Second Series *September 1, 1929* *Vol. 34, No. 5*

THE

PHYSICAL REVIEW

ELECTRON SCATTERING IN ATOMIC AND MOLECULAR HYDROGEN

By Gaylord P. Harnwell*
Palmer Physical Laboratory, Princeton University

(Received July 27, 1929)

Abstract

An apparatus for generating an electron beam of known energy was designed to rotate about an axis perpendicular to the beam, and through which it passed. Those electrons scattered in the neighborhood of the axis through a given angle entered an analyzer in which an energy spectrum was obtained. The scattering gas was hydrogen admitted from the center of a discharge tube. When the discharge was in operation it was estimated that more than 60 percent of the hydrogen was in the atomic condition. At a given electron velocity and angular setting the electron energy spectrum could be analyzed into component peaks which were interpreted as due to elastic, inelastic and ionizing collisions. One inelastic loss of about 8 volts was found to occur and several were observed in the neighborhood of 12.5 volts. From the areas under these peaks the number of electrons scattered through the particular angle could be computed. From these results the number of electrons scattered elastically was plotted as a function of the angle both for the case of atomic and molecular hydrogen. The scattering in both cases was very similar. In the former case the results agreed well within the experimental error with the theoretical curves predicted by quantum mechanics.

THE field of electron scattering is one of particular interest at present for in it modern quantum mechanics is able to make certain definite predictions which are at variance with the older theories and these predictions are capable of direct experimental verification. In fact, one of the chief supports of this theory is its complete and accurate agreement with the results obtained by Davisson and Germer, G. P. Thomson, and others working with electrons scattered by metal surfaces. An additional test of the theory from a slightly different angle is provided by the scattering of electrons in gases. The present writer[1] working in several gases found the scattering much larger than could be accounted for classically, and E. G. Dymond[2] has obtained electron scattering curves in helium in excellent agreement with theorectical curves calculated by N. F. Mott.[3] In view of these re-

* National Research Fellow in Physics.

[1] G. P. Harnwell, Phys. Rev. **33**, 559 (1929).

[2] E. G. Dymond, Proc. Roy. Soc. **A122**, 571 (1929).

[3] N. F. Mott, Nature **123**, 717 (1929).

sults it was thought to be of particular interest to investigate the phenomenon of electron scattering in atomic hydrogen. Theoretically it is much the simplest case. The calculations are free from the approximations necessary in the present state of the theory when dealing with more complicated atoms or molecules. From this point of view it is the most satisfactory gas in which to work, but unfortunately the experimental difficulties are considerable. The most important of these is the difficulty in obtaining a large concentration of atomic hydrogen in the scattering chamber. Also, as it is not possible to have the hydrogen completely in the atomic condition, it is important to know what fraction is dissociated. However, it was not found possible to measure this quantity accurately and various methods of estimation had to be used, as will be discussed later. During the course of this work the scattering in molecular hydrogen was investigated in some detail and several points of interest were found.

The apparatus used was very similar to that described in a previous paper.[2] The scattering chamber is indicated diagrammatically in Fig. 1.

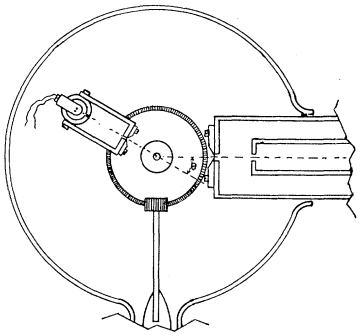

Fig. 1. Scattering chamber.

The electrostatic analyser is not shown. The alterations were mainly in the nature of refinements. The electron gun was redesigned with several points in view. The form of the filament was changed to that of a very narrow hairpin in the hope of decreasing the magnetic field due to the filament current. It was completely enclosed in a copper cylinder in the front of which a slit was cut. This was done in order to decrease the amount of thermal ionization and dissociation in the scattering region, and also to decrease the area of glass wall exposed to the filament as it could not be completely out-gassed. The exit slit of the electron gun was adjustable and made much finer so that the emerging electron beam was more accurately defined. As in the previous apparatus the electrons were accelerated to the first slit by a constant field and then retarded to the desired velocity by an opposing field between the first and second slit. The rotation was obtained by means of a clock gear upon which the gun was mounted and which in turn was supported by arms (not shown) extending from the analyser. This engaged a pinion mounted in a ground glass stopper which could be turned from outside the bulb. A pointer which moved over an angular scale was attached

to the stopper and owing to the gear ratio of 21:4 the angles could be measured more accurately than had been possible previously. Those electrons scattered through an angle θ entered the analyser. This was an electrostatic analyser identical with that described in the paper already referred to. The slits were made as fine as possible for increased accuracy though this entailed a decrease in intensity of the electron beam reaching the Faraday cylinder. For this reason it was found possible to work only with electrons with energies above one hundred volts, though the electrometer sensitivity was increased considerably over that previously used. The inside of the scattering chamber was sputtered with platinum to make it conducting and avoid any errors due to stray electrostatic charges. The electron gun rotated about a hollow axis and along this axis the scattering gas was admitted to the chamber through a short length of glass tube about two millimeters in diameter. A few centimeters above this jet was a large pumping exit, this was arranged so that it could be disconnected if desired. When this was disconnected the gas was pumped out only through the narrow slit in the front of the analyser, and the pressure in the bulb was much higher and also presumably much more uniform in the scattering region. The necessity for this will be seen later. The gas admitted through this small tube was drawn from the center of a Wood's discharge tube. This tube was of fairly small bore and about two meters in length. The hydrogen was admitted to this tube through artificial leaks from the high pressure reservoir. It was generated electrolytically and when atomic hydrogen was being investigated it was passed through no drying agents. When working with molecular hydrogen the gas was stored over P_2O_5 and passed through a liquid air trap. As before the scattering chamber was placed in the center of a framework of coils to neutralize the effect of the earth's and any stray magnetic fields. The current in the coils and the zero position of the gun were determined empirically as described in the paper previously referred to.

Unfortunately it was not found possible to counteract completely the effect of all stray magnetic fields. The main difficulty was caused by the filament current. When the angular setting of the electron gun was changed or when the filament current was increased as was found necessary at large angles the entire energy scale was shifted by a few volts. This, however, was not of great importance if the scale remained uniform. By comparing curves obtained under different conditions this was found to be the case as nearly as could be determined. The maximum error which could be introduced in this would be of the order of two or three percent. Also the heat of the filament and the electrons emerging from the gun undoubtedly ionized and dissociated a certain amount of the hydrogen when the Wood's tube was not in operation. As these effects were undoubtedly small and could not even be estimated they have been neglected. An additional complicating effect was introduced by the scattering of electrons from the front slit of the analyser at small angles. This, however, could be measured accurately by removing the hydrogen from the apparatus and it has been allowed for in the subsequent work. It was only apparent below ten degrees and the correction

to be applied was less than five percent. An additional correction had to be applied at angles below ten or fifteen degrees as the gas pressure was apparently not uniform throughout the effective scattering region. When the pumping exit from the scattering chamber was open apparently a large amount of the hydrogen entered the pumping exit directly from the jet without ever colliding with the walls of the bulb. Thus the pressure decreased radially from the axis about which the electron gun rotated. This was checked by closing this pumping exit thereby increasing the pressure in the scattering chamber and reducing the rate of flow of gas. This made the pressure throughout the bulb quite uniform and by adjusting the pressure to its former value the curves obtained under the two conditions for molecular hydrogen could be compared and the correction to be applied in the former case determined. This correction was found to be of the order of ten percent at small angles and has been applied to the curves which will be given later.

The voltage scale of the analyser was checked by comparing it directly with the accelerating voltage of the electrons. This was done by decreasing the accelerating voltage in small steps and recording the analyser voltage at which the elastically scattered peak appeared. However, even with this calibration, errors of as much as four or five percent might occur in the voltage scale due to unsteady conditions in the scattering chamber particularly when the discharge tube was in operation. This is probably less than the error arising from the uncertainty in the analysis of the curves obtained. The energy losses in hydrogen are so close together that even with the greatest resolution which could be obtained the peaks were not completely resolved. It was thus necessary to analyse the curves obtained into their component peaks which introduced a certain amount of uncertainty as to their intensity and exact position. The error made in position was probably larger than that in intensity.

The fraction of the hydrogen in the scattering chamber which was in the atomic state when the Wood's tube was in operation could not be measured directly. But from the work of Wood,[4] Bonhoeffer,[5] and Kaplan,[6] an estimate of this quantity could be formed. They found the optimum pressure for the formation of atomic hydrogen in a discharge to be about 0.5 mm. Unfortunately the most favorable pressure in the scattering chamber was from 0.02 mm to 0.05 mm. Due to the small tube through which the hydrogen was admitted from the discharge tube to the scattering chamber the pressure in the discharge tube was probably two or three times this, but undoubtedly less than the optimum. However, the center of the discharge tube when it was in operation gave every evidence of the presence of a large amount of atomic hydrogen. The tube exhibited a deep purple color and small bits of metal which had fallen in were raised to incandescence. The Balmer series from this portion of the tube was very strong and the second-

[4] R. W. Wood, Proc. Roy. Soc. **A102,** 1 (1922).
[5] K. F. Bonhoeffer, Zeits. Physik. Chem. **113,** 199 (1924).
[6] J. Kaplan, Phys. Rev. **30,** 639 (1927).

ary spectrum could hardly be discerned visually. Probably at least 90 percent of the hydrogen in that region was atomic. A certain amount of recombination undoubtedly occurred in passing into the scattering chamber. The rate of flow was such, however, that the time taken in passing from the discharge to the scattering region was about a fifth of a second. Part of this distance was through a narrow tube. When the tube was performing most favorably little bits of the sputtered coating in the pumping exit from the scattering chamber could be seen to glow, though not brightly, showing that some of the hydrogen passed through the scattering bulb in the atomic condition. Taken in conjunction with the evidence from the scattering curves themselves which will be mentioned later it was estimated that about sixty percent of the hydrogen was dissociated.

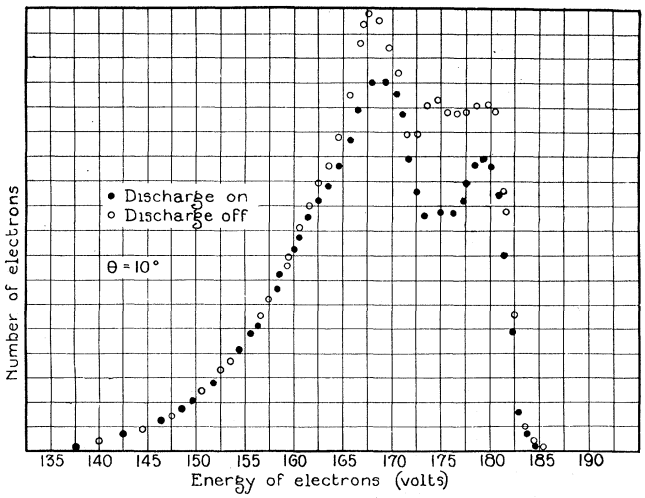

Fig. 2. Typical curve showing energy losses at 10° scattering. Energy of incident electrons 180 volts.

Before discussing the intensity of electron scattering as a function of the angle there are some points of interest in connection with the types of energy losses observed. A typical curve is given in Fig. 2. In obtaining such a curve the angular setting of the electron gun and the accelerating voltage of the electrons are kept constant while the potential across the plates of the analyser is varied. The electrometer current is plotted against the energy of the electrons in volts as calculated from the analyser potential. The curve in Fig. 2 is quite representative of all those obtained though, of course, the relative intensities of the peaks vary with angle. This curve was obtained with 180 volt electrons deflected through 10°. The circles represent points obtained when the discharge tube was not in operation and hence represent the scattering from molecular hydrogen. The peak on the right at the 180 volt abscissa represents those electrons which have been scattered elastically and will be referred to as the primary peak. About five volts to the left is another peak of approximately the same height. Upon analysing the curve

this is seen to be somewhat farther away and considerably smaller and represents an energy loss which will be discussed a little later. Another slightly unsymmetrical peak occurs about 12.5 volts to the left of the primary peak. At 10° this is seen to be considerably larger than the primary peak and is probably made up of several components. There appear to be several smaller and more doubtful energy losses between 14 and 25 volts which will be referred to later. Beyond 25 volts the points seem to lie on a smooth curve gradually approaching zero about 45 volts to the left of the primary peak. All the curves obtained show these salient characteristics with only small variations. Many curves were taken at each angular setting and in the discussion which follows, values obtained from the averages of these curves will be given.

It is necessary to analyse a curve such as Fig. 2 into its component peaks. It was found that the peaks obtained with this apparatus were quite symmetrical so the process can be carried out with little ambiguity. When this is done it is seen that the first peak to the left of the primary peak represents an energy loss of between 5.5 and 7.5 volts. This is a somewhat surprising result. The current views of the structure of the hydrogen molecule such as given by Heitler and London,[7] Winans and Stueckelberg,[8] and Condon and Smyth[9] give no reason for expecting a characteristic energy loss of this value. Due to the proximity to the primary peak it is difficult to fix this critical potential accurately. However, the lowest recognized critical potentials are three or four volts greater than this, well beyond the limits of error. The energy of dissociation of the hydrogen molecule, though never observed as a characteristic energy loss, is calculated to be about 4.5 volts. The peak observed appears to lie somewhat higher than this though it is possible that there is some undiscovered correction that would lower it by the volt or so necessary for agreement. It is possible that this is the correct explanation but in view of the work of Jones and Whiddington [10] this does not seem particularly promising. These investigators worked with hydrogen in an apparatus approximately equivalent to the present one when the electron gun is set at $\theta = 0$. They analysed their scattered electrons magnetically. They obtained the same type of curves given in this paper though their accuracy was probably greater and there were many differences in the conditions of the experiments. They also obtained a peak in the neighborhood of 7 or 8 volts and their accuracy was such that it probably could not be due to a loss of 4.5 volts. They observed this peak only when the original energy of the electrons was between 26 and 14 volts. The peak due to the 12.5 volt critical potential was present from about 13 volts up, but the 8 volt peak rose rapidly to approximate equality with the 12.5 volt peak with 18 volt electrons and then dropped to zero at about 26 volts. With the present apparatus it was not possible to work at these voltages and the 8 volt

[7] W. Heitler and F. London, Zeits. f. Physik **44,** 455 (1927).
[8] J. G. Winans and E. C. G. Stueckelberg, Proc. Nat. Acad. **14,** 867 (1928).
[9] E. U. Condon and H. D. Smyth, Proc. Nat. Acad. **14,** 871 (1928).
[10] Jones and Whiddington, Phil. Mag. **6,** 889 (1928).

peak was never observable at a gun setting of $\theta = 0$. It was observed only at larger angles and there was always much smaller than the 12.5 volt peak. The apparent ratio of this peak to the 12.5 volt peak decreased as the voltage increased though this effect was not large. Jones and Whiddington advanced the suggestion that this was a hitherto unobserved characteristic energy loss of the hydrogen molecule. The theory that it is an effect due to the molecule receives considerable support from the type of curve obtained in the presence of atomic hydrogen as will be discussed later. The possibility of its being due to adsorbed hydrogen on the slits was considered but in view of its intensity and the geometry of the apparatus this seems unlikely. For its variation with angle is very nearly the same as the 12.5 volt peak which would not be true if it were caused by an adsorbed layer on the slit surfaces. That it is not a characteristic of the apparatus is shown by the fact that it is absent in work that has been done in helium and though there is evidence of such a peak in nitrogen it is smaller and of a somewhat different character. In the same way this is evidence against the possibility of its being due to a nitrogen impurity. Water vapor was undoubtedly present to some extent in all the work but in greatly varying amounts, and this seemed to have no effect on the intensity of the peak. At present it seems to be a real though unexplained phenomenon and further work with this peak at lower voltages is in progress.

The next large peak to the left represents a loss of approximately 12.5 volts. It appears, however, not to be a simple peak and contains at least one large, two small components. The small component on the right represents a loss of about 11 volts and the one on the left between 13 and 14 volts. The dependence on pressure and angle of all these components seems to be the same, and when the dependence on angle is discussed later the sum of these peaks will be the quantity referred to. This group of peaks appears to represent the well-known series of critical potentials lying in this region. They are discussed in detail in the paper of Jones and Whiddington already referred to. To the left of this large peak the curve does not seem to be perfectly smooth but is best analysed into a broad peak of small intensity lying between 15 and 25 volts, and a continuous portion extending on to the left. Some indication as to the nature of this broad peak is given by its variation in intensity with the pressure. When the pressure in the scattering chamber is varied through as large a range as possible this peak varies more rapidly than the first inelastic peaks discussed. The first inelastic peaks vary approximately linearly with the pressure but this peak varies as some higher power. Also the variation in intensity of this peak with angle is less than for the others. Hence this peak is probably caused by those electrons which have suffered two inelastic collisions. As can be seen they occur in the approximately correct region of the energy scale.

The points to the left of these peaks appear to lie on a smooth curve which slopes gradually to the axis at about 135 volts. This continuous portion is probably due to electrons which have suffered one ionizing collision.

The shape of this peak in conjunction with some earlier work[11] gives some interesting evidence on the energy distribution between the electron which does the ionizing and the electron which is ejected. For with a slightly different arrangement of potentials capable of detecting electrons entering the analyser with very small energies a peak very near the zero on the energy scale can be obtained. The slope of this curve on the high voltage side is very similar to the slope of the curve in Fig. 2 between 135 and 155 volts. Owing to the difficulty in working in this low voltage region the results are not of great accuracy. But if the correct explanation is that the continuous curve above 135 volts is due to one of the electrons from the ionization process and the peak near zero to the other the shapes are of interest in connection with the energy distribution. The inference from the slopes would be that at an ionizing collision the energy is not distributed equally between the two electrons, but that one or the other emerges with nearly the total excess of original energy over the ionizing energy. From the curves there would be a certain finite probability of energy sharing between the two electrons which would drop off fairly sharply from the maximum probability of one electron having all the energy.

A typical scattering curve when the Wood's tube is in operation is such as is given by the solid dots in Fig. 2. There are certain obvious changes in character indicating a fairly large proportion of atomic hydrogen. The primary peak is somewhat reduced in magnitude which was an effect almost always observed. This means that the elastic scattering in atomic hydrogen is less than in the molecular form. This is in a general way in agreement with the theoretical prediction. The next peak to the left representing the electrons which have been scattered with a loss of 6 or 7 volts is seen to have dropped very greatly in intensity. It was never possible to obtain a curve in which it had disappeared completely but there seemed to be a rough correlation between the behavior of the Wood's tube and the intensity of this peak. At some times the atomic hydrogen seemed to be produced more efficiently than at others and during these periods the peak was at its minimum. This is the strongest evidence obtained that this peak was due to an energy loss directly attributable to the molecule. The peak at 12.5 volts is seen to be altered also, the apex is no longer at 12.5 but is nearer 11 volts. On analysis it is seen that the component in the neighborhood of 10 or 11 volts has risen very much and the 12.5 volt peak has dropped. The lower characteristic energy loss is what would be expected in atomic hydrogen where the first critical potential is 10.5 volts. The behavior of these peaks in conjunction with the evidence already mentioned is the basis on which the proportion of atomic hydrogen in the scattering chamber has been estimated. The rest of the curve is very similar to that obtained without the discharge, in fact, within the limits of experimental error they are the same.

In passing it might be mentioned that the ratios of these component peaks to one another are of some interest in connection with the probability of ionization or excitation at a collision. The areas of these peaks at a single

[11] G. P. Harnwell, Phys. Rev. **33**, 632 (1929).

angular setting can not be compared directly as they vary differentially with angle as will be mentioned in connection with Fig. 3. However, with the aid of these two types of curves an estimate of the total number of electrons scattered by elastic, inelastic, and ionizing collisions can be made. The ratio of each of these to their sum gives the probability of the various types of collisions. As the results are very uncertain at small angles the process is not susceptible of great accuracy. An estimate was made of these probabilities with 180 volt electrons, with these approximately 30 percent of the collisions result in excitation and about 25 percent in ionization. This last is in fairly good agreement with the results obtained by Compton and Van Voorhis.[12] This means that out of 20 collisions approximately 9 are elastic 6 inelastic, and 5 result in ionization.

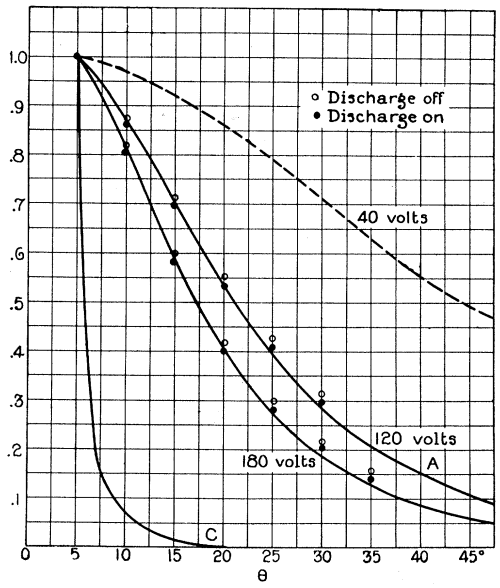

Fig. 3. Intensity of scattered electrons as a function of angle of scattering.

Figure 3 represents the intensity of the scattered electrons as a function of the angle of scattering. As in Fig. 2 the circles represent the case of molecular hydrogen and the dots that of atomic and molecular hydrogen combined. The ordinates of these points are proportional to the areas under the component peaks of Fig. 2 multiplied by the $\sin^2$ of the angle. One of the sine factors is for the variation in effective scattering volume which decreases as the angle increases, the other factor is for reduction to solid angles. As has been mentioned previously there were two corrections to be applied to these areas. The first is that due to the scattering from the slits of the analyser and the second due to the variation in pressure in the scattering region. It has been indicated how these corrections could be determined

[12] K. T. Compton and C. C. Van Voorhis, Phys. Rev. **27**, 724 (1926).

and they have been applied to the points given in Fig. 3. The conditions were so complicated at angles below 5° due to the original electron beam that it was thought best to omit that region. It gave no indication of the maximum of these curves as the results were completely masked by those electrons which entered the analyser without having collided at all. In view of this the curves have all been reduced arbitrarily so as to pass through the unit ordinate at 5°.

The two solid lines marked A in Fig. 3 have been plotted from the formula given by Born.[13]

$$\psi_r=(1/4)(a/r)^2\{(2+z_0^2)/(1+z_0^2)^2\}^2.$$

In this formula ψ_r is proportional to the number of electrons scattered in the solid angle between θ and $\theta+d\theta$, θ being measured from the original beam.

$$z_0=a\kappa_0\sin\theta/2 \qquad \text{and} \qquad a=h^2/4\pi^2me^2$$
$$\kappa_0=2\pi/\lambda_0$$

λ_0 is the deBroglie wave-length associated with the electron and the other quantities have their usual significance. This formula applies only to elastic scattering from atomic hydrogen. An equivalent formula has been given by Sommerfeld.[14]

$$|(\psi'/\psi)|^2=(e^2z/2Er)^2/(\sin^2\theta/2+\alpha^2)^2$$

where $\alpha=\lambda Z/2\pi a$. In deriving this formula he considered a hydrogen atom with Z electrons in the first quantum state. As a first approximation this might be expected to indicate the changes to be expected in the scattering for the case of the molecule. This would in general correspond to an increase in Z which would not only increase the total amount of scattering, but would also decrease the rate of change with angle. These two effects are observed in the experimental curves.

As can be seen by Fig. 3 there is little difference in the behavior of the electrons scattered in atomic or in molecular hydrogen. Both sets of points lie very well on the proper curves. The points obtained in molecular hydrogen, however, lie farther away than those obtained when atomic hydrogen was present. If it were assumed that 75 percent of the hydrogen was atomic and that hence these points lay partway between the values for molecular hydrogen and the correct values the points would be in slightly better agreement with the theoretical curves, but in either case they agree with them well within the limits of error. The deviations, such as they are, are amply accounted for by the variations in the discharge conditions and hence changes in the relative concentrations of the atomic and molecular states. The agreement affords very interesting evidence in favor of the most recent developments of the quantum mechanics. It is another very interesting point that the scattering by the molecule agrees so closely with that predicted

[13] M. Born, Gottinger, Nachr. p. 146 (1926).

[14] Atombau und Spektrallinien Wellenmechanischer Ergänzungsband, p. 231.

for the atom. Dymond[2] also found that the scattering in helium bore a very close resemblance to that predicted for atomic hydrogen. Of course nothing is shown about the absolute values by these curves because of the convention that had to be adopted in plotting them but the general forms are seen to be very similar.

The apparatus which had been used previously was less accurate but capable of working at much lower electron voltages. With this apparatus curves were obtained with electrons whose original energy was as low as 20 volts. Apparently there were some complicating effects in the region below 40 volts, either due to the apparatus or inherent in the scattering process. Above that value, the curve for which is indicated by the broken line in Fig. 3, the points all lay fairly well on their respective curves. The electron

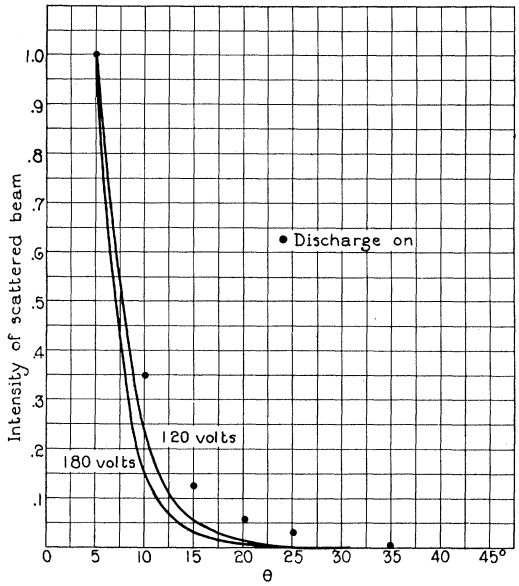

Fig. 4. Intensity of inelastically scattered electrons as a function of the angle of scattering.

energies used were 40, 75, and 100 volts. The points obtained at the lower voltages all lay above those of the higher voltages, but the accuracy was not such as to warrant their inclusion in Fig. 3. They would have occupied the region between the 120 volt curve and the broken line. The steepest curve on the left indicates the values which would be obtained from an inverse square law scattering center, plotted with the same convention as to passing through the unit ordinate at 5°. This is the curve which is approached as the electron velocity is increased. This can be seen from the theoretical expression. An increase in velocity corresponds to a decrease in α, and when α is zero this becomes the well-known Rutherford scattering formula.

Figure 4 is plotted on the same scale as Fig. 3 and with the same convention as to passing through the unit ordinate as 5°. The experimental points

represent the combined areas under the peaks due to inelastically scattered electrons. They are from the curves obtained using electrons of 180 volts energy. The data for this voltage and for 120 volts are the same within the limits of error. The complication of peaks is such that it did not seem fruitful to attempt an analysis of them into those due to molecular and those due to atomic hydrogen. The points given were obtained in the presence of the discharge. The solid lines have been plotted from the formula given by Born[13] for the angular scattering of those electrons which at the scattering encounter have excited the hydrogen atom to the second quantum state. This formula is:

$$\psi_a = 0.9886(a/r)^2(\kappa_1/\kappa_0)/\left\{z_1^2(1+z_1^2)^5\right\}.$$

Here $z_1 = 2a/3\ (\kappa_0^2+\kappa_1^2-2\kappa_0\kappa_1\cos\theta)^{\frac{1}{2}}$; κ_0, θ, and a have the same significance as before, and $\kappa_1 = 2\pi/\lambda_1$, where λ_1 is the deBroglie wave-length associated with the scattered electron.

It can be seen that the experimental points do not lie on the predicted curve. This is not at all surprising as by far the largest contribution to these points is made by the electrons scattered by the hydrogen molecule with a loss of about 12.5 volts. The remarkable thing is that they lie as closely as they do in the region of the theoretical curves. It can be seen that the curve defined by these points is much steeper than the elastic scattering curves. This means that at large angles many more electrons are scattered elastically than inelastically. This is a general characteristic of all the experimental curves which have been obtained. From a macroscopic view point this is rather surprising, for it would seem reasonable to suppose that an exciting or ionizing collision would represent a "more complete" interaction between the atom or molecule and the colliding electron than a collision which left the atom unchanged. If this were so one would be tempted to assume that the original trajectory of the electron would be less important among those factors determining its ultimate direction of ejection. This, however, is not the case. An electron appears to have a better chance of continuing on in its original direction if it has collided inelastically than if it has had a perfectly elastic encounter. In this the results are quite in agreement with the new quantum theory. This same general phenomenon has been observed in nitrogen as will be reported later. It has also been observed by Dymond[2] in helium, though, of course, for these more complicated cases theoretical curves are not available.

In conclusion it is a great pleasure to express my appreciation to Professor K. T. Compton for the privilege of working in the laboratory, and to him and the other members of the department, particularly Professor Condon, for their interest and many helpful suggestions.