A VACUUM TUBE TO ILLUSTRATE THE SLOW DIFFUSION OF THE
RESIDUAL GASES IN HIGH VACUA.

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IN operating a Geissler pump it is often surprising to note how long it is necessary to wait between strokes in order that the pressure may be equalized in different parts of the pump. This is especially noticeable at high exhaustions, and whenever there is at any point a considerable contraction in one of the connecting tubes the slow diffusion often causes considerable delay. Crookes has called attention to this phenomenon in his papers upon high vacua, and, I believe, cites instances where it was necessary to wait an hour or more before measurements of pressure with the McLeod gauge could be made with consistent results. While lecturing recently on subjects connected with high vacua it occurred to me that it would be desirable to give an illustration of this phenomenon. The vacuum tube, or rather the pair of tubes, which is described below, was therefore constructed for the purpose.

Two ordinary cylindrical tubes with aluminum terminals at the ends were connected by a capillary tube about 20 cm. long, the latter being sealed into the walls in such a way as to make the combined tube present the appearance of a letter H. The bore of the capillary tube was about .5 mm. in diameter. Each of the two tubes connected by it was about 15 mm. in diameter and 20 cm. long. Connection to the pump was made through a short glass tube leading from near the end of one of the pair of tubes forming the vertical legs of the H.

During the exhaustion of this combination tube, air from the tube that is directly connected to the pump can readily flow into the latter at each stroke; but the exhaustion of the more distant tube can only take place as the result of the transference of air through the long capillary. At high exhaustions this transfer takes place very gradually, and the apparatus affords an illustration of the phenomenon described by Crookes upon a considerably exaggerated scale.

The condition of the vacuum in each of the two tubes is indicated by the character of the discharge sent through it by an induction coil. When the pressure has been reduced to about 3 or 4 mm. a characteristic Geissler discharge is shown in both tubes and no marked difference can be seen between the two; but as the exhaustion proceeds beyond this point, especially if the pump is operated rather rapidly, the vacuum in the tube nearer the pump is seen to increase much more quickly than that in the more distant one. A condition of affairs may readily be reached such that one tube shows all the characteristics of a rather high Crookes' discharge, the walls, for example, becoming brilliantly fluorescent under

the influence of the cathode rays, while the other tube still shows a stratified Geissler discharge, with no indication of cathode rays. This extreme difference may be maintained for a considerable time, and the gradual equalization of pressures in the two tubes is readily followed by watching the corresponding changes in the appearance of the discharge. After the pressure has been equalized by long standing, so that cathode rays are being developed in both tubes, the phenomenon can be shown in the inverse order by very gradually allowing air to enter the pump. It is important, however, that the air should not be permitted to enter too rapidly, for at pressures of a centimeter or more the air seems to pass through the capillary tube quite readily. It is only at high exhaustions that the phenomenon is shown in its most striking form.

Since the combination tube has four terminals it is possible to change the connections so as to modify the experiment in a great variety of ways. One of the terminals of one tube, for example, may be used as a cathode, while one of the terminals in the second tube forms the anode. The capillary connecting tube will then be brilliantly lighted, and often shows a distinctly different color at one end from what it does at the other. The cause of this variation in color I have not yet found time to investigate. It is quite possible that it is due merely to a difference in the density of the air; but a hurried examination of the spectrum indicates that there is a complete change of the more prominent lines in going from one end of the capillary to the other. In preparing the tube and filling it with air no precautions whatever were taken to avoid the presence of impurities. It is, therefore, quite probable that vapors from the flame, and possibly other impurities, were present. These would probably pass through the capillary at different speeds, so that it seems not improbable that by the slow diffusion through the capillary a nearly complete separation of the residual gases might have been produced.

When one terminal is used from one of the two tubes and the other terminal from the other, it is possible to have the conditions such that the region near the anode is stratified, while the region near the cathode shows the characteristics of a high vacuum Crookes' discharge. Upon reversing the direction of the current, the change in the appearance is most striking. In the first case cathode rays are developed in large amounts, in the other case there is no trace of these rays. This form of the experiment may be shown fairly well by one of the older forms of spectrum tube with the capillary somewhat smaller than that usually employed.

When the negative terminal is in the denser gas and the positive terminal in the rarer no cathode rays are developed at the cathode itself. But at the positive end of the capillary a sharply defined bundle of

cathode rays proceeds from the opening of the capillary straight across to the opposite wall of the tube. It is usually possible to see the luminous path of the rays through the gas as well as the fluorescent spot which they develop on the glass. The rays are readily deflected by a magnet and behave in every way as though the opening of the capillary were a real cathode. In fact, this form of the experiment affords as good an illustration of Goldstein's secondary cathode rays¹ as I have seen.

Another modification of the experiment with the H-tube is to connect the two in parallel. The discharge will then pass through the tube of least resistance, and the change in resistance due to pressure changes can be illustrated. This arrangement is, however, not so satisfactory as to connect the two cathodes only in multiple, while using a single anode. The discharge will then divide between the two cathodes. If the experiment is performed before the pressures in the two tubes have been equalized by diffusion through the capillary, one of the cathodes shows the blue glow characteristic of low vacua at the same time that the other is giving off an abundance of cathode rays. Upon reversing the current, so that the two *anodes* are in multiple, the discharge passes from one anode only, namely, from the one nearer the cathode.

It will be seen that the *H*-tube described may be used for a great variety of purposes in the way of illustration. It has the disadvantage that it must be kept in connection with the pump; for, although the difference in pressure between the two tubes will last for a long time, the two ends of the capillary will ultimately reach the same pressure. This difficulty might be avoided by using a stop cock to shut off the connection between the two tubes. Probably a tube of caustic potash on one side would serve the same purpose. There are, however, so many advantages in carrying on the exhaustion in the presence of the class, that it seems to me desirable to do so in experiments of this kind whenever it is possible.

¹ Goldstein, Wiedemann's Annalen II, p. 832, 1880.