intensity is greatest close to 80° and that it falls off regularly as the angle departs therefrom.

We conclude, therefore, that the momentum of the electron in its orbit within the atom does not affect the direction of ejection in the way demanded by the theory of Auger and Perrin. While this does not constitute definite evidence against the physical reality of electronic orbits, it is a serious difficulty for the conception.

A detailed discussion of the general question here raised in the light of new experimental results will be published elsewhere.

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[2] Loughridge, D. H., in press.
[3] Bothe, W., *Zs. Physik,* **26,** 1924 (59–73).
[4] Auger, P., and Perrin, F., *J. Physique Rad.*, **8,** 1927 (93–111).
[5] Bothe, W., *Zs. Physik,* **26,** 1924 (74–84).
[6] Watson, E. C., in press.

THE CHARACTER OF THE GENERAL, OR CONTINUOUS SPECTRUM RADIATION

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Communicated August 6, 1927

The impacts of electrons against atoms produce two different kinds of radiation—the general, or continuous spectrum and the line spectra. By far the greatest amount of energy radiated belongs to the general, or continuous spectrum and not to the line spectra. In the X-ray region, in particular, the continuous, or general radiation spectrum carries most of the radiated energy. In spite of this, and because the line spectra have an important bearing on atomic structure, the general radiation has received much less attention than the line spectra in the recent development of fundamental ideas in physical science. The experiments described in this note deal with the general radiation and not the line spectra.

Some time before the appearance of X-ray spectrometers in research work carried on in this country the writer performed a number of experiments on the general X-radiation. The object of these experiments was to determine whether the impacts of electrons, all of which had practically the same velocity when they struck the target of an X-ray tube, would produce homogeneous, monochromatic radiation. The experiments showed that the general radiation coming from a tube operated at a constant voltage was by no means homogeneous. The advent of the Bragg's X-ray spectrometer enabled us to show the now well-known fact that the general radiation has a sharply defined lower wave-length limit, and that the spectrum extends from this limit toward longer wave-lengths, with a maximum intensity the exact position of which depends on experimental conditions. The average or "effective" wave-length of the continuous spectrum may be 30, 50 or even several hundred per cent greater than the short wave-length limit.

The application of the quantum theory predicts that there can be no radiation produced of higher frequency than that given by the Einstein quantum equation; for the maximum energy that an electron can have

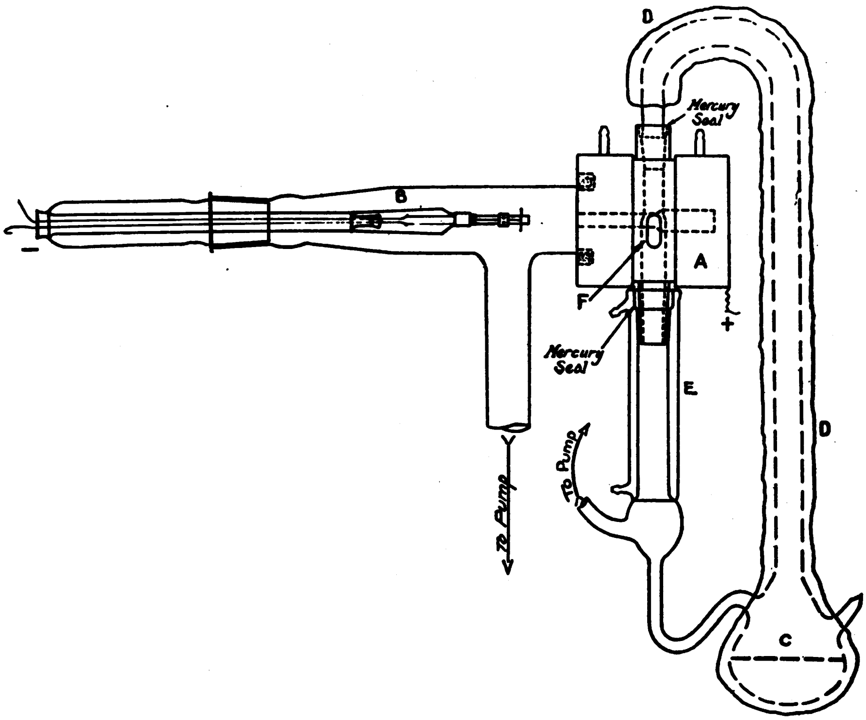

FIGURE 1

when it impinges against an atom is Ve, and if it produces radiation, the $h\nu$ value of the radiation cannot be greater than Ve. The explanation of the radiation that has wave-lengths longer than the limit has been the object of some theoretical speculations. In these the obvious assumption has usually been made that radiation of longer wave-length than the limit comes largely from the impacts against the atoms of the target of electrons that have had their energy reduced by previous collisions with other atoms. The following two questions, however, do not appear to have been definitely answered by direct experimentation. Firstly, the question as to whether when an electron hits an atom in such a way as to produce radiation other than that of the atom's line spectrum it produces a monochromatic ray or not. Secondly, the question as to whether when an electron produces general radiation it gives up its entire kinetic energy to that radiation. The object of the researches to be described in this note has been to obtain experimental evidence bearing on these fundamental questions. In particular, the problem has been to produce and examine radiation coming from the impacts against atoms of electrons all of which have substantially the same kinetic energy at the moments of impact. To realize the conditions, electrons from a hot wire cathode have been shot into mercury vapor at a very low pressure. The

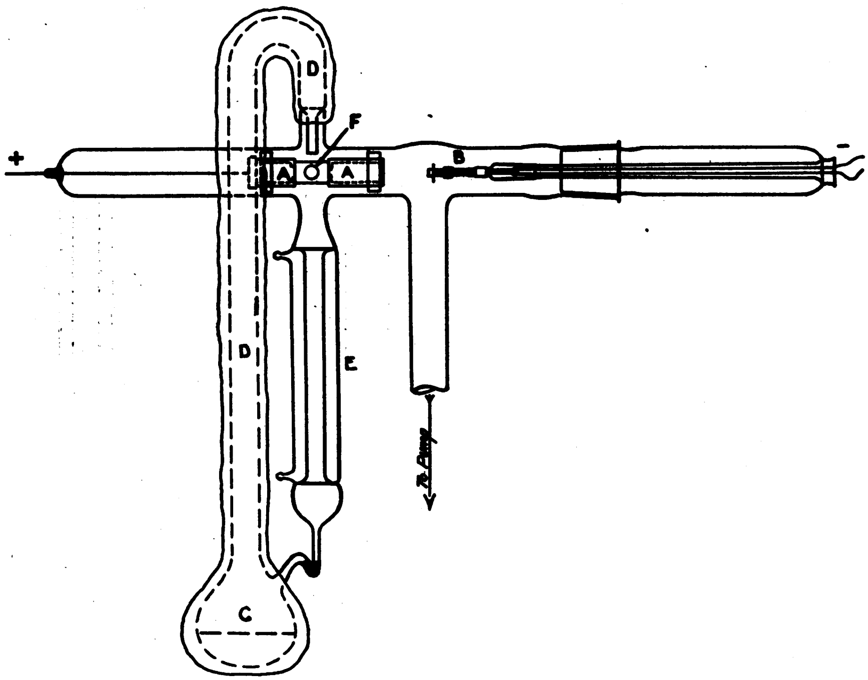

FIGURE 2

difference of potential through which the electrons fell came from a high-tension, large-capacity storage battery, the positive pole of which was put to earth and the mercury vapor was inside of a metal anode also connected to earth. Under these conditions all of the electrons must have had substantially the same kinetic energy when they entered the anode through a hole and struck the mercury atoms. The mercury vapor being at a very low pressure, probably very few of the electrons struck other atoms before they hit the atoms in such a way as to produce radiation.

Two different types of apparatus were used in the experiments. In that represented by figure 1, the anode was water cooled, and in that represented by figure 2, the anode was not cooled and got so hot during the bombardment by the electrons that no mercury could have condensed inside of it. In each figure, *A* represents the anode and *B* the Coolidge hot wire cathode which furnished the electrons. Both parts of the anode, *A*, in figure 2, that to the right and that to the left of the window, *F*, consisted of brass tubing with brass ends containing holes for the electrons to enter by. The mercury vapor came from a heated reservoir, *C*, and passed around through the connecting tube, *D*, and down through the anode. The water cooling jacket, *E*, condensed the mercury vapor below the anode. The mercury system, therefore, formed a kind of mercury diffusion pump. The heat to vaporize the mercury came from an electrical heating coil immersed in a thick coating of asbestos and wound around the reservoir, *C*, and the tube, *D*. In order to prevent the condensation of mercury in the connecting tube, *D*, the coils of wire were so arranged as to produce a much higher temperature in the tube, *D*, than in the reservoir, *C*. This heating system furnished a reasonably constant stream of mercury vapor that could be regulated by varying the electrical heating current. The mercury itself formed a sort of thin target that continually reproduced itself. The radiation generated at the points of impact of the electrons against the mercury atoms was observed through thin windows, *F*, made of mica in the apparatus of figure 1 and of glass in the apparatus of figure 2.

FIGURE 3

In order to determine the exact points from which the radiation passing through the windows actually came, pin-hole camera photographs were taken of the interior of the anodes. A sheet of lead with a pin hole in it was placed opposite and a short distance in front of the window, *F*, and several cm. back of the lead, a photographic film contained in an envelope of black paper so opaque that nothing but X-radiation could have made a photographic impression on it. Figure 3 *A* and *B* are copies of photographs taken with the apparatus of figure 1. Photograph *A* represents the points in the interior of the anode from which the radiation came when electrons entered the anode, but when no mercury vapor passed through the mercury system. This photograph shows the walls of the opening through which the radiation was observed, together with a drop of mercury that had collected at the bottom of the hole. Photograph *B* represents the source of radiation when the mercury stream passed through the anode as well as the stream of electrons. It indicates radiation from the walls of the hole and from the globule of mercury and, in addition, radiation coming from the space in which the electrons struck the mercury vapor. It is this latter radiation which has been investigated in the experiments described below. The radiation to be examined may be separated from the wall radiation by placing a lead screen in the position occupied by the photographic film and drilling a hole through this screen at the place corresponding to the darkening on the film due to the mercury radiation. Experiments showed that no perceptible radiation came from the thin windows themselves.

The homogeneity or lack of homogeneity of a beam of radiation may be determined in different ways. Firstly, the absorption of the radiation may be measured and the effective wave-length of the beam calculated. The effective wave-length of a beam in a given case may be defined to be the wave-length of a homogeneous beam that is absorbed to the same extent as the actual beam. Secondly, the homogeneity may be examined by deflecting a beam of rays by means of prisms, or gratings, etc. (in the X-ray field by crystal gratings), and the wave-length determined by the usual procedure. The latter method is far more accurate than the former and gives in addition to the average wave-length at least a rough estimate of the distribution of energy in the spectrum. The former method, however, presents certain advantages, especially in the problem now under discussion, for far less intense radiation can be tested by it. In these experiments an important point was to use as little mercury vapor as possible in order to avoid multiple impacts of electrons against the mercury atoms. For this reason the absorption method of examining the homogeneity of the radiation has been used first. The mercury heating current was regulated so as to vaporize just enough mercury to give radiation that could be detected and measured by its ionizing effect. Radiation of such small intensity cannot be examined by means of a spectrometer.

In order to measure the absorption of the beam of rays coming from the mercury vapor an ionization chamber with a thin mica window in it and containing methyliodide was set up opposite the window, F, and lead plates with holes in them were placed in the line of the beam so that only the radiation coming from the impacts of the electrons against the mercury entered the chamber with sufficient intensity to be detected. That this was the case in the actual experiments is indicated by the fact that no perceptible ionization current could be observed when the mercury pump was not running. A quadrant electrometer measured the ionization current.

In order to examine general radiation that does not contain any of the line spectra it is necessary to operate the tube at a voltage insufficient to produce the L series lines of mercury. The longest lines in the L series of mercury require a voltage of 12,300 volts and, therefore, in the experiments here described a little less than 12,000 volts was used. A current was sent from the high-tension storage battery through a circuit containing manganin wire resistances totalling a little more than 6,000,000 ohms. The X-ray tube was placed in parallel with 4,029,000 ohms of this resistance. This arrangement of circuits avoided the blowing out of the fuses in the battery, due to heavy discharges through the tube that occasionally occurred. By measuring the current passing through the 4,029,000 ohms with a standardized milliammeter an accurate estimate of the voltage applied to the tube could be made. The current actually used amounted to 2.95 milliamperes and the voltage actually applied to the tube was, therefore, 11,890 volts. This voltage produces the M series lines of mercury, but they have such long wave-lengths and are so easily absorbed by the windows in the X-ray tubes that no appreciable radiation from the M series could get into the ionization chamber. Thus the ionization current must have been due entirely to general radiation.

The short wave-length limit of the X-radiation produced by the above difference of potential of 11,890 volts was 1.040 Å. The point to be decided by these experiments was how close to this particular wave-length limit the average, or effective wave-length of the beam of X-rays coming from the mercury vapor really lay.

Absorption measurements with both types of tubes (Fig. 1 and Fig. 2) have been made with substantially the same results in each case. An experiment with the hot anode tube represented by figure 2 will be described in detail. In this experiment the fraction of radiation passing through a thin sheet of aluminum was determined. The sheet had an area of 9.801 cm.[2] and it weighed 0.2718 gram. Hence the mass per unit area, ρd, was 0.02773. The average value of the mass coefficient of absorption μ/ρ for aluminum given by Richtmyer and Allen is 13.9 for λ = 1.00 and 20.0 for λ = 1.10. In order to obtain an independent measurement of the absorption of X-rays of given wave-lengths by *this particular* sheet of aluminum, and in order to correct for any possible lengths by the sheet of aluminum was determined. The γ_1 and γ_4 lines in the L series of tungsten were employed with wave-lengths of 1.096 and 1.026 Å, respectively. An X-ray spectrometer with a tungsten target tube was adjusted so as to reflect each of these lines successively and the fraction of each passing through the sheet of aluminum was measured. In the case of the γ_1 line, λ = 1.096 Å, the ratio of the intensity of radiation falling on the aluminum to that coming through it amounted to 1.747. This gives a value of μ/ρ = 20.2, in close agreement with the above-mentioned measurements of Richtmyer and Allen. In the case of the γ_4 line the ratio of intensities was 1.544 giving a value of μ/ρ = 15.9. Dr. E. Lorenz very kindly checked these values in separate experiments.

In order to determine the effective wave-length of the radiation coming from the mercury through the window of the X-ray tube the sheet of aluminum, calibrated as described, was placed between the tube and the ionization chamber, the distance from the sheet of aluminum to the window of the ionization chamber being large so that the amount of scattered radiation from the sheet of aluminum that entered the ionization chamber might be neglected. Two series of measurements were made of the ratio of the ionization currents without and with the sheet of aluminum in place. The average value of the ratio of the radiation falling upon the aluminum sheet to that which pass through was 1.74 in the first series and 1.76 in the second. These ratios are probably correct to within one or two per cent. They are the same as that obtained in the calibration of the sheet of aluminum with the γ_1 line within the limits of error of the measurements. The effective wave-length, therefore, of the X-ray beam coming from the mercury vapor through the window under the conditions of voltage, etc., described above does not differ perceptibly from that of the γ_1 line in the L series of tungsten, namely: $\lambda = 1.096$ Å.

Another series of similar measurements was made with an additional sheet of aluminum inserted as a filter between the X-ray tube and the ionization chamber. Under these conditions, the ratio of the radiation falling on the calibrated sheet of aluminum to that which passed through the calibrated sheet was 1.79, a slightly greater value than that obtained without the additional sheet of aluminum. The difference between the two, however, is scarcely greater than the errors of measurements in experiments of this kind. The ratio 1.79 corresponds to an effective wave-length of 1.11 Å. From these experiments, we may conclude that the aluminum filter does not reduce the effective wave-length coming from the mercury perceptibly and that this effective wave-length is 1.10 Å to within the limits of error of the measurements.

Since the short wave-length limit of the spectrum for the voltage used was 1.04 Å, we see that the effective wave-length of the beam was only about 6% greater than the limit. This difference, although small, is greater than the probable error of measurement and indicates that the beam of X-rays, although approximately homogeneous, was not exactly so. It was a great deal nearer homogeneity than would have been the case had the target of the X-ray tube been a solid one.

The effective wave-length, λ_e, of a beam of X-rays may be defined by the following equation:

$$e^{-f(\lambda_e)}\int I d\lambda = \int I e^{-f(\lambda)} d\lambda,$$

where $f(\lambda)$ is nearly proportioned to λ^3.

If we calculate the effective wave-length of a band in the spectrum of uniform intensity, I, extending from $\lambda = 1.04$ to $\lambda = 1.16$, in other words, a band about 10% in width, we find that its value is $\lambda_e = 1.10$. Hence, the beam of X-rays actually coming from the mercury through the window in our experiments is equivalent, insofar as its absorption in the sheet of aluminum is concerned, to a band 10% broad extending from the short wave-length limit of the radiation toward longer wave-lengths.

It does not seem probable, however, that the actual X-ray band is of uniform intensity throughout. One would naturally expect the form of the intensity wave-length curve to be similar to that of a solid target, although very much narrower. The intensity curve for a solid target rises rapidly from the short wave-length limit to a maximum and then falls with decreasing rapidity toward the longer wave-lengths. If this is the actual shape of the intensity curve for the mercury radiation and if much of the radiation has wave-lengths longer than 1.16, most of the X-ray quanta coming from the mercury through the window must have wave-lengths lying between the short wave-length limit 1.04 and 1.10 Å. In any case, we see that a large proportion of the electrons give up most of the kinetic energy that they ever possessed to the X-ray quanta when they produce the X-radiation.

There are several reasons why the electrons that produce the X-radiation when they hit the mercury atoms may not all have the maximum kinetic energy represented by the voltage applied to the tube, namely Ve. If electrons come from a Coolidge cathode held at a constant potential below the anode, there is a slight spread of velocities when they pass through a hole in that anode. Some experiments made by Mr. Hudson in our laboratory on the magnetic deflection of such electrons after they had passed through a long tube indicated that the spread of velocity was not large for voltages above 10,000 volts. The kinetic energy of only a few of the electrons differed from the value Ve after they had come through the tube. In the experiments described in this note on the impacts of electrons against mercury atoms, some of the electrons may have hit mercury atoms before the impacts which actually produced the X-radiation and may have had their kinetic energies reduced by ionization. Again the impacts of the electrons against the solid interior walls of our anodes must have generated a large amount of X-radiation and this X-radiation must have produced photo-electrons with kinetic energies less than the value of Ve. The X-radiation produced by the impacts of the electrons against the solid walls of our anodes did not enter the ionization chamber, for no ionization could be detected when the mercury pump was not running. Some of the photo-electrons from this radiation, however, must have struck the mercury vapor atoms and these impacts were impacts of electrons of smaller kinetic energy than Ve. It is impossible to estimate what proportion of the electrons hitting the mercury atoms had kinetic energies less than Ve. There must have been some such collisions, however, and this fact means that on the average the amount of energy transformed from the kinetic energy of an electron to the energy of the quantum must be closer to the kinetic energy of the electron *at the time of impact* than to Ve. In other words, in a large number of impacts, at least, the electron transfers almost if not all of its kinetic energy to the quantum of radiation when it produces that quantum, and the radiation thus produced is nearly if not exactly monochromatic.

THE STRUCTURE OF THE ATMOSPHERIC ABSORPTION BANDS OF OXYGEN

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Communicated July 18, 1927

Although the atmospheric oxygen bands have been the subject of many investigations, the details of their structure have remained only partially explained. The earlier investigators[2] did not have any theory to guide them and it can readily be understood that they often came to contradictory results. In the present paper we have tried to account for the structure of the bands as completely as possible. Our progress has been based on new wave-length measurements which we believe to be more accurate than the previous ones.

1. A recent paper by one of us,[3] gives details of the derivation with the interferometer of the wave-lengths of the lines in the α, B and A bands best suited to that method. With these lines as standards, the other lines in these bands have been measured on spectrograms obtained with a large Michelson plane grating used in the third and fourth orders at 30-feet focus. Such photographs were made at both high and low altitudes of the sun, since the faintest atmospheric lines are best observed with maximum air-path and the strongest ones with minimum air-path. At best the measurement of the widest lines is difficult and of relatively low accuracy. For example, some lines in the A band have a total width of about $1A$, even when observed on Mount Wilson with solar altitude exceeding 45°. The finer lines, on the other hand, can be seen only with high resolving power, and even with the sun close to the horizon they are faint and hard to measure. For the widest lines in the A band the usual micrometer measurements were supplemented by the use of a registering, thermoelectric microphotometer, giving a definite increase of accuracy. Some of these lines give evidence that under more favorable conditions of observation they might be resolved into close pairs.

For the α' band, $\lambda\, 5788 - \lambda\, 5834$, we have made no measurements, but have derived the wave-lengths on the International system by