Explanation of Abnormal Low Voltage Arcs.

IT is well established that arcs in gases or vapours may be maintained at voltages as low as their ionising potentials, or, in cases where cumulative ionisation is possible, as low as their radiating potentials, provided a hot cathode is used as a source of electrons to stimulate the arc. Considerable discussion has arisen over certain cases in which arcs have been maintained at still lower voltages,[1] since at such voltages the electrons are known not to effect partial or complete ionisation of molecules with which they collide.

Recently Bar, v. Laue and Meyer [2] and, independently, the present writers,[3] have shown that this may be accounted for by the existence of oscillations the peak voltage of which always exceeds the lowest radiating potential of the gas. An experimental and theoretical study of these oscillations has shown them to be in the nature of current interruptions occasioned by the rise in current and consequent drop in voltage occurring when the ionisation is sufficient to create a positive space charge around the filament. Under such conditions there is nothing to prevent a rise in current to its saturation value. With such a rise, the increased potential drop in the series resistance reduces the voltage across the arc. If this reduction takes the voltage to a value below the lowest critical potential of the gas, the current can be maintained only so long as the supply of previously excited atoms persists, after which the current decreases, the voltage rises, and the cycle is repeated. Reactance in the circuit is not, as believed by Bar, v. Laue and Meyer, essential to the oscillations, though it does affect the wave form.

The above phenomenon does not explain all cases of abnormal low voltage arcs, however, for we have maintained arcs in helium, mercury vapour and argon, without oscillations, at voltages well below the lowest critical voltages of the gases. Also Holst and Osterhuis [4] have reported steady arcs in argon at 3·5 volts and neon at 7·5 volts, whereas the lowest critical potentials of these gases are 11·5 and 16·7 volts respectively. To account for this, these authors have proposed a rather elaborate theory of progressive ionisation. The following experiments, however, explain entirely these abnormally low voltages simply on the basis of well-known phenomena.

A short hot-filament cathode and a sheet nickel anode were placed about 1 cm. apart, and a 3 mm. length of 1 mil wire projecting from a glass stem was introduced as an exploring electrode in a bulb filled with pure argon at 2 mm. pressure. This electrode was used according to Langmuir's recent method,[5] and was movable to different points in the discharge by a flexible copper-to-glass seal.

It was found that the arc could easily be maintained at an applied voltage of about 4 volts, without oscillations. Under these conditions, however, *the gas near the filament was found to be at a potential of about* 11·5 *volts above that of the filament*, and there was an electric field in the direction reverse to the applied field throughout most of the space between the electrodes. Furthermore, the concentration of ions, either positive or negative, was found to decrease from about 100×10^{10} per cc. near the cathode to about 2×10^{10} per cc. near the anode. The average kinetic energy of the electrons outside the region of the cathode drop was found to vary from 2 to 4, in equivalent volts. Analogous results were found in a mercury arc, operating at about 3·5 volts.

Evidently there is *always* a sufficient cathode drop to produce ionisation. If the ionisation is intense, positive as well as negative ions move toward the anode, and at approximately equal rates. To cause this, the reverse electric field, caused by difference in rates of diffusion of electrons and positive ions, takes such a value as to cause the two types of ions to move toward the anode at nearly equal rates. It is easily shown that the number of ions of either sign is at least a million times greater than the excess of one kind over the other, except in the region of the cathode drop.

A fuller treatment of this problem and its significance in the Geissler tube discharge will soon be published.

We are indebted to Dr. Irving Langmuir for suggesting this general line of explanation of the abnormal arc.

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[1] Compton, Lilly and Olmstead, *Phys. Rev.*, 4, p. 282, 1920; A. C. Davies, Proc. Roy. Soc., A, 100, p. 599, 1922.
[2] *Zeits. f. Phys.* 20, p. 83, 1923.
[3] *Science*, 59, p. 166, 1923.
[4] *Physica*, 4, p. 42, 1924.
[5] *Gen. Elec. Rev.*, p. 731, Nov. 1923.

De Broglie's Theory of the Quantum and the Doppler Principle.

L. DE BROGLIE (*Phil. Mag.*, Feb. 1924) has recently suggested a theory of the quantum in which the quantum is supposed to be a corpuscle of exceedingly small rest mass M which moves with a velocity βc, where β is less than unity by an exceedingly small amount. The momentum of such a corpuscle is $M\beta c/\sqrt{1-\beta^2}$, and is equal to that of the light quantum $h\nu/c$. Since β is so nearly unity, the momentum may be written as $Mc/\sqrt{1-\beta^2}$. Different values of the frequency ν are explained as being due to different values of β.

Let us suppose that an atom is moving towards the observer with a velocity $\beta_1 c$, and that while moving with this velocity the atom ejects a quantum in the direction of the observer, the frequency of the quantum being ν_0 and its velocity $\beta_0 c$ relative to an observer on the atom. The momentum of the quantum relative to the atom is then $h\nu_0/c = Mc/\sqrt{1-\beta_0^2}$. By applying the relativity theorem of the addition of velocities, we have that, if βc is the velocity of the quantum corpuscle relative to the stationary observer,

$$\beta c = (\beta_0 + \beta_1)c/(1 + \beta_0\beta_1).$$

Hence $$1 - \beta^2 = \frac{(1-\beta_0^2)(1-\beta_1^2)}{(1+\beta_0\beta_1)^2}.$$

Remembering that β_0 very nearly equals unity, and assuming that β_1 is small, we have

$$1 - \beta^2 = (1-\beta_0^2)(1-\beta_1)^2.$$

Hence if ν is the frequency relative to the stationary observer we have

$$h\nu/c = Mc/\sqrt{1-\beta^2} = Mc/(1-\beta_1)\sqrt{1-\beta_0^2} = h\nu_0/c(1-\beta_1).$$

If now we put $\beta_1 = v/c$, where v is the velocity of the atom relative to the stationary observer, we have

$$\nu = \nu_0 c/(c - v),$$

which is the equation expressing the Doppler principle when the velocity v of the radiating atom is small compared with c.

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St. Louis, Mo., May 23.

THE result obtained by Mr. Jauncey seems to be quite correct, and I already knew that it was possible to explain all the forms of Doppler effect by means of my "light quantum" conception.

By studying the collision of a moving electron with a light quantum, I have also obtained a formula for the change of frequency which involves both the Doppler effect and the Compton effect.

In a recent number of the *Phil. Mag.* (May 1924) Mr. William Anderson has stated a curious and perhaps not very probable consequence of my views.