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ANGULAR SCATTERING OF ELECTRONS IN HYDROGEN AND HELIUM

By Gaylord P. Harnwell*

California Institute of Technology, Pasadena

Communicated June 9, 1928

In view of the recent work which has been done by Davisson and Germer,[1] G. P. Thomson,[2] and others in investigating the angular scattering of electrons by crystals, and the work of E. G. Dymond[3] in extending these investigations to the scattering of electrons by helium, it was thought worthwhile to see if similar results could be obtained for this scattering by other monatomic and diatomic gases. The phenomena observed when electrons are scattered by crystals are susceptible of explanation in a very satisfactory way on the wave mechanics hypothesis, but the theory is less fully developed for the case of gases and the results obtained by Dymond for scattering in helium have so far met with no adequate explanation. However, selective angular scattering might conceivably be expected in a monatomic gas. In this case it might be supposed that atomic hydrogen would also give rise to similar phenomena, and in view of its greater simplicity an explanation would present less serious mathematical difficulties. Hence, the following work was undertaken primarily to investigate the possibility of selective angular scattering in atomic hydrogen. Molecular hydrogen was also used though there was less reason to expect the phenomena in a diatomic gas. Finally, the experiments performed by Dymond in helium were repeated under as nearly similar conditions as possible.

The apparatus used is shown in figure 1. The scattering chamber consisted of a glass bulb about ten centimeters in diameter. A large ground glass stopper mounted vertically through a mercury seal carried the electron gun, *G*. This consisted of a tungsten filament mounted behind two collimating slits about a quarter of a millimeter wide and a centimeter and a half apart. By means of the ground glass stopper this could be rotated through nearly a complete circle. The angular setting could be read by means of a pointer attached rigidly to the stopper carrying the gun and an angular scale attached to the bulb. The front slit of the gun was about two and a half centimeters from the center of the bulb. As an electrometer was not available the electrons could not be analyzed magnetically and a scheme similar to that used by Davisson and Germer had to be adopted. A brass tube carrying a slit S_1 about a tenth of a millimeter wide projected through a wax joint to within a few millimeters of the center

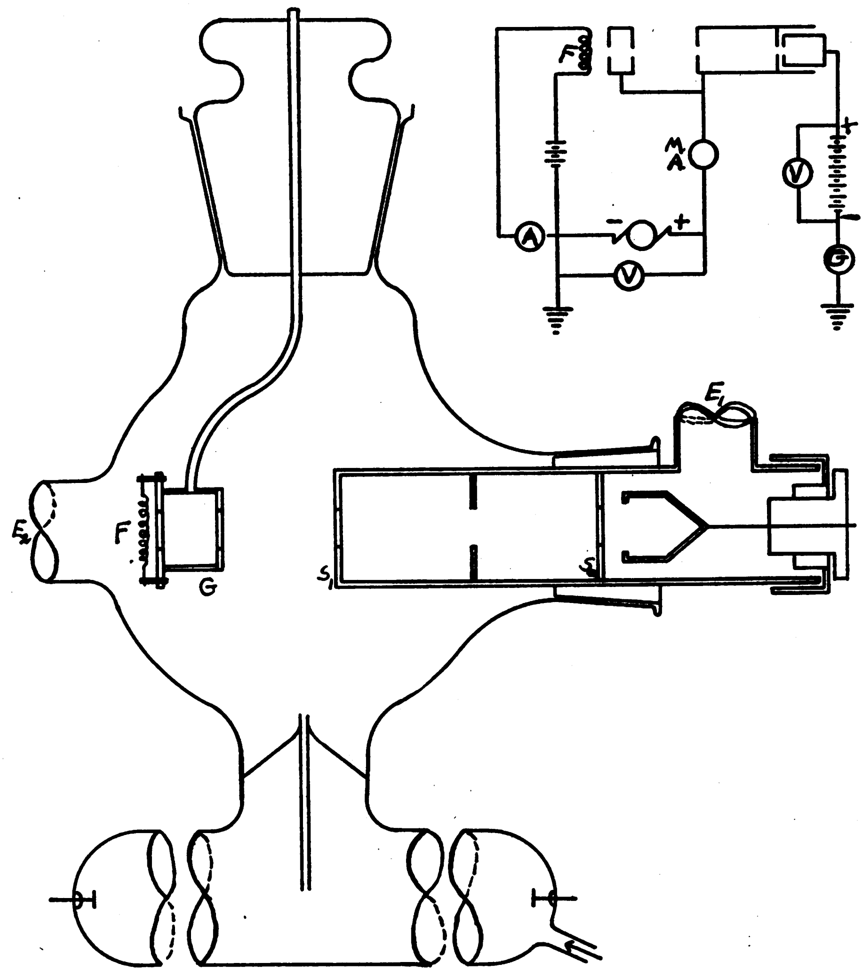

FIGURE 1

of the bulb. About four centimeters farther in the tube was placed a collimating slit, S_2, and immediately behind this an insulating plug supported a Faraday cylinder as shown. By varying the potential of the Faraday cylinder those electrons which had lost less than any given fraction of their energy could be collected. A diaphragm was mounted between S_1 and S_2 and a skeleton partition supported S_2 so that little resistance was offered to the flow of gas in the brass tube. A continuous flow method was used and the pressure in the brass tube could be kept lower than that in the scattering chamber by means of diffusion pumps evacuating through E_1. The other exit E_2 was connected to a second set of diffusion pumps.

A discharge tube about a meter and a quarter long was mounted with its center directly below the scattering bulb. A capillary tube of one millimeter bore and six or eight centimeters long led from the discharge tube up toward the center of the scattering bulb. When the discharge tube which was excited by a 25,000 volt transformer was in operation the many line spectrum was hardly detectable in the region immediately surrounding the capillary tube. Judging from the reports of other workers under similar conditions there was probably a very large percentage of atomic hydrogen present. The hydrogen was generated electrolytically and admitted to the discharge tube through an artificial leak. The pressure in the discharge tube could be varied up to about a millimeter in order to get the proper conditions for the discharge. The pressure in the scattering bulb could be varied relatively to that in the discharge tube by using both exits E_1 and E_2, or only E_1. Pressures in the scattering bulb up to 5×10^{-2} millimeters were used. An ionization gauge (not shown) connected directly to the scattering bulb which had been previously calibrated in hydrogen by means of a Macleod gauge was used to measure these pressures. The pressure in the discharge tube was measured by a Macleod gauge connected to the inlet tube. When investigating molecular hydrogen exactly the same apparatus was used, but the discharge tube was not run. In the last experiments the hydrogen generator was removed and a tank containing commercial helium was attached through a charcoal tube immersed in liquid air.

The scheme of potentials finally adopted is also shown diagrammatically in figure 1. The filament, F, was grounded and the body of the gun and the brass tube surrounding the Faraday cylinder were raised to a potential of from 200 to 800 volts by means of a D. C. generator. Below 200 volts difficulty was experienced because of the diminished intensity of the electron current reaching the Faraday cylinder, and 800 volts appeared to be the upper limit of the region of interest. The thermionic current to the electron gun was measured by a milliammeter and was kept constant during a run at a value of from five to ten milliamperes. The potential between the filament and the Faraday cylinder was always (except for various tests) kept at one-tenth that existing between the filament and the body of the electron gun. So that only those electrons which had lost less than one-tenth of their original energy were able to reach the collector and be recorded. Other arrangements of the potentials differing in various respects from the one just described were experimented with, but the above arrangement was decided on as giving the most satisfactory conditions. Also during the first part of the experiments immediately to be described the scattering chamber was surrounded by a shielding screen of copper gauze at the same potential as the electron gun and the tube surrounding the Faraday cylinder.

Molecular hydrogen was first introduced into the apparatus, and the peaks in the galvanometer current which were found to appear as the electron gun was moved around in a circle from its zero position were investigated under various conditions of pressure and of electron speed, as given by the potential difference existing between the filament and the slits of the gun. The zero position was determined quite accurately by the very sharp maximum found at any pressure and at any voltage used when the gun pointed directly into the collector. The voltages used were all too high to show any appreciable small angle scattering in either hydrogen or helium and hence as the gun was moved away from its zero position the current to the Faraday cylinder dropped practically to zero in two degrees or less. At high pressures when the mean free path was approximately from one-fifth to one-tenth the diameter of the bulb the peaks were rather low and broad. This was due very probably to the fact that the primary effect under observation was interfered with by subsequent collisions of the electrons. Under any of the conditions used only one peak appeared. At speeds corresponding to 800 volts and at the highest pressure used it appeared at about 52 degrees. As the voltage was decreased to 200 the peak moved slowly but continuously down to about 36 degrees. At lower pressures the behavior of the peak with voltage was of the same character but the actual amount of the variation became less and less down to a pressure of about 1×10^{-3} millimeters. Below this pressure the angular variation of the peak with voltage was reversed slightly, the peak corresponding to 800 volts appearing at a slightly smaller angle than that obtained at 200 volts. The peak became higher and sharper as the pressure was decreased. Below the pressure of 1×10^{-3} the peak became very high and narrow being of the order of one degree in width. But when all the gas was removed from the apparatus the peak did not disappear. The intensity of this peak represented under various circumstances from one-tenth to one-quarter the number of electrons which were found to reach the Faraday cylinder when the gun was pointing directly into the collector. However, the sensitivity of the galvanometer used was such that any peaks of over one-thousandth the intensity of the original beam could easily have been detected.

After this work the discharge was run under conditions such that the hydrogen existing in the region where the scattering took place was probably to a very large per cent in the atomic condition. The same procedure outlined above was repeated. The peak was found to be present and to behave in exactly the same way within the limits of error. No new peaks were observed. As this peak was found to be present, though very narrow, even when the pressure was as low as 1×10^{-5} millimeters it could not reasonably be due to angular scattering from the gas. A possible explanation was thought of in the charging up of the glass walls of the scattering bulb opposite the electron gun and consequent deflection of the electron stream by the electrostatic charge.

In order to test this possibility the electron gun was removed and the inside of the scattering chamber was given a heavy coating of magnesium by vaporization from a filament. Some experiments showed that this magnesium layer was of high conductivity and in electrical contact with the tube surrounding the Faraday cylinder. Consequently, in the following work it was at the same potential as this tube and the body of the electron gun. The electron gun was then returned to position and the above experiments were repeated using the same procedure, the only altered condition being the presence of the shielding layer of magnesium on the inside of the scattering bulb. Under these conditions no peaks whatever were observed at any pressure or voltage in either molecular or atomic hydrogen. As has been mentioned above any peaks equal in magnitude to one-thousandth of the original beam could have been detected. In the course of several weeks after the magnesium coating had worn off in spots under the influence of the hot filament small peaks began to appear at various angles. These remained when there was no gas in the apparatus, showing fairly conclusively that the peaks observed were due to electrostatic charges on the inside of the scattering bulb.

In the light of these negative results it was thought to be of interest to repeat Dymond's experiments as nearly as possible in the present apparatus. Helium was introduced into the apparatus and investigated in an exactly similar way as that which has been described for hydrogen. In the presence of the film of magnesium no peaks were observed. As the film wore off certain peaks appeared which behaved with pressure exactly as those described for hydrogen. These did not disappear when the pressure was reduced to the lowest possible value, which was approximately 1×10^{-6} millimeters of mercury.

The results may briefly be summed up as follows. No favored angles for electron scattering from hydrogen or from helium were observed, and in the case of helium the results obtained by Dymond were not able to be reproduced.

In conclusion it is a pleasure to thank Mr. Arnquist for his assistance in taking readings, the California Institute of Technology for the facilities extended for the work, and the National Research Council for its support which made the work possible.

* NATIONAL RESEARCH FELLOW.

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[2] G. P. Thomson, *Proc. Roy. Soc.*, **117**, 600, 1928.

[3] E. G. Dymond, *Physical Review*, **29**, 433, 1927.

THERMODYNAMICS BASED ON STATISTICS. I

BY GILBERT N. LEWIS AND JOSEPH E. MAYER

CHEMICAL LABORATORY, UNIVERSITY OF CALIFORNIA

Communicated June 19, 1928

Many attempts have been made to deduce thermodynamics from statistical mechanics, and no one can doubt the intimate relationship or even the complete identity of the two sciences. Nevertheless, it has not hitherto been found possible to proceed by a single path unambiguously from simple statistical assumptions to the laws of thermodynamics. This we hope to have accomplished in this paper and the following.

When the Second Law of Thermodynamics was first accepted, it was regarded as an exact law of universal validity. The concept of entropy which Clausius associated so intimately with his statement of the second law, was regarded as a quantity which could be defined, or at least the changes in which could be defined, without the slightest ambiguity. It was Gibbs who first suggested the idea, which was developed with so much acumen by Boltzmann, that entropy is related to a probability and that the second law expresses, not an infallible prediction, but a reasonable expectation. Indeed, Clausius' statement that an isolated system proceeds in a uniform direction toward a state of maximum entropy, seems, according to modern views, to be unsatisfactory, for we believe that any particular (microscopic) state of an isolated system will in endless time recur over and over.

Boltzmann, following Clausius, considered entropy to be defined only to an arbitrary constant, and related the difference in entropy between two states of a system to their relative probability. An enormous advance was made by Planck who proposed to determine the absolute entropy as a quantity, which, for every realizable system, must always be positive (third law of thermodynamics). He related this absolute entropy, not to the probability of a system, but to the total number of its possibilities. This view of Planck has been the basis of all recent efforts to find the statistical basis of thermodynamics, and while these have led to many differences of opinion, and of interpretation, we believe it is now possible to derive the second law of thermodynamics in an exact form and to obtain