



## XXI. On the ionizing potential of sodium vapour

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A simple relation exists in the general case between the distances  $OH_1$  and  $OH_2$ . Let

$$u = \frac{v_1}{\mu_1}, \quad v = \frac{v_2}{\mu_2}, \quad f = \frac{f_2}{\mu_2} = -\frac{f_1}{\mu_1},$$

$\mu_1$  and  $\mu_2$  being the refractive indices of the first and last media.

Then

$$OH_1 = \frac{a}{1 - \frac{v}{u}} - (\mu_2 - \mu_1)f,$$

or 
$$\frac{OH_1}{f} = \frac{a}{v} - (\mu_2 - \mu_1).$$

Also, 
$$\frac{OH_2}{f} = \frac{a}{u} - (\mu_2 - \mu_1);$$

therefore 
$$\frac{OH_2}{vf} - \frac{OH_1}{uf} = (\mu_2 - \mu_1) \left( \frac{1}{u} - \frac{1}{v} \right) = \frac{\mu_1 - \mu_2}{f},$$

or 
$$\frac{OH_2}{v} - \frac{OH_1}{u} = \mu_1 - \mu_2.$$

If  $\mu_1 = \mu_2$ ,

$$OH_1 = \frac{af}{v} \quad \text{and} \quad OH_2 = \frac{af}{u}.$$

## XXI. On the Ionizing Potential of Sodium Vapour.

By R. W. WOOD and S. OKANO\*.

THE experiments of Frank and Hertz, McLennan and others have shown that, when the vapours of mercury, cadmium, zinc, and magnesium *in vacuo* are bombarded by electrons from a hot cathode, a single line spectrum is emitted, provided the kinetic energy of the electrons does not exceed a certain critical value.

In the case of mercury, Frank and Hertz showed that the single line  $\lambda = 2536.7$  appeared when a potential difference of 4.9 volts was applied between the hot cathode and the anode wire, this being the voltage required by the quantum relation for the frequency of the line 2536.7.

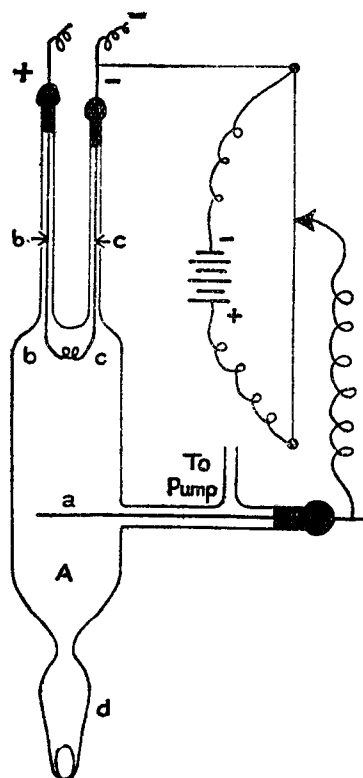
It is of course very important to ascertain whether the quantum relation holds in the case of all metallic vapours, as it has been found to do in the case of the four above enumerated, and we have accordingly carried out an extensive series of experiments with the vapour of sodium, which does

\* Communicated by the Authors.

not appear to have been investigated up to the present time. A *résumé* of our results was presented at the annual meeting of the American Philosophical Society in May.

In the majority of our experiments we have used bulbs made of the new pyrex glass manufactured by the Corning Co. This glass shows much less discoloration from the action of sodium vapour at high temperatures than any of the glasses which have been on the market heretofore, and on account of its very low expansion coefficient requires little or no annealing, being almost as satisfactory as fused silica in this respect. It can be obtained in the form of tubing of all

Fig. 1.



sizes, flasks of various forms, beakers, &c.; consequently it is possible to make very elaborate apparatus with little difficulty. The apparatus with which the minimum ionizing potential of sodium was measured is shown in fig. 1.

The cathode was a spiral of fine tungsten wire (5 mils. diameter) attached to two stout copper wires *b* and *c*, the ends of which were split and then squeezed together. The sodium was placed in *d*, and after exhaustion of the bulb, distilled into *A*, after which it was sealed off. The anode *a* was of platinum. The electrodes were sealed in with sealing-wax, the lateral tubes through which the cathode wires pass having a bore only slightly larger than the diameter of the wire to prevent the diffusion and condensation of sodium vapour on their walls. There is bound to be a loss of the vapour through the tube leading to the pump, but this cannot be helped; for if we seal off the tube from the pump the vacuum is rapidly impaired by the liberation of hydrogen from the sodium. Experiments on the resonance radiation of sodium vapour have shown that it is practically impossible to remove all of the hydrogen from the metal by repeated distillation *in vacuo*, for the metallic vapour carries down hydrogen with it, when it condenses on the wall. The tungsten wire was heated by the current from a small storage-battery, and the potential applied as shown in fig. 1, by a potentiometer, consisting of a wire of 10 ohms resistance stretched on a metre stick, and from one to three or more dry cells.

In our first experiment we started out with an applied potential of 6 volts between the cathode spiral and the anode wire. The tungsten was raised to normal incandescence, and the bulb heated by brushing its surface as uniformly and rapidly as possible with the flame of a Meker burner. A bright yellowish glow appeared around the anode, and the spectroscope showed, in addition to the D lines, the red and green lines of the subordinate series. On diminishing the applied potential we found that the subordinate series faded gradually and disappeared entirely at 2.34 V. The D lines, however, remained bright. On still further reducing the potential we found that the yellow glow at the anode wire disappeared at a potential of 0.5 V., though we could still see the D lines in the spectroscope at still lower potentials, or even with the connexion at *A* broken.

This we subsequently found was due to the fact that the potential drop along the tungsten filament was sufficient to cause a glow around the positive leading-in wire, and some of this light was reflected into the spectroscope from the wall of the tube. If the potential difference between the terminals of the filament exceeds about three volts, arcing takes place when the bulb is heated, without the application of any potential between *a* and *c*, the yellow glow filling the

greater part of the bulb, and showing the subordinate series as well as the D lines.

In the case of vapours for which the single line emitted lies in the ultra-violet, and evidence of its presence is obtained by the spectroscope, it is obviously necessary to make sure that the potential difference between the terminals of the hot cathode is not responsible for the appearance of the line.

When the single line lies in the visible region there is less trouble, since, with diminishing voltage, the glow contracts to a thin skin covering the positive electrode, which may be either the auxiliary anode "*a*" or the positive terminal "*b*" of the hot cathode, according to whether the applied potential, or the potential due to the drop along the cathode filament, is responsible for the emission.

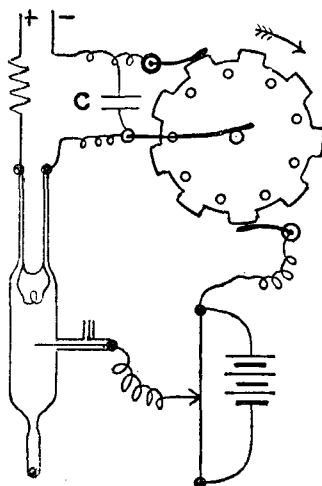
By using a very short filament we succeeded in reducing the potential difference between its terminals to about one volt; but even in this case we detected the D lines when the spectroscope was directed towards the terminal "*b*." They were so faint, however, that there was not much chance of their being seen by reflexion from the walls of the bulb.

The anode wire in this case was perfectly straight, and by viewing it "end on" the visibility of the faint luminous glow surrounding it was enormously enhanced. To still further increase the sensibility of the method, we formed an image of the end of the wire on the slit of the spectroscope by means of a lens (see fig. 1). This was accomplished without difficulty by throwing an image of the sun on the wire. On darkening the room we found that we could observe the D lines at the wire "*a*" until the applied potential was reduced to 0.5 volt, or perhaps a little less than this. The exact point at which the line disappears depends of course upon the condition of the eye.

To remove entirely the possibility that the potential drop along the tungsten wire was contributory, we employed two methods. In the first or stroboscopic method, we employed a brass disk with wide teeth and small holes as indicated in fig. 2. This wheel interrupted the heating current, and by viewing the tube through the apertures we observed the condition at the auxiliary anode only at the moments when there was no potential difference between the ends of the tungsten filament. (The circuits were of course simpler than indicated in fig. 2.) This method gave good results when used with the steel tube (which will be described presently),

as in this case the sodium glow could be viewed against an absolutely black background and the light of the filament cut off by means of a suitably placed screen.

Fig. 2.



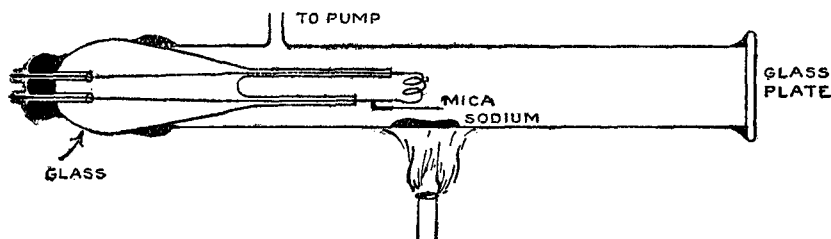
The second method was very similar except that we arranged the circuits as shown in fig. 2, the rotating wheel applying the potential between the hot cathode and the anode wire only for the time intervals during which the heating current was shut off. The condenser C was inserted to lessen the spark at the break. In both cases the wheel was turned at a speed sufficient to maintain the filament at a constant intensity without any visible flicker.

Our earlier observations were confirmed by both of these experiments. The D lines appeared when the potential between the hot cathode and the wire was 0.5 V. or greater. As this value is so much below that required by the quantum relation (2.1 V.) it was necessary to make sure that the emission of the D lines was not due to some secondary action, the light from the incandescent filament for example.

To test this point we mounted the tungsten filament at the centre of a steel tube, as shown in fig. 3. Immediately

below the filament and close to it was a very thin film of mica, which stopped the electrons but transmitted the light. The sodium was placed below the filament and vaporized by a small bunsen flame. The cathode end of the tube was

Fig. 3.



wrapped with black cloth, and as the sloping walls of the glass tube reflected no light in the direction from which observations were made, the background was practically black.

In this experiment the steel tube was made the anode, and with a potential difference of 0.5 V. between it and the cathode, the yellow glow of the sodium vapour appeared above the mica plate but not below it. This indicated that the light from the cathode played no part in the production of the phenomenon. We also tried illuminating the tube shown in fig. 1 with a concentrated beam from the arc, but no difference in the brilliancy of the D line or the potential at which it appeared could be detected.

There remained apparently only the possibility that the effects might be due in part to a contact difference of potential. We made a number of experiments to test this point, using various materials (copper, platinum, tungsten, &c.) as anodes, and obtaining always the value 0.5 V. The sodium vapour, however, usually condenses on the anode, making the experiment inconclusive.

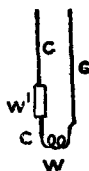
In one case, to prevent the condensation, we mounted a tungsten anode wire along the axis of the incandescent spiral cathode wire. This gave a value of 1.4 V. for the minimum potential; but we feel certain that the higher value was due to the deflexion of the electrons away from the anode by the magnetic field of the spiral.

The most conclusive experiment was made with a cathode of the form indicated by fig. 4. The portions C are of copper wire, while the spiral and loop (W and W') are of 5 mil. tungsten wire.

In this case we are not using an auxiliary electrode, and

the potential difference results from the drop across the spiral. The glow appears around the tungsten loop  $W'$  and its copper supporting wires, which are at a temperature sufficiently high to prevent any condensation of sodium.  $W'$  remains below a red heat, while  $W$  is at incandescence.

Fig. 4.



The potential difference can be varied somewhat by changing the heating current, and consequently the temperature and resistance of the spiral.

We found in this case that the D-line glow appeared and disappeared at the same instant on the tungsten loop  $W'$  and its two supporting wires of copper: this appears to indicate that contact difference of potential plays no part in the production of the D-line glow.

The conclusion that we have reached, as the result of all of our experiments, is that the D-line emission results from the application of a potential of 0.5 volt or more, and that the subordinate series appears at 2.3 V.

The two points are determined, however, by the visibility of the lines in a Schmidt & Haensch pocket spectroscope, which is a most efficient instrument, but the lines fade gradually in each case, and there seems to be no point at which there is a discontinuity. This is perhaps to be expected, as a result of the wide variation in velocity of the electrons expelled from the hot cathode.

The average velocity of these, in the case of an incandescent tungsten wire, is the equivalent of a potential drop of about 0.4 volt.

Assuming the Maxwell distribution, there must be a considerable number moving with a sufficient velocity to excite the D-line emission without the application of any electromotive force.

It seems desirable to arrange an experiment with sodium vapour in which we can deal with a stream of electrons in which all are moving at very nearly the same velocity. This could be accomplished perhaps by magnetic separation.

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May 1917.