These observations also have a bearing on a recent theoretical conclusion by Fröhlich[2], that solid long-chain substances, notably polar ones, should exhibit an absorption band, associated with oscillatory motion of portions of the chains, centred at a wave-length lying between 1/10 and 1/100 cm. and of sufficient width to cause appreciable absorption in the cm. region. On this basis the power-factor would increase with decreasing wave-length towards the far infra-red ; the fact that our results show the power-factor to be decreasing at 1·23 cm. suggests that the effect is still small compared with that arising from the loss mechanism operative at longer wave-lengths. The cause of the widely spread basic loss observed is not yet fully elucidated, but there is reason to suppose that it is due, at any rate in large measure, to the presence of polar groups introduced by traces of gaseous impurity in the original ethylene gas. The accuracy of measurement depends on the wave-length but may in general be taken as ± 10 per cent or better.

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[1] Jackson and Forsyth, *J. Inst. Elect. Eng.*, **92**, Pt. iii (1945).
[2] Fröhlich, British Electrical and Allied Research Association Report No. L/T. 157.

'Shot-Effect' in Diodes Under Retarding Field Conditions

THE magnitude of the fluctuations of current i in a diode valve known as 'shot-effect' obeys the well-known formula due to Schottky[1]

$$\overline{(i - I)^2} = 2eI\Delta f.\Gamma^2, \quad . \quad . \quad . \quad (1)$$

where I is the mean current, Δf is the integrated band-width of the measuring instrument, and e the electronic charge. The factor Γ^2 is theoretically equal to unity under 'saturated conditions', that is, when the potential increases monotonically towards the cold electrode, and under 'retarding field conditions' when it falls monotonically towards that electrode ; under usual working conditions, however, the potential has a minimum somewhere between the electrodes and $\Gamma^2 < 1$.

Formula (1) has been verified extensively under saturated conditions, but no satisfactory investigation has been carried out so far under true retarding field conditions owing to the experimental difficulties involved. It can be easily shown that under such conditions in a parallel-plane structure the average current I obeys the law :

$$I = J \exp\left(\frac{eV}{kT}\right), \quad . \quad . \quad . \quad (2)$$

where J is the total emission current from the cathode and V the 'anode potential' (which, of course, is in fact negative). From (2) follows immediately :

$$I\rho = \frac{kT}{e}, \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where

$$\rho = 1/\frac{\partial I}{\partial V}$$

is the differential resistance of the valve. This shows that the product $I\rho$ is strictly constant in the retarding field region and should provide a direct measure of the cathode temperature T.

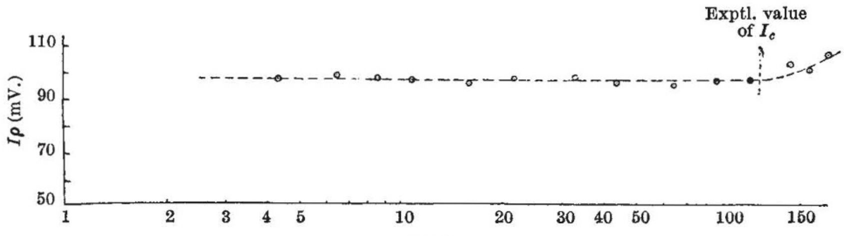

Fig. 1. EXAMINATION OF VALVE CHARACTERISTIC UNDER RETARDING FIELD CONDITIONS

One of us (D. K. C. McD.) has carried out experiments with a number of close-spaced diodes, and the accompanying graph demonstrates convincingly that the true retarding region was covered over a wide current range up to a limiting current I_c. The cathode temperature deduced from (3) also agrees satisfactorily with other estimates. The 'shot effect' was then measured under the same conditions and found to satisfy formula (1) with the factor Γ^2 becoming unity for I smaller than I_c. By comparing these results with those of previous workers[2], it appears that the latter had in fact not even reached the true retarding field region in their experiments.

Alternatively, to ascertain under what conditions a true retarding field exists, one may investigate theoretically the potential distribution between the two electrodes of a diode when the cold electrode is negative and thus calculate the limiting value I_c of the anode current for which the potential minimum due to the space-charge will just reach the anode. This has been done by various authors by studying the movement of the individual electrons in their transit from cathode to anode, and also recently by one of us (R. F.) by a statistical method based on earlier work by Laue[3]. The results of both theories agree, apart from a small difference in the numerical factor. For example, in the case of a plane-parallel diode, one obtains for I_c :

$$I_c = C \cdot \frac{(kT)^{3/2}}{e\sqrt{m}} \cdot \frac{s}{d^2} \quad . \quad . \quad . \quad (4)$$

where s is the area of, and d the distance between, the electrodes; m is the electronic mass ; C is a numerical constant.

It appears that the limiting value I_c calculated from (4) may be considerably larger (say, up to a factor of 10) than the actual value according to the above-mentioned experiments ; this is also evidenced in the work of Möller and Detels[4] directed primarily to the determination of cathode temperature by observing the slope of the logarithm of current (I) against voltage (V) as an alternative to equation (3). The most probable explanation of this fact is to assume the existence of a potential barrier v at the anode surface which would prevent the slower electrons from penetrating into the anode. This would reduce the value of I_c by a factor $\exp\left(-\frac{ev}{kT}\right)$, which for a value of v of approximately 0·2 v. and T about 1,000° K. equals 1/10 approximately, thus enabling agreement to be restored between theory and experiment.

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[1] Schottky, W., *Ann. Phys.*, **57**, 541 (1918).
[2] For example, Williams, F. C., *J. Inst. Elec. Eng.*, **78**, 326 (1936).
[3] v. Laue, M., *Jahrb. d. Rad. u. Elek.*, **15**, 205 (1918).
[4] Möller, H. G., and Detels, F., *Jahrb. d. draht. Teleg. u. Telep.*, **27**, 74 (1926).

Total Emission Damping with Space-charge-limited Cathodes

IN the course of an investigation of the properties of thermionic valves at high frequencies, made on behalf of the Admiralty in the Valve Laboratories of Messrs. Standard Telephones and Cables, Ltd., I observed in July 1943 a source of energy loss and noise which had up to that time escaped notice. It appears to be of sufficient importance to be taken into consideration in the design of ultra high-frequency amplifiers.

I was, at the time, attempting to measure the energy loss in oxide cathode coatings, and for this purpose had prepared some planar diodes with variable interelectrode spacing and very low inductance connexions. They formed a continuous part of a resonant coaxial line, which was terminated by the anode to cathode space. The damping which was imposed on this line by operating the diodes was measured by the change in Q of the system. The first measurements were made at 3,300 Mc./s.

The effect observed was the occurrence of appreciable damping at high negative values of bias, values considerably in excess of that required to prevent the flow of a measurable direct current. A negative bias of 20 volts made the effect negligible, but at 10 volts it was appreciable, and at 5 volts the effective resistance was about 200 ohms/sq. cm.$^{-1}$ of cathode surface. At 1 volt the effect had increased to about 50 ohms/sq. cm.$^{-1}$. The anode/cathode space was 0·008 cm.

The damping depended upon cathode activity. It could be reduced by cooling the cathode or by drawing a large current for a few moments immediately prior to the measurement to deactivate the cathode. It was not a rapid function of signal-level. A 60-db.. increase in signal, making the level a few millivolts, made no definite difference to the magnitude of the damping. It increased with frequency in the decimetre- and centimetre-wave ranges. At low frequencies it was not detectable.

The damping appears to be due to the emission from the cathode surface, which, for the best part, returns to the cathode after making an excursion into the field. It may be a second-order term caused through the finite transit-time of this excursion, and the dependence of the position of reflexion on the phase of the high-frequency field. For these reasons I propose calling it 'total emission damping'. Since the observed damping is the statistical average of the random movement of a large number of electrons, it follows that it behaves too as a source of noise having the general characteristics of 'shot' noise.

Against the disadvantages of 'total emission damping' in the performance of ultra high-frequency amplifiers may be set a possible advantage in its use as a non-destructive means of assessing cathode activity.

The subject is being studied in more detail and it is hoped to publish a full account and theoretical treatment elsewhere.

Publication of this letter has been delayed by security regulations.

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May 12.