RADIATION POTENTIALS OF ATOMIC HYDROGEN

By P. S. Olmstead and K. T. Compton

Abstract

Atomic hydrogen was produced by thermal dissociation of molecular hydrogen with a tungsten furnace which could be maintained at 2800°K during observations. Electrons were emitted from an equipotential oxide coated platinum rod thrust into the furnace. Radiation was excited by electrons falling through an accelerating difference of potential between the rod and the equipotential tungsten cylinder forming the wall of the furnace, and was detected by its photoelectric action on a platinum disk placed beyond the open end of the furnace. This disk was shielded from ions produced in the furnace by an intervening set of charged plates. Radiating potentials were observed at 10.15, 12.05, 12.70, 13.00, 13.17, 13.27 volts, with additional radiation at the ionizing potential 13.54 volts. Within the probable error of the observations, less than 0.05 volt, the agreement with the Lyman spectral series and with the Bohr theory is exact.

Introduction

During the last few years various papers[1] have put closer and closer limits on the various radiating and ionizing potentials of hydrogen. Each successive paper has brought forward a new method or an improvement on an old one to separate ionization from radiation effects, and, in the more recent papers, to separate atomic from molecular effects. Bohr's theory of the hydrogen atom has been closely verified by this work, though the experimental curves have never set the radiation or ionization potentials to a greater degree of accuracy than tenths of a volt. For this reason the authors decided to study one phase only of the problem, namely, radiation from the hydrogen atom. This means that our apparatus must be highly selective. It must be free from all effects due to the hydrogen molecule, and, in addition, no effects due to ionization of the atom should be observed. This gives an opportunity

[1] Davis and Goucher, Phys. Rev. **10**, 101, 1917;
Bishop, Phys. Rev. **10**, 244, 1917;
Foote and Mohler, J. Opt. Soc. Amer. **4**, 49, 1920; Bur. Stan. Sci. Papers No. 400;
Horton and Davies, Roy. Soc. Proc. A **97**, 23, 1920;
Franck, Knipping and Kruger, Ber. D. Phys. Ges. **21**, 728, 1920;
Found, Phys. Rev. **16**, 41, 1920;
Compton and Olmstead, Phys. Rev. **17**, 45, 1921;
Boucher, Phys. Rev. **19**, 189, 1922;
Olmstead, Phys. Rev. **20**, 613, 1922;
Duffendack, Phys. Rev. **20**, 665, 1922;
Olson and Glockler, Proc. Nat. Acad. Sci. **9**, 122, 1923.

to find out whether there is one resonance potential for the hydrogen atom or several, corresponding, respectively, to the lines of the Lyman series. The paper by Olson and Glockler, mentioned in the note, gives this information, but with the heat of dissociation of the molecule included. Our paper, however, deals with a method which is more fundamental, and, in this way, eliminates many of the difficulties of Olson and Glockler and avoids all uncertainty in interpretation. We have measured the radiation potentials of the atom alone. To determine the heat of dissociation would be an entirely separate problem.

Apparatus

To solve the problem mentioned it was necessary for the apparatus to have the following two important features; first, hydrogen must exist only in the atomic state in the part of the apparatus in which the experiment is taking place; second, the receiving electrode must detect *only* radiation. These two factors involve several others. In order to obtain atomic hydrogen only we must be able to change all molecular hydrogen into atomic hydrogen in the region of the reaction. We must also be able to keep out effects due to positive or negative ions or electrons.

The first of these difficulties was overcome by using a tungsten furnace similar to one previously described.[2] It consisted of a cylinder of tungsten foil .001 inch in thickness stretched between two nickel-plated iron electrodes, each of which was water-cooled. It was about 4 cm long and 1 cm in diameter. Using a current of 150 amperes the potential drop in the furnace was 4.5 volts. The temperature near the center of the furnace could be maintained at 2800°K for a time long enough to make observations. This was sufficient to keep more than 99 per cent of the hydrogen in the furnace in a dissociated condition,[3] since the pressure was only a few hundredths of a millimeter.

For this problem an improved method of accelerating the electrons was used (see Fig. 1). For the source of electrons a single platinum wire was thrust into the furnace. The tip of this wire was hammered down to give as large a surface as possible, and then was coated with the Wehnelt oxides. This made it possible to get from an equipotential point a large emission of electrons due to the heat of the furnace. The emission could be increased or diminished by regulating the distance the point extended into the furnace. Inside the tungsten cylinder, constituting the furnace, a second cylinder, 7 mm in diameter was placed and connected electrically with one end of the furnace so that an accelerating

[2] K. T. Compton, J. Opt. Soc. Amer. and Rev. Sci. Inst. **8**, 910, 1922

[3] Duffendack, loc. cit.[1]

potential could be applied between the platinum point and this inner cylinder. Since both these are equipotential surfaces, no corrections due to potential drop have to be applied to the experimental results, leaving only that due to the distribution of velocities of the electrons. As stated in a recent paper[4] this is an important factor only in the case of very intense effects, and is not large in the present case since moderate tem-

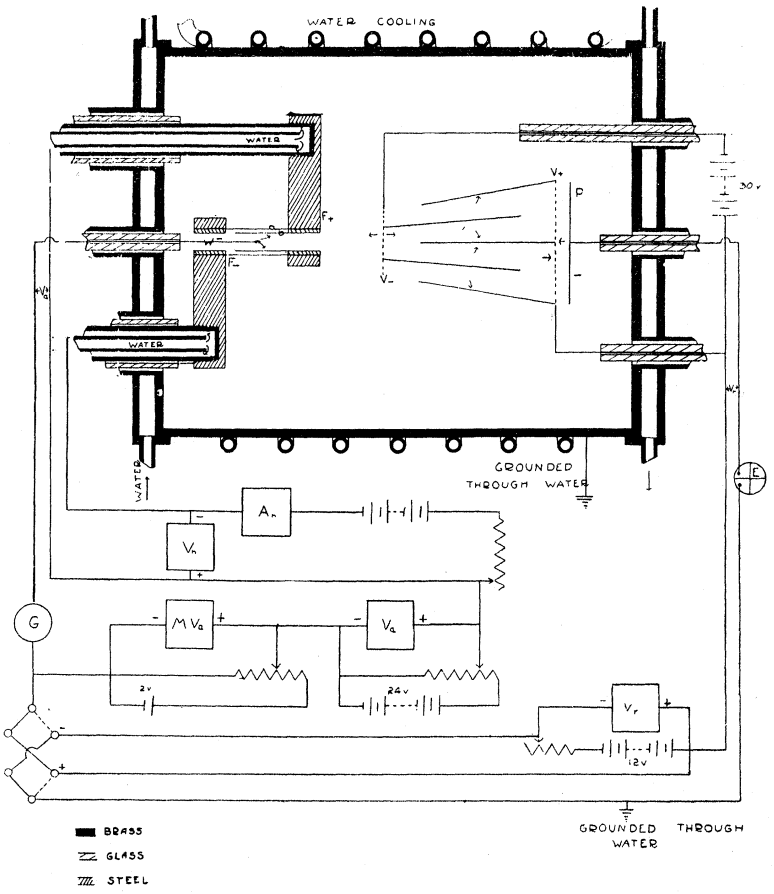

Fig. 1. Diagram of apparatus and electrical connections

peratures gave adequate emission from the oxide coated wire. This will be discussed further in studying the experimental results.

To detect the radiation resulting from collisions of the electrons and the hydrogen atoms, a plate was placed at the end of the furnace and perpendicular to it. A potential was applied to draw the photoelectrons from the plate, the effects being observed by means of a Compton electrom-

[4] Olmstead, Phys. Rev. **20**, 613, 1923

eter. However, since positive or negative ions or electrons might register in addition to the radiation, a set of fins, charged alternately positively and negatively, patterned after those used by Kurth,[5] was placed between the end of the furnace and the plate. This made it possible to observe the effect of radiation only.

The various potentials were applied in the usual way for a four element tube. The furnace was placed so that its positive end was at the same potential as the inner cylinder. This made it impossible for any electrons to be accelerated from the platinum point through a higher potential drop than that between the platinum point and the equipotential cylinder.

Experimental Results and Discussion

Three examples of the experimental results are given in Figs. 2, 3 and 4. Each of these curves represents a stage in pushing the problem to its successful solution. Fig. 2 is the first curve which was taken, and, as may be seen, it was found that several breaks due to the atom were

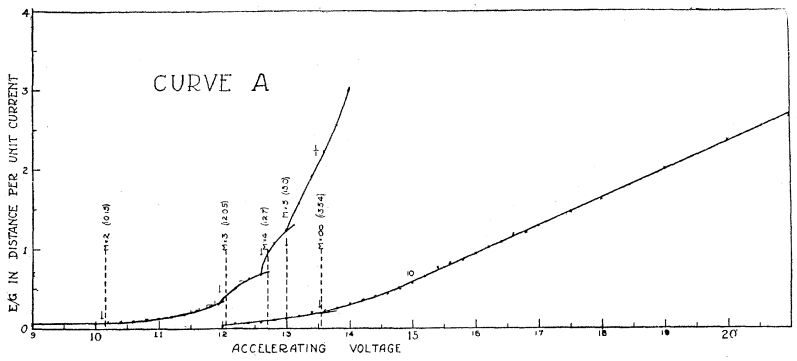

Fig. 2

definitely indicated, but effects due to the molecule, which are usually very strong, were entirely missing. No ionization effects were observed. In the case of the molecule we ordinarily expect an effect due to dissociation of the molecule plus ionization of one atom at about 16 volts. In the figure this part of the curve is very nearly a straight line. Effects which are due to dissociation of the molecule and radiation from one of the atoms, would be at potentials in the neighborhood of 12.6, 14.6, 15.2, etc. Using the data of Olson and Glockler the values would be even higher. No indication is found of any of these lines. This shows that our tube is entirely free from any effects due to the hydrogen molecule.

[5] Kurth, Phys. Rev. **18**, 462, 1921

Unfortunately, before we had an opportunity to study further the phenomenon given by our first experimental curve, we were forced to postpone our work because the furnace burned out and had to be replaced. This was quite a delicate operation, and it was a considerable length of time before we could proceed with the work.

Fig. 3 gives one of the first curves taken when the apparatus had been set up again. In this it was seen that the breaks were not nearly as sharp as might be expected from the results given in Fig. 2. After studying this curve and several more like it, for a short time, we found the cause to be that in replacing the furnace, we had turned it around end for

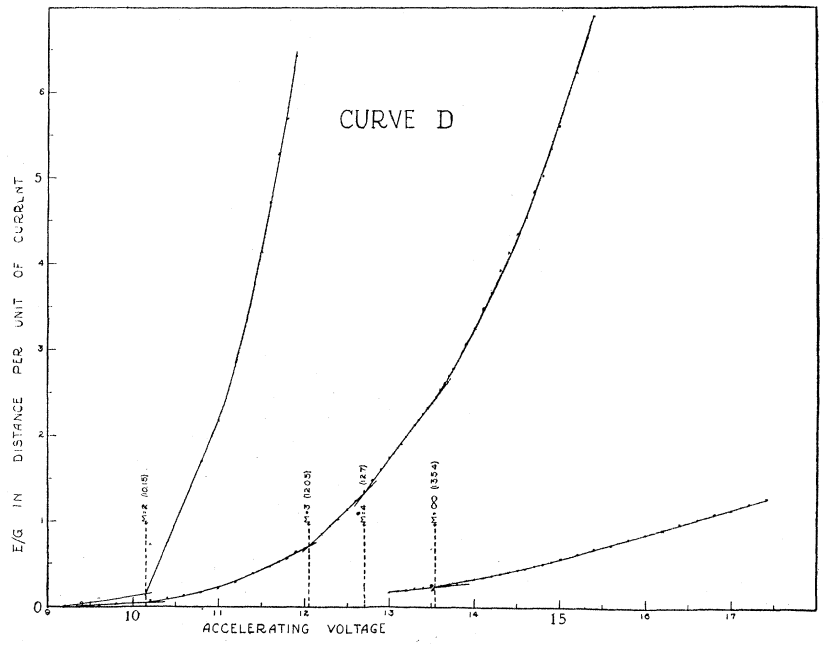

Fig. 3

end, and had thus interchanged the potentials. This made it possible for some electrons to be accelerated by more than the potential between the equipotential point and the equipotential surface, This means that the electrons emitted by the point would have a wider range of velocities, and that breaks due to them would not be as sharp as in the case of Fig. 2.

The obvious correction to make was to interchange the leads of the furnace and make it impossible to get a greater fall of potential than that between the two equipotential surfaces. This was done in the curves for which Fig. 4 is typical. In this curve the breaks are remarkably sharp.

The first break is different in shape from the others. It corresponds to an electron fall from the second orbit to the first, giving the first line of

the Lyman series. On first thought one would say that this effect should be a very strong one, but the curve shows that the second break which corresponds to a fall from the third to the first orbit is more marked than the first. It is well known that the first line of the Balmer series, but not the other lines, is almost always obtained reversed spectroscopically in an electron discharge tube.[6] This is similar to what happens in this case. Only a small amount of the radiation actually formed reaches the plate of the tube; the rest is taken up and re-emitted by other hydrogen atoms, and in this way is dispersed to various parts of the tube. This, ap-

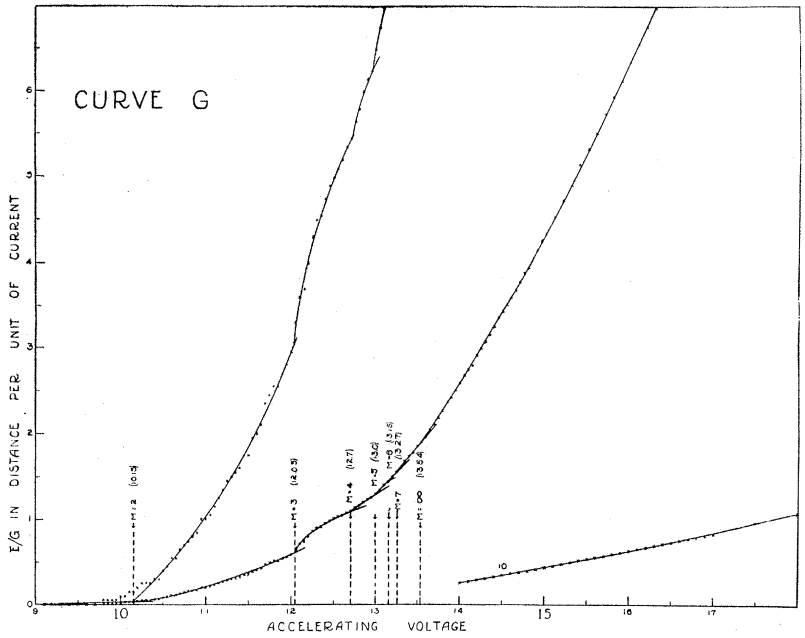

Fig. 4

parently, answers the question of Olson and Glockler about where the first line of this series should appear, and why they do not observe it as one of their breaks.

This radiation was found gradually to increase from zero with increase in electron velocity above the critical value. This is due, in part, to the distribution of velocities of the electrons. Some will have velocities greater than the average and thus will tend to start the effect before the point at which the average electron gives the effect. The way in which this works is given more in detail in a previous paper.[7] To elim-

[6] See, e.g., Wood's Physical Optics

[7] Olmstead, loc. cit.[4]

inate the effect of this distribution the best straight lines are drawn on either side of the break to determine the break point. In the case of breaks other than the first, the effect due to the distribution of velocities is very small. In other words, the average electron is the one that counts in giving an added effect. The faster and slower electrons produce the same effect as before, but when this is added to some original effect the weight of these electrons is discounted.

The presence of the break at a point corresponding to the ionization potential of the atom needs explaining. As this is a converging frequency of all lines in the Lyman series, this break might be taken as the sum effect of all radiations beyond those definitely indicated, which cannot be separately picked out. A better explanation, perhaps, is that this increase is in conformity with the well-known fact that the spectrum of hydrogen comes out much stronger after reaching the ionizing potential,[8] due partly to the more favorable distribution of potential between the electrodes, which increases all radiations. In fact, until the ionization potential is reached, only the first line of the Lyman series has been observed spectroscopically. This work shows, however, that it should be possible to get each line of the series to appear at its own characteristic potential. It has been assumed hitherto that the potential corresponding to the first line was the resonance potential, but in view of this work it seems that there are several resonance potentials, each of which corresponds to a line of the Lyman series.

This work has given a further check on the Bohr picture of the hydrogen atom in that the first six lines and converging frequencies of the Lyman series, corresponding to 10.15, 12.05, 12.70, 13.00, 13.17, 13.27 and 13.54 volts have been experimentally determined. In addition, it has opened the whole field of radiation potentials to closer investigation. The method, as outlined, is especially applicable for the study of radiation from the atom in the case of diatomic gases. The authors are at present investigating nitrogen, and will probably continue with other gases.

This work was performed in the Palmer Physical Laboratory at Princeton.

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PRINCETON, N. J. (K. T. Compton),
May 29, 1923.

[8] For instance, Hughes and Lowe, Phys. Rev. **21**, 292, 1923