(1/\sqrt{1-\beta^2}-1)$ = the total energy of a single cathode electron, is only emitted at the single definite angle ϕ_e. This angle ϕ_e corresponds to $d\nu_0/d\phi = 0$ and is given by

$$\cos \phi_e = (1-\sqrt{1-\beta^2})/\beta\ . \qquad (7)$$

Since the angle ϕ_e is always less than 90°, it appears that the "end radiation" is only emitted on the forward side of the target. Furthermore, the higher the speed of the cathode electron, the more nearly directly forward the "end radiation" becomes. On this point the present theory disagrees with Sommerfeld's theory. For Sommerfeld explains the fact that the forward radiation exceeds the backward in frequency as due to a Doppler effect—the emitting cathode electron moves forward as it radiates. Now in the "end radiation" all the energy of the cathode electron is given to the quantum and none is left for the radiating electron. Hence in this case the electron cannot be moving forward as it radiates and no Doppler effect can exist.

The present theory agrees in essential particulars with such general observations on the frequency of the impulse radiation as are available. So far as the writer is aware, the complete spectrum of the impulse radiation for all angles has not been determined experimentally, and a detailed test of the present results is not available. It is certain that in a test of the present theory extremely thin targets must be used or scattering within the target may so modify the spectrum as to destroy the value of the test.

Polarization Phenomena

The term "electric force" derives most of its present significance from the wave theory. On a corpuscular quantum theory this term needs

[11] J. Stark, Phys. Zeitschr. **10**, 902 (1909)

[12] W. W. Loebe, Ann. der Phys. **44**, 1033 (1914)

[13] E. Wagner, Report on the Continuous X-Ray Spectrum, Jahr. d. Rad. Elek. **16** (Dec. 1919)

[14] W. Friedrich, Ann. der Phys. **39**, 377 (1912)

definition. We shall adopt the view in the present discussion that *the impulse which enters in the creation of the quantum and which acts perpendicular to the direction of propagation of the quantum* (*the impulse CB in Fig. 1*) *defines the direction of the "electric force" of the quantum.* That is, we suppose the plane parallel to the impulse *CB* and through the line of propagation of the quantum to be the plane of the electric force. We further suppose this plane to remain fixed so long as the quantum does not pass through matter. We do not suppose that when a quantum is absorbed, producing a photo-electron, it exerts an impulse on the photo-electron equal to the impulse entering into its creation, but simply that the photo-electric impulse is parallel to the emission impulse. The magnitude of the photo-electric impulse which a particular quantum may exert would seem to depend on the circumstances in which the quantum finds the photo-electron.

Before considering the results of the present view, let us make for comparison a short review of the principal results of the wave theory concerning polarization phenomena. In particular let us consider the theory of Sommerfeld[1] and that of Rubinowicz.[15]

Sommerfeld's theory is based on the classical view that an electron radiates whenever it changes velocity. Thus when a cathode electron impinges upon a target, it is retarded and radiates. There is set up a disturbance in the aether which proceeds outward with the velocity of light in all directions. At a particular point in space the electric force varies in magnitude but remains constant in direction as the pulse passes. The electric force is confined to a plane through the point and the retardation vector of the electron, and is perpendicular to the line from the point to the emitting electron.

The theory of Rubinowicz is based on the postulate: "If in a change of configuration of the atom, its momentum or moment of momentum alters, then these quantities are to be reproduced completely and unabated in the momentum or moment of momentum of the radiation." In general (not as applied to line spectra where quantum considerations leading to the "Principle of Selection" are imposed) this theory gives the radiation as elliptically polarized at some angle to the "momentum axis of the wave." As the pulse passes over a particular point in space the electric vector varies both in magnitude and direction. We may think of the electric intensity at a point as being represented vectorially by the rotating radius of an ellipse whose plane is perpendicular to the line from the point to the radiating atom.

[15] A. Rubinowicz, Phys. Zeitschr. **19**, 441 and 465 (1918)

On both these theories, then, the pulse due to a single quantum emission sets up a varying electric (and magnetic) field at (sooner or later) every point in space. In considerable contrast to this, the present view regards the quantum as a corpuscle which can exert a force on an electron only in a single direction. However, we may still compare statistically the polarization of a beam of radiation on the three views provided that on the present view we regard a beam as consisting of a sufficiently large number of quanta to speak of an average distribution of electric vectors.

We shall study first the radiation produced by constant speed cathode electrons at the constant angle ϕ. Corresponding to a quantum of definite frequency ν, the point B may lie anywhere on the circle of center P on plane Ω (see Fig. 1). It is evident that the electric force of such a quantum must lie within the angle 2ω defined by tangents drawn through C to the circle. It is easy to show that the angle ω is given by

$$\cos^2\omega = \frac{2h\nu\sqrt{1-\beta^2}\,(1-\beta\cos\phi)}{m\beta^2c^2\sin^2\phi}\,. \tag{8}$$

If a beam consisting of a large number of quanta of the same energy content proceeds at the angle ϕ we should expect to get their electric vectors all within the angle ω on either side of the XOZ plane. If we resolve the electric vectors into components parallel to CP and perpendicular thereto, it is obvious that we should get as a statistical result a greater force in the XOZ plane than perpendicular to it. The XOZ plane, the plane of the maximum electric force, is exactly coincident with the plane of the maximum electric force as given by the Sommerfeld theory and as observed by Barkla[16] and others.

The present theory differs somewhat from that of Sommerfeld in that the degree of polarization depends on the frequency of the radiation. For, at the constant angle ϕ, as the frequency varies, the polarization angle ω varies. The result of this is that the harder the radiation, the smaller the polarization angle ω and the higher the degree of polarization. For low frequencies the electric force may be in almost any direction, but for high frequencies the electric force is confined within a very sharp angle. This prediction is in exact agreement with Kaye's statement:[17] By "filtering out the soft rays from the primary beam by use of a suitable screen, the polarization can be doubled. Hardening of the primary x-ray tube, however, apparently diminishes the effect."

[16] C. G. Barkla, Phil. Trans. Roy. Soc. **204,** 467 (1905)
[17] G. W. C. Kaye, "X-Rays" p. 117

The results of the present theory do not conflict with those of Rubinowicz in one important respect. If we identify his "momentum axis of the wave" with our direction of the cathode stream and take an average electric force in the *XOZ* plane and perpendicular thereto as we have done above, we find agreement in the comparative magnitudes of these two components. It should be noted that Rubinowicz's spherical wave is symmetrical with respect to a plane perpendicular to the angular momentum axis of the wave. No method has as yet been suggested for orienting these axes so as to give the observed asymmetrical emission in the impulse radiation. On the other hand, both Sommerfeld's theory (by aid of the Doppler effect) and the present theory give a one sided emission agreeing with observation.

Bohr,[18] by use of his "Principle of Correspondence," obtains results similar to those of Rubinowicz. We shall therefore not discuss Bohr's results except to remark that an element of uncertainty is intentionally introduced by the requirement that the polarization and intensity phenomena be only approximated by the classical theory. The classical theory is required by Bohr only to give good statistical results for these phenomena. In the present case we are forced also to treat these phenomena statistically since we are unable to predict either the size of the quantum or the direction of its electric vector for an individual emission.

Intensity Phenomena

The present theory concerns itself with the individual quantum emission and leaves the intensity distribution as a statistical problem. Before attempting a study of the intensity distribution, further information is needed as to the nature of the coupling impulse between the cathode electron and the cooperating nucleus or electron. Assumptions (we reserve these for a later paper) on the nature of the coupling may affect in a vital way such statistical matters as the intensity distribution without materially affecting the relations brought out above for the individual quantum emission.

It is interesting to compare the curves giving (see Fig. 2) the frequency range 0 to ν_0 which may be emitted at various angles, with some intensity curves due to Stark.[11] These curves were obtained by measuring photographically the intensity of the impulse radiation in different directions from a thick carbon target. The radius vector represents the blackening of the film. These experimental intensity curves and the present theoretical frequency range curves have the same general shape and both show their maxima at angles less than 90° on the forward side of the target.

[18] N. Bohr, Kopenhagener Akademie, 1918

Since the frequency curves show it to be impossible to get radiation in the exact forward or exact backward directions, the decrease in intensity in these regions shown by Stark's curves is of some interest.

Loebe, by a method similar to that of Stark, has determined[12] the angle of maximum intensity corresponding to several voltages, and has shown that this angle decreases as the speed of the cathode electron increases. Loebe's maxima of intensity show a truly remarkable agreement with the predictions of Sommerfeld's theory. The angle of emission of the maximum frequency as given by the present theory shows a similar forward shift as the speed of the cathode electron increases, but the angle is uniformly greater than that of Loebe's intensity maxima.

It seems reasonable to expect a close connection between the dynamically possible frequency range for a given angle and the intensity of emission at that angle.[19] The greater the frequency range the greater the intensity we should expect. A simple assumption would be that the intensity is proportional to the range of frequency. Besides giving general agreement with Loebe's results, this is equivalent to the assumption that the final momentum vector of the electron after emission is directed at random, subject to the necessary condition that its vector AB end on the circle PB. Since we choose to ignore the nature of the reaction between the cathode electron and the atom upon which it impinges, this assumption seems to be the simplest which could be made. It may also be shown that this assumption leads quite reasonably to an initial slope for the "isochromats" (graphs of intensity against voltage across the tube for constant frequency) which agrees with the observations of Duane.[20] These points are mentioned, not with the intention of proving anything, but only to show that the present theory does not conflict with present observations on intensity phenomena. Corresponding to every plausible assumption which might be made as to the nature of the coupling impulse, a similar argument may be presented.

Final Remarks

The present view of the "vector quantum" leads to a general agreement with observation on the phenomena of polarization and intensity. In many formal respects it agrees with the wave theories. It agrees with

[19] As a matter of fact the present theory does not require any connection whatever between the possible frequency range and the intensity at any angle. Simply because we have a possible frequency range at a given angle does not require the target to radiate at all in that direction. We may very well get an intensity distribution quite different from the frequency range curves. However, the fact of observation that these curves are quite similar is of some interest.

[20] W. Duane and F. L. Hunt, Phys. Rev. **6**, 166 (1915)

the quantum theory on frequency phenomena. In contrast to the wave theory (but in no fundamental disagreement with Bohr's "Principle of Correspondence") the present theory requires a statistical treatment of polarization and intensity phenomena.

Perhaps the most interesting feature of the present theory (provided it is borne out by experimental tests) is its bearing on the problem of the mechanism of radiation. On the present view we may imagine the quantum as a tiny corpuscle which is undergoing a sideways vibration as it proceeds (for example a vibrating di-pole). There is nothing on the present view which prevents us from assigning a sideways cyclic variation in momentum to the quantum and accounting on the usual quantum ($\int\int dp\, dq$) basis for the fact that the vibrating radiant corpuscle possesses an "energy quantum." In fact, the conception of a frequency as associated with a corpuscle possessing an energy quantum hints strongly at a cyclic variation going on within the corpuscle. On this view then the mechanism of radiation is the "vector quantum" itself and not a wriggling ether.

WASHINGTON UNIVERSITY,
SAINT LOUIS, MISSOURI,
March 6, 1924.