ANGULAR SCATTERING OF ELECTRONS IN HELIUM, NEON, HYDROGEN AND NITROGEN

By G. P. Harnwell*

Abstract

An attempt has been made to investigate in a qualitative way the angular distribution of electrons scattered by a gas. The gases which were used were helium, neon, hydrogen and nitrogen. The energy of the primary beam of electrons varied from 75 to 300 equivalent volts. It was found that those electrons which were scattered elastically were deflected in general through only a few degrees. In helium less than one-thousandth of the 200 volt electrons were scattered through 15°. Electrons which had sustained an exciting collision were scattered through slightly larger angles. Evidence of electrons which had suffered two inelastic collisions was obtained, these were distributed through still larger angles. A general tendency for slower electrons to be scattered through larger angles was observable.

The problem of the angular scattering of electrons in gases is one which has been attacked by indirect methods by several investigators. In particular, Langmuir[1] has obtained very interesting evidence on the angular distribution of electrons scattered by mercury vapor in a discharge tube. The method used was an indirect one but very definite conclusions as to the variation of angular scattering with the energy were reached. These results are capable of verification by a more direct means.

During the progress of the present work two further papers have appeared bearing on the extremes of angular scattering. A paper by Jones and Whiddington[2] dealt with their investigation of 0° scattering in hydrogen. They found that of those electrons which were undeflected from their original beam by far the largest proportion had lost no energy at all. There were a few electrons which had lost amounts of energy varying from 0 to 12.26 volts. A large number of electrons were observed which had lost 12.26 volts, there was also a small number of electrons which had lost more than this amount, and some evidence pointed to a small group of electrons which had lost 24.5 volts. The energy of the electrons was determined by analysis in a magnetic field.

The second paper is by R. Kollath.[3] He investigated the electrons scattered through 90° in various gases. He used only slow electrons and found that of the order of one percent of the electrons were scattered through this large ang'e. The scattered electrons were practically homogeneous and had lost no energy; this was determined by applying a retarding potential to the collector. Scattering at right angles was found to depend very markedly

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[1] Langmuir, Phys. Rev. **31,** 357 (1928).

[2] Jones and Whiddington, Phil. Mag. **6,** 889 (1928).

[3] Kollath, Ann. d. Physik **87,** 259 (1928).

on the primary energy of the electrons and the ionization potential of the gas which was employed in the scattering.

The present investigation has been concerned with the angular scattering of electrons in the four gases, helium, neon, hydrogen, and nitrogen. Angles varying from 0° to 90° were used. The energy of the primary electrons was in the range from 75 to 360 equivalent volts. The energy of the scattered electrons was measured by an electrostatic filter.

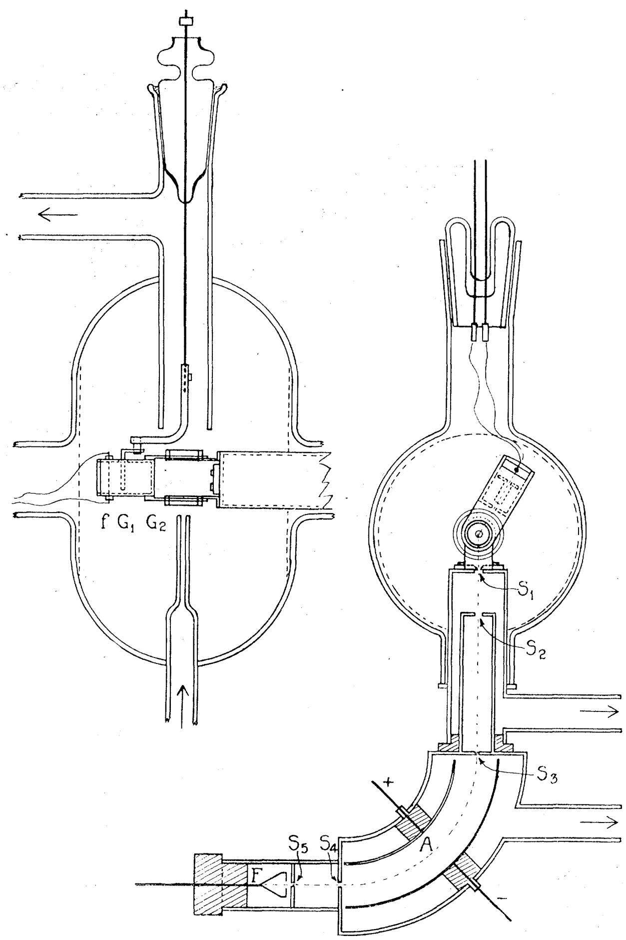

Fig. 1. Diagram of apparatus.

The apparatus used was in a general way similar to that used by Dymond[4] and by the present writer.[5] The main points of difference were in the mounting of the electron gun, in the arrangements for admitting the gas, and in the analysis of the scattered electrons. The apparatus is represented diagrammatically in Fig. 1.

[4] Dymond, Phys. Rev. **29,** 433 (1926).

[5] Harnwell, Proceedings of the Nat'l. Academy **14,** 564 (1928).

The electrons were supplied by a 4 mil thoriated tungsten filament. This was formed in the shape of a very narrow hairpin to reduce the magnetic effect of the filament current. It was mounted in the rear of the short thick-walled copper tube which formed the electron gun. The filament current was supplied through rather long flexible leads to allow for the motion of the electron gun. Immediately in front of the filament was a large slit or diaphragm which will be referred to as D. This was insulated from the filament and from the rest of the tube forming the gun. A constant potential was in general maintained between the filament and this diaphragm to supply the electron stream. A second slit about half a millimeter wide formed the front of the electron gun. This determined the width and direction of the electron beam and also by varying the potential difference between it and the filament it determined the energy of the electrons emerging from the gun. The entire gun was made of copper, the necessary insulation was obtained by means of mica sheet which gave some trouble till by repeated heating it had become, as nearly as possible, outgassed.

Two arms extended about a centimeter and a quarter forward from the top and bottom edges of the gun. At the ends of these arms were holes about a centimeter in diameter. Two similar arms extended out from the face of the analyser. In the end of each of these was a short section of thin walled brass tubing, about one centimeter outside diameter, and a millimeter long. These arms sprang apart slightly so that when the holes in the arms of the gun were placed over the short lengths of tubing the gun was held in position. It was able to rotate through about 100° on both sides of the zero position about the center of the holes as an axis. The front slit of the gun was about 0.75 cm from this axis.

The face of the analyser which supported the gun also contained an adjustable slit. This was about a centimeter and a half from the axis about which the gun revolved. It was made as fine as possible, about a tenth of a millimeter throughout the following work. It served to determine the beam of scattered electrons entering the analyser and also to maintain as great a difference of pressure as possible between the scattering chamber and the analyser. The inside of the scattering chamber was lined with copper gauze for purposes of electrostatic shielding. The body of the gun, including the front slit, the part of the analyser projecting into the scattering chamber, and the copper gauze were all maintained at the same potential, so that as nearly as possible the scattering chamber was free of any electric fields.

The region immediately behind the first slit S_1 of the analyser was evacuated by a mercury diffusion pump through a liquid air trap. About a centimeter behind this slit was another slit S_2 about a millimeter wide, which was insulated from S_1 but metallically connected with the main body of the analyser. The purpose of this arrangement was to enable a field to be applied between S_1 and S_2 to accelerate electrons which entered the analyser. This was only resorted to when working with electrons whose original energy was less than 75 volts. Above 75 volts, S_1 and S_2 were generally kept at the same potential. Below 50 volts the action of the analyser was not satisfactory. The small residual magnetic field distorted its normal characteristics.

Slits S_3 and S_4 were about two millimeters in width. Between them the electrons were deflected through 90° by the difference in potential between the two curved plates, insulated from the body of the analyser, in chamber A. The action of this analyser is very simple but its disadvantage is that it does not differentiate between velocities but only between energies. However, if only electrons are used the masses are all equal and the energy determines the velocity. Additional resolution was obtained by a fifth slit S_5, one millimeter in width situated immediately in front of the Faraday cylinder. This latter was supported in an ebonite plug. As can be seen by reference to Fig. 1, there was an additional pumping exit from chamber A.

The gas employed for the scattering was admitted through a capillary tube of approximately two millimeters bore. This tube was arranged along the axis about which the gun revolved and the open end extended up to within a few millimeters of the lower of the two arms supporting the gun. Coaxially with this tube and a few millimeters above the upper arm was a large bore glass tube through which a high speed mercury diffusion pump exhausted the region immediately above that in which the scattering took place. It was found that by this arrangement a higher concentration of gas could be maintained in the scattering region than by any other method that was tried. The limiting condition, of course, is the low pressure which must be maintained in the analyser. An endeavor was also made to avoid an arc in the scattering chamber as it was feared that under those conditions disturbing effects would be introduced. In the following work where curves were obtained in the presence of an arc this will be mentioned specifically. It only occurred when working with electrons of low primary energy. It should be mentioned that the ends of the two glass tubes extending into the scattering chamber were covered with metal caps which were connected with the copper screen and other metal in the chamber to ensure as nearly as possible the absence of an electric field.

Down through the center of the exhausting tube extended a tungsten and copper rod in the end of which was a key which fitted snugly into a slit in the electron gun. This supplied a metallic connection with the first diaphragm D of the gun and also a method of rotating the gun under vacuum. This tungsten rod was supported in a ground glass stopper as shown on the diagram. Angles were read either by a beam of light reflected from a small mirror carried by the stopper or by a pointer arm and protractor. Because of the torsion play in the rod, angles could not be measured with an accuracy of greater than one degree.

The scattering chamber and analyser were placed at the center of a cubical frame of wire coils sixty centimeters on a side for neutralizing the earth's and any other stray magnetic fields. The coils were found necessary for electrons of even as high as 200 volts energy as the total path of the electrons was about 18 centimeters, and the maximum allowable deflection less than a millimeter. It was found that the magnetic effect of the filament current had also to be taken into consideration. However, this could only be partially compensated by the external coils. This introduced a certain amount of difficulty as the magnetic field had to be adjusted empirically for different values of the current. The method of adjusting the compensating magnetic field was as follows. With no gas in the apparatus the gun was set at its zero position so that the primary beam was directed straight into the analyser. The potential across the plates in the analyser was set at its proper value and the magnetic field was varied till a maximum number of electrons reached the collecting electrode.

Considering only those electrons moving in a circle between the plates the following relation is easily obtained. Let V_1 equal energy of electrons, V_2 equal the potential between the plates, and d equal the distance between the plates, then the electric force toward the center of rotation is: $F_e = V_2 e/d$. The centrifugal force is: $F_m = mv^2/r$ or as: $mv^2/2 = V_1 e$, $F_m = 2V_1 e/r$. These are equal so:

$$V_1 = rV_2/2d.$$

This gives the relation by which the energy of the electrons may be calculated from the analyser potential. This relation was found to be strictly fulfilled except for very small values of V_1, where various disturbing effects appeared.

A final point which should be mentioned is that of the variation with angle of the actual volume of gas concerned in the scattering. Theoretically the volume concerned is that common to the two dihedral angles formed by the filament and slit of the gun, and collector and slit of the analyser. These angles are small and to a sufficient degree of approximation the sides may be taken as parallel. For this limiting condition the volume, except in the case of very small angles, would be inversely proportional to the sine of the angle. There are, however two further considerations. The first is that the contribution from each small element of this volume is not equal. Because of the high gas density a fraction of the electrons scattered from the regions farthest from the analyser will be again scattered and fail to reach the collector. Conversely, those electrons scattered near the collector slit will have a better chance of being recorded than those from the central part of the volume effective in the scattering. The accuracy of the results is not sufficient to justify a detailed examination of this question. The second consideration in a measure offsets this effect. Because of the method of admitting the gas it is probable that a cross section of the region of greatest density is not greater than a few square millimeters. Almost all of the electrons are scattered from this region. This is the justification for neglecting the first of these two considerations. It also greatly reduces the variations of the scattering volume with angle. As the exact weights of these various factors can not be measured in the present apparatus, the curves which will be given later are uncorrected for the angular variations of the volume concerned in the scattering.

The two rare gases which were used were helium and neon. These were obtained in a fairly pure state and further purified in the containers, from which they were drawn directly into the apparatus, by means of a Misch metal arc. The hydrogen which was used was prepared electrolytically and dried by passage over phosphorus pentoxide and through a liquid air trap. The nitrogen was generated from ammonium nitrite and dried in the same way. The gases entered the apparatus through artificial leaks. The pressure in the scattering volume was varied by varying the pressure behind the leaks. A McLeod gauge was connected as closely as possible to the tube entering the scattering chamber. However, due to the distance involved and the diameter of the tubing admitting the gases to the scattering chamber, it is probable that the actual density of the gas in the scattering region was that corresponding to a pressure about half that recorded by the McLeod gauge. Gas pressures of the order of 0.1–0.3 millimeters were generally used as it was found that these were the greatest pressures at which the apparatus gave satisfactory results.

Helium.—The first case which will be discussed is the scattering in helium of electrons with energy equal to 75 equivalent volts. As has been previously

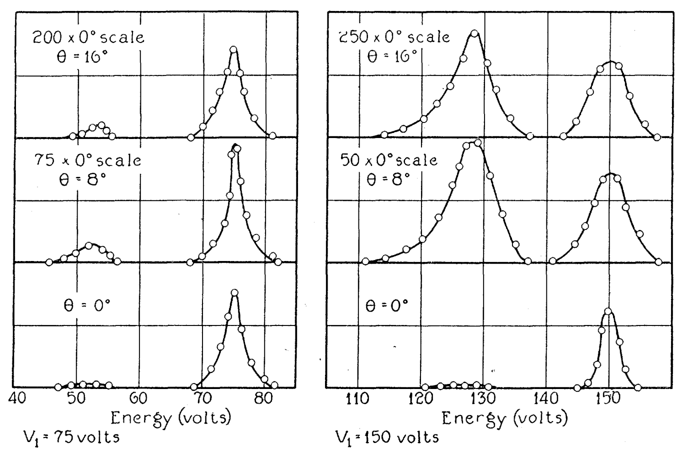

Fig. 2. Typical scattering curves for He.

mentioned the angle between the incident and scattered beam is the measurement most subject to error. In the following discussion when two curves are given as having been obtained at the same angle it is to be remembered that the exact value of the angle is only known with an accuracy of plus or minus 1 degree. It should also be mentioned that this analyser has a characteristic in common with the magnetic analyser in that the shape of the curves, though always symmetrical, is not independent of the energy of the electrons. The peaks are very narrow when electrons have a small energy, but as the energy of the primary beam increases, the peaks become quite broad.

A typical series of curves obtained in helium is given in Fig. 2. In these curves the electrometer current which represents the number of electrons entering the collecting electrode, is plotted against the energy of the electrons. These curves were obtained at a pressure as registered by the McLeod gauge of 0.2 and 0.3 millimeters. It may be estimated that the electrons on the average suffer one or two collisions in passing through the region of high pressure. When no gas is present in the apparatus the peak at 0°, which is the only one observable, is perfectly symmetrical. But when helium is admitted it can be seen that the curves slope less sharply on the low voltage side. In the case of helium this effect is as great in the case of the primary peak (due to elastic collisions) as in the case of the secondary peak (due to partially inelastic collisions). The exact value of this slope seems to be a function of the angle though it only varies between narrow limits. This has not been investigated extensively, but for many combinations of angle and voltage in helium the primary peak slopes more gradually on the low voltage side than does the secondary peak. This is not true in the diatomic gases which will be mentioned later. The reason for this is not clear but it is probably connected with the fact that the secondary peak is associated with a radiating potential as will be discussed later. This asymmetry of the peak decreases with the gas pressure and undoubtedly represents the presence of electrons which have lost a small amount of energy of the order of one to four volts by some presumably elastic process. However, the maximum energy which could classically be lost in an elastic impact is of the order of 1/1000 of the original energy, and in that case there would be no forward component of the velocity. As some of these electrons have lost nearly 5 percent of their energy and still continue in their original direction, or are deflected less than one degree, the result is certainly inexplicable classically.

At angles greater than 0° it will be seen that there is a large number of electrons which have lost a definite amount of energy. The mean value of the energy loss from a large number of observations is 22 volts. This definitely identifies the energy loss as due to the numerous excitation potentials of helium in this region, rather than to the ionizing potential.

Confirmatory evidence is given by the shape of this secondary peak. For if this represents those electrons which had ionized a helium atom it might be expected that the secondary peak would be very much broader on the low voltage side than the primary peak, for energy in excess of the ionizing energy could be carried off in continuous amounts by the liberated electrons. Reference to Fig. 2 will show that this is not so. These peaks are of much the same shape as the primary peaks. Also it might be expected if ionization occurred, that a broad peak would appear at voltages from zero to $V_1-24.5$ volts representing those electrons ejected from the helium atoms. No such peak was observed, however, this is not conclusive as the intensity might well have been below the sensitivity of the electrometer, owing to the fact that this group of electrons is distributed over such a wide range of energies. Except at 0° the variation, if any, with pressure of the ratio of the primary to the secondary peak is very slight. Of course, at 0° as the pressure decreases the primary peak increases as there are fewer collisions, and the secondary peak decreases for the same reason. This is only so when the original beam of electrons is directed straight into the analyser. When only scattered electrons enter the analyser the peak ratio remains approximately constant. This is to be expected for there is no reason, except for multiple scattering, to suppose that the ratio of elastic to inelastic collisions is a function of the pressure. Evidently the effects observed are due to single scattering.

As can be seen from Fig. 2 the number of electrons scattered at these high voltages decreases very rapidly as the angle between the primary beam and the scattered beam increases. In the case of 75 volt electrons some are scattered through angles as great as 25° or 30° but in general the scattered electrons are confined to a region much more closely surrounding the original beam. The amount of scattering at any angle is certainly a function of the primary voltage.

The general tendency is that the slow electrons are scattered most. The following table gives very approximately the angle at which the number of elastically scattered electrons in helium is reduced to 1/1000 of its value at 0°.

V_1= 75	150	200
θ = 22°	18°	15°

This table is of interest but the values of the angle θ can not be taken as having any particular significance. They would be different for a different value of the pressure on account of the electrons at 0° which enter the analyser without colliding, as can be seen from the preceding paragraph, and the pressure could not be kept accurately constant. However, they may be relied on to give the general tendency of the scattering. Kollath[3] found very appreciable numbers of electrons scattered through 90° in the neighborhood of the critical potentials, and preliminary experiments by the present writer which will be reported later, show the same results.

The ratio of the intensity of the secondary peak to the intensity of the primary peak also shows some very interesting variations with angle and voltage. At 0° for all voltages this ratio is seen to be very small. The secondary peak at that angle is barely distinguishable. At first sight this might be thought to be due to the large number of electrons entering the analyser which have come through the high pressure region without colliding. However, this is inadmissible as a complete explanation for two reasons. The first is that when the thermionic current is kept constant, at the pressure used the 0° peak was less than one-tenth its value when no gas was present. Thus at least nine-tenths of the electrons suffered collisions sufficient to deflect them from the original beam. Under these circumstances from the data given by Compton and Van Voorhis[6] approximately one ionizing collision is made per centimeter. The mean free path between exciting collisions is presumably still smaller. Hence a very large percentage of the original beam should have made exciting collisions, and if the electrons had a large probability of continuing in the forward direction a secondary peak quite comparable in magnitude with the primary peak should occur. The second reason for not considering the smallness of the secondary peak to be due to a lack of exciting collisions is that in the case of hydrogen, which will be discussed later, the secondary peak at 0° is quite comparable to the primary peak. If the probability of an exciting collision is of the same order of magnitude as the probability of an ionizing collision, the difference between the two gases

[6] Compton and Van Voorhis, Phys. Rev. **27**, 724 (1926).

can not be attributed to a very great difference between the probabilities of an exciting collision in these gases. For from the data of Compton and Van Voorhis only about twice as many ionizing collisions are made per centimeter in hydrogen as in helium, whereas the ratio of the secondary peak to the primary peak at 0° in hydrogen is twenty to thirty times what it is in helium. The only explanation, therefore, of the smallness of the secondary peak at 0° is that an electron which suffers an exciting or ionizing collision in helium has only a very small chance of proceeding on in its original path. There is very little variation of the size of this secondary peak or in the ratio of it to the primary peak with voltage. There is some evidence that at voltages above 300 it increases appreciably, but this is doubtful. Judging from the ionization free path there is probably little change in the mean free path between exciting collisions in this voltage region. The probability of ionization varies only very slightly though this might account for the possible increase of the secondary peak at voltages in the neighborhood of 300.

On examining the electrons which are scattered at a small angle, for instance, 8° as given in Fig. 2 a very marked change in the ratio of the peaks appears. The absolute areas of all the peaks decrease, though not so markedly as it would seem from Fig. 2, for it can be seen that they must be multiplied by a factor depending on the sine of the angle since the scattering is presumably symmetrical around the cone of angle θ about the original beam. But the ratio of the secondary peak to the primary peak increases several fold even at the lowest voltage. At this angle the ratio also increases with the voltage up to about 150 volts from which value it appears to decrease slightly. It attains about the same size as the primary peak between 100 and 150 volts. At 16° and 75 volts the ratio does not change greatly from what it was at 8° but from that point the variation with voltage is very rapid and the peaks are equal somewhere between 75 and 100 volts. From there on up to 350 volts the secondary peak continues to be larger. At 24° and 75 volts, the secondary peak is larger than the primary one and the scattering at this angle at higher voltage is too weak to be detected.

Because of the slight change particularly in magnetic field inherent in the motion of the electron gun, the numerical values of the areas of the peaks are not accurately comparable, but the values obtained can certainly be relied on in a qualitative way. The general picture of the scattering as given by these curves is then the following. The number of electrons scattered elastically decreases very rapidly as the angle between their path and the original beam increases. The effect of increasing the voltage is to concentrate these electrons more within those solid angles close to the original beam. The fraction of the electrons which are scattered inelastically is a function of the voltage, presumably approximately that given by the work of Compton and Van Voorhis. These electrons have not the same tendency to be confined to those angles close to the original beam. As the angle increases beyond a certain minimum angle, which may be 0° the concentration of these electrons diminishes, but not as rapidly as for the elastically scattered electrons. Throughout the range investigated for electrons with an energy of 100 volts or more an angle could always be found beyond which there were more electrons scattered inelastically than elastically. On going to higher voltages this angle decreased. At higher voltages these inelastically scattered electrons also tended to become more concentrated in those solid angles close to the original beam. The evidence is not sufficiently accurate to say definitely whether the tendency of the inelastically scattered electrons to concentrate about the axis with increasing voltage is strictly proportional to the same tendency seen in the elastically scattered electrons, or whether these two processes may occur at different rates.

Before leaving the subject of helium it should be mentioned that in the curves obtained at voltages above 300 volts there was evidence of electrons which had lost twice the radiating energy. The intensity of the peaks due to these electrons was not sufficiently great to enable them to be studied. At 360 volts this peak appeared to decrease less rapidly as the angle increased than did the other peaks. This is in general what would be expected if this peak were due to electrons which had suffered two collisions for the angular variation would be almost obliterated.

Neon.—The behavior of the electrons scattered in neon was in many respects similar to that observed in helium. The mean distance between the peaks was in this case 18 volts instead of 22. This also fits in very well with the conclusion that this energy loss represents a radiating potential, or the mean of several radiating potentials. At 0° the secondary peak is practically absent below 200 volts, above that potential it increases slightly but is never large; this might be interpreted as showing that neon tends to scatter these electrons which have collided inelastically through large angles. This conclusion is supported by other evidence. It should be mentioned that it is more difficult to interpret the curves obtained in neon because the peaks are closer together, and at high electron velocities the curves do not drop to the axis between peaks.

In general it may be said that electrons which have suffered elastic collisions are deflected through larger angles in neon than in helium. Owing to the tendency for an arc to strike in neon and the consequent difficulty in keeping the thermionic current constant the small peaks at large angles could not be measured accurately and a table similar to that given for helium can not be given for neon. However, the same tendency is observable at the extremes of voltage. At 360 volts the scattering is reduced to one-hundredth its 0° value at about 12°, and at 75 volts it is reduced to the same fraction at about 18°. The tendency towards concentration about the primary beam at high electron velocities is thus evident, but electrons of the same velocity seem to be scattered through larger angles than in the case of helium. In view of the much greater mass of the neon atom this is a tendency which might be expected from purely classical considerations. However, the effect is probably not due entirely to the difference in mass as will be seen when the diatomic gases are considered.

As in helium, the secondary peak increases in relation to the primary peak as larger angles are examined. But there is one rather striking difference between the two gases. Throughout the angular region investigated which in neon was from 0° to 20° the secondary peak, though it increased, always remained smaller than the primary peak. This is in accord with the well-known fact that in neon the probability of excitation is unusually small in comparison with other gases. This may be accentuated by the fact that those electrons which collide inelastically in neon are deflected through larger angles than in the case of helium. Nitrogen resembles neon in this respect. There is also evidence, from the curves, of a group of electrons which have suffered two inelastic collisions. These appear at a lower voltage than in helium as would be expected from the difference in the radiating potentials of the two gases.

The general picture of the scattering is thus the same as in helium. However, the elastically scattered electrons of the same voltage are deflected through larger angles in neon. This is still more true of the inelastically scattered electrons. The same tendency to concentrate about the primary beam with increased voltage was observable in neon.

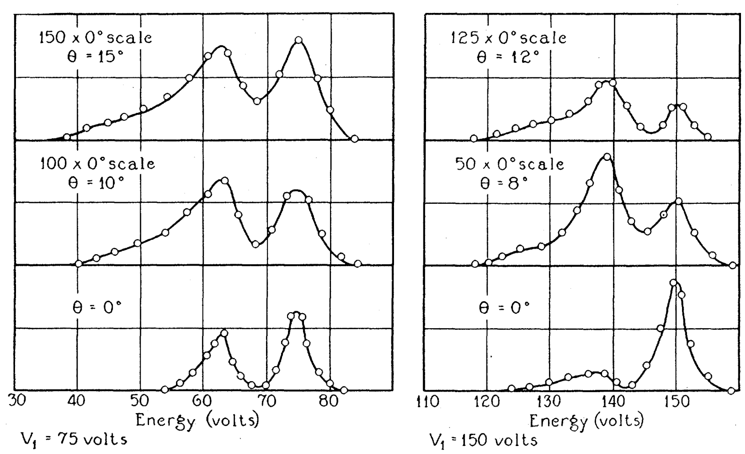

Fig. 3. Typical scattering curves for H_2.

Hydrogen.—The first diatomic gas investigated was hydrogen, and as can be seen from Fig. 3 the results differ in several respects from those obtained in helium. This is particularly so for the scattering at 0°. The curve obtained for 100 volt electrons is strikingly similar to the photometer curve given by Jones and Whiddington.[2] Most of the electrons which enter the analyser have lost no energy. There is a peak corresponding to the loss of enough energy to excite the hydrogen molecule and there is also some evidence of electrons which have suffered two inelastic collisions. The mean difference between the peaks of a large number of curves is 12.3 volts which is in good agreement with the value of 12.26 obtained by Jones and Whiddington. Their results can only be compared with the 0° curves as they had no method of investigating other angles.

The angular scattering of the electrons which have collided elastically is very similar to that observed in helium. The accuracy is not sufficient to establish definitely whether they are deflected through smaller angles than in helium, but they are certainly not deflected through larger angles. This is in a general way what would be expected classically from the difference in mass between the hydrogen molecule and helium atom. This similarity however, does not apply to the secondary peaks.

The most striking difference is seen to be at 0°; for here, at all voltages used the secondary peak is very much larger than in helium or neon. This is perhaps related to the fact that a larger number of ions is formed per centimeter in hydrogen than in helium. This effect should be greater at low voltages as is seen to be the case, but even at 75 volts only three times as many ionizing collisions are made per centimeter in hydrogen as in helium. The factor at these low voltages as given by these curves is very much larger than this, so that it is unlikely that the effect is due entirely to this cause. The conclusion is then that an electron which collides inelastically, has a better chance of being undeflected or of being deflected only through a fraction of a degree if the collision takes place with a hydrogen molecule than if it is with a helium atom. The voltages used are well above any of the critical potentials so in all probability the difference in the values of these potentials in the two gases is not directly the cause of this difference in behavior. It may be connected with the fact that the hydrogen is in the molecular state and the results obtained in nitrogen lend some support to this view. The general behavior of the secondary peak with variation in angle and voltage is the same as in the monatomic gases; but its rate of decrease with angle is less than in either of the other gases which have been discussed. At 75 volts the secondary peak decreases more rapidly with angle than the primary peak. However, for voltage above 75 the secondary peak definitely becomes much larger than the primary peak. This can be seen at 100 volts and is still more strikingly so at 150 volts. The behavior above 200 volts is not as regular as in the preceding gases. The probable cause of this is the complication introduced by the large number of electrons which have suffered two or more inelastic collisions. At these high voltages the peaks broaden out and as they are close together in hydrogen the analysis becomes difficult.

As would be expected electrons which have lost twice the energy necessary to excite radiation appear at much lower voltages than in helium or neon. Their number is small but larger in proportion than in the other two gases. The distribution of these in angle is a little uncertain, but they appear to have the distribution which would be expected if the second collision had the same deflecting effect as the first.

Nitrogen.—The behavior of electrons in nitrogen shows many points of similarity with the cases previously discussed. The mean distance between the primary and secondary peaks is 12.9 volts. This is a slightly greater value than was observed in hydrogen as would be expected in view of the excitation potentials of nitrogen. In none of the cases is the resolution sufficient to distinguish between the various excitation potentials. The secondary peaks are rather broad, indicating that more than one of these contribute. This would be expected from the band-like character of the nitrogen excitation spectrum.[7] The amount of the peak due to each of the various radiating potentials can not be ascertained.

The scattering of the electrons which have only collided elastically resembles very closely that observed in neon. The most probable angle at

[7] Brandt, Zeits. f. Physik **8**, 32 (1921).

which these electrons are scattered is even a little larger than in the case of neon which was in turn considerably greater than for helium or hydrogen. This again is a result which might be expected from purely classical momentum considerations, though the agreement may be merely fortuitous. The tendency of these electrons to concentrate in the solid angles close to the original beam as their velocity increases is also present, but as in hydrogen this is not so marked as in the rare gases. It seems even less evident than in the case of hydrogen. The reason for this variation with voltage and for the difference in the behavior of the gases is rather obscure and is a point upon which further investigation is in progress.

At 0° the secondary peak is more prominent than in helium or neon but less so than in hydrogen. The number of collisions per centimeter resulting in radiation in nitrogen is probably much greater than in hydrogen, so it must be presumed that at a radiating collision there is a much greater probability of deflection than in hydrogen.

The variation in the ratio of the two peaks with angle is much the same as in the previous cases. The primary peak diminishes much more rapidly than the secondary one. But, as in the case of neon, as far as 20° the primary peak is still the larger. As in hydrogen the peak representing those electrons which have suffered two inelastic collisions occurs at quite a low voltage. The variation with angle and voltage is much the same as in the case of hydrogen.

Thus the behavior of the scattered electrons in nitrogen has certain points in common with that observed in both neon and hydrogen. As in the case of neon, which also has a large mass, there is a tendency for both primary and secondary electrons to be scattered through larger angles than in helium or hydrogen. But in common with hydrogen there seems to be quite a large probability for an electron to sustain an inelastic collision without deflection. This is not so marked, however, as in the case of hydrogen.

The cases which have so far been discussed are all for electrons with energies equal to or greater than 75 volts. This voltage was chosen as the minimum, as it was well above the point at which the complications which would be expected in the neighborhood of the critical potentials, would become evident. The gases used were chosen as being easily obtainable and representative of monatomic and diatomic molecules. Mercury vapor and atomic hydrogen are also of considerable interest but so far the work with these gases is only in its preliminary stages. The region below 75 volts is one of great interest and it has been investigated in some detail in helium and hydrogen. However, the results obtained have not been sufficiently established to be presented at this time.

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