quenching of $^3P_2$ by impurities appears to be mainly by $^3P_1$. CO is threefold as effective as $N_2$. $H_2$ and $CO_2$ are comparable to CO, but even at 1 ma, $H_2$ cleans up rapidly and $CO_2$ is changed to CO (and HgO). The striations in pure gas evidently depend on the two-stage ionization associated with $^3P_2$.

The apparently small contribution of single-stage ionization may mean that the electron energy distribution is hardly Maxwellian, being deficient at the high speed end and that the cross section for ionization of the $^3P$ states, especially $^3P_2$, is large[1] compared with that of normal Hg.

Equation (1) indicates that impurities absorb relatively little energy directly from the electrons but act by quenching $^3P_2$ (the main source of ions).

[1] B. Klarfeld, Tech. Phys. U.S.S.R. 5, 913 (1938).

## A New Form of Discharge in Gas Mixtures: The Flashing Discharge

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IN the previous letter it was shown that when impurities are added to a 1-ma d.c. hot cathode, positive column discharge in 3-mm A+Hg at 27°C in a 3½-cm tube, the voltage rises markedly and the running striations gradually disappear. At about fivefold normal voltage (with ~4$\mu$ $N_2$ or 0.13$\mu$ CO) the discharge suddenly breaks into a "flashing" form which the rotating mirror and the oscilloscope show is both striated and current modulated. A typical wave form is shown by Fig. 1A. The frequency may be from 25 to 10,000 c.p.s., increasing with the $N_2$/Hg ratio, irradiation with Hg light, current, and decreasing A pressure. The current modulation varies from 25 percent with 10 megohms ballast to nearly 100 percent with 0.2 megohm. The striations are sharp and convex on the cathode side (Fig. 1C) and appear stationary; they are one to one-half tube diameters apart, growing closer with more $N_2$. The flashes are bright with Hg light, but between flashes the tube appears to be dark. Flashing is favored by a high $N_2$/Hg ratio, by low current and by irradiation with strong Hg light; it has been an over-all positive characteristic. It is less striking in Kr+Hg and is entirely absent with Xe+Hg.

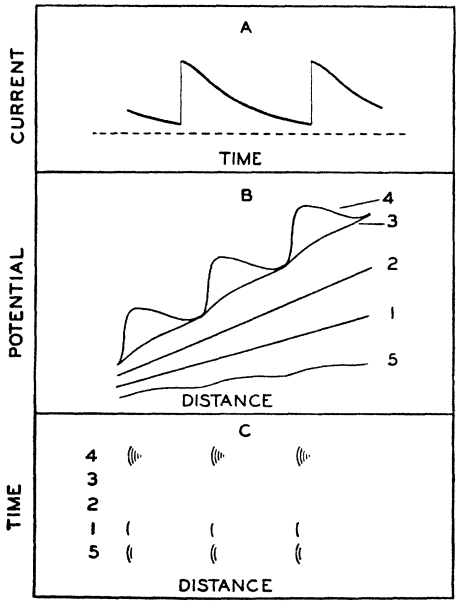


FIG. 1. Characteristics of the flashing discharge.

The following explanation of flashing appears to be in accord with all the observations. At times 1 and 2 (Fig. 1) the gradient is essentially uniform and rising, the brightness (essentially an afterglow) low and the discharge only partly self-maintaining because of net loss of ions by diffusion to the walls. At time 3 the gradient has risen so high as to be unstable, tending to localize. This process takes place extremely rapidly so that at time 4 the gradient is sharply stepped, producing electrons with 12 to 14 volts energy, as indicated by the observed volts per striation. These electrons strongly excite A metastables (and resonance atoms), A′, which quickly ionize Hg. Argon resonance radiation meanwhile diffuses rapidly and the resulting resonance atoms and metastables produce Hg ions by collision in the regions between the striations. The result is that in an extremely short time very high ion densities are built up locally and to a lesser extent throughout the tube. The high stepped gradient meanwhile collapses, while the current rises abruptly. It may be just at the beginning of this time or slightly before that the visible light is mainly produced. In the period just following, few ions are produced but the ionization is decreasing by diffusion to the walls and perhaps recombination. As a result the voltage rises and there is progressively more ionization, probably two stage via $^3P_0$ (since irradiation shortens the time between flashes), but the discharge never becomes self-maintaining till the onset of the next flash.

In the dark period, e.g., at 2, Fig. 1, most of the energy is going into 2537 via $^3P_2$ (quenched by the $N_2$) and $^3P_1$, ions coming largely from $^3P_0$, while at 4 it is going mostly into Hg ionization via A′. The two processes require such different conditions that both can scarcely occur together. The result is an almost cataclysmic change from one to the other; and a sharp jump in the current is the unfailing sign of flashing.

Flashing does not occur with Xe because Xe′ cannot ionize Hg. A little Xe added to A+Hg+$N_2$ stops flashing because the Xe absorbs the energy that would otherwise have gone to excite A, Kr+Hg flashes because two of the Kr′ states can ionize Hg.

## Grain Counts and Corrected α-Particle Range-Energy Curve for Ilford E-1 Emulsions*

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IN 1937 Wilkins[1] published a set of curves showing the number of grains in corresponding lengths of proton, deuteron, and $\alpha$-particle tracks. These tracks were recorded in Ilford R-2 emulsions, now obsolete. This work has now been repeated using Ilford E-1 nuclear emulsions 200$\mu$ thick. The emulsions were from the same batch of plates and were developed together after exposure as recommended by Wilson and Venselow[2] for 200$\mu$ emulsions. Grains in equivalent lengths of tracks were counted using a Spencer microscope with 120× objective and 10× eyepieces.

The number of developed grains in 10$\mu$ intervals, as measured from the end of the track, was counted. Then an average number for each interval was computed from corresponding intervals of all the similar tracks. Figure 1 represents the average number of grains in a given length of track as measured from the end of the track. Curve I was obtained from 110 proton tracks, curve II was obtained from 48 deuteron tracks, and curve III was obtained from 15 $\alpha$-particle tracks. Occasionally, near the end of the tracks, the grains were too closely packed to be clearly differentiated, therefore an estimation was made. This assumed number per 10$\mu$ interval was 16 for protons, 17 for deuterons, and 20 for $\alpha$-particles.

In the course of analyzing the emulsions in which elastically scattered $\alpha$-particle tracks were recorded from the bombardment of various thin targets[3] by 20-Mev $\alpha$-particles from the Washington University cyclotron, it was noted that the predicted ranges

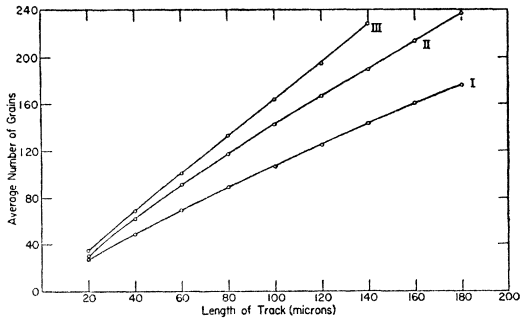


FIG. 1. Average number of grains in a given length of track as measured from the end of the track. Curve I is for protons, curve II is for deuterons, and curve III is for $\alpha$-particles.

for the $\alpha$-tracks were greater than the actual measured ranges. The discrepancy was as much as ten percent. In determining the predicted ranges, use was made of the range-energy curve for $\alpha$-particles as given by Lattes.[4] The curve was verified below 10 Mev but above this value serious departure was found.

The error was assumed to have come from one of two sources. Either the cyclotron beam did not contain 20-Mev $\alpha$-particles but rather 17.5-Mev $\alpha$-particles, or the range-energy curve was in error above 10 Mev when applied to Ilford E-1 nuclear emulsions. The first source was eliminated by two considerations; first, it was improbable that a cyclotron producing 10-Mev deuterons would produce 17.5-Mev $\alpha$-particles, and second, the elastically scattered $\alpha$-particle tracks from $C^{12}$ and $O^{16}$ at angles greater than 90° to the cyclotron beam were correctly predicted assuming 20-Mev $\alpha$-particles and using the lower part of the range-energy curve. The curve may be modified as shown in Fig. 2. Curve I is that given by Lattes and curve II is that derived from the Lattes' proton range-energy curve which this author has found to apply to Ilford E-1 nuclear emulsions when various targets were bombarded with 5-Mev protons from the Washington University cyclotron. By assuming that within the experimental limits an $\alpha$-particle and a proton of the same velocity has the same range, i.e., an $\alpha$-particle with four times the energy of a proton, loses energy four times as fast due to its double charge, one arrives at curve II. With the modified curve, the ranges of the elastically scattered $\alpha$-particles are accurately predicted.

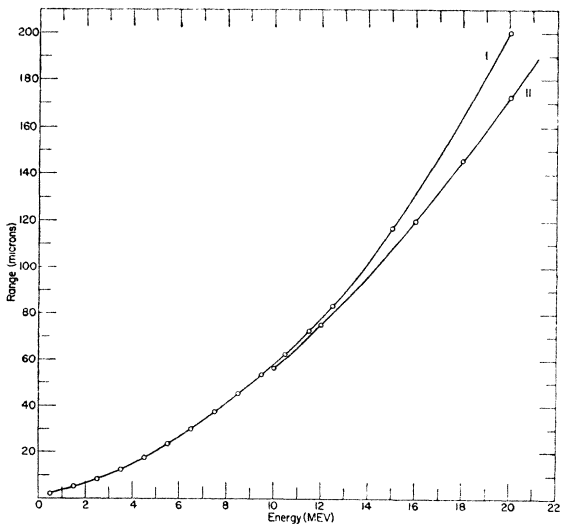


FIG. 2. Alpha-particle range-energy curve. Curve I is that obtained by Lattes (see reference 4). Curve II is a modified curve as applied to Ilford E-1 nuclear emulsions.

I wish to express my gratitude to Messrs. Chia-Hua Chang and Shu-Lung Wang for their careful reading of the plates. I also wish to thank Dr. Robert N. Varney for his many helpful discussions.

* Assisted by the joint program of the ONR and AEC.

[1] T. R. Wilkins and H. J. St. Helens, Phys. Rev. **54**, 783 (1938).
[2] M. J. Wilson and W. Venselow, Phys. Rev. **75**, 1144 (1949).
[3] Results to be published.
[4] Lattes, Fowler, and Cuer, Proc. Phys. Soc. London **59**, 883 (1947).

## The Probable Energy Loss of Electrons in Matter*

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ALTHOUGH the energy degradation of electrons passing through matter is of interest in many experiments, there have been no good measurements of this quantity since the early work of White and Millington.[1] While the average energy loss can be calculated by more or less familiar formulas,[2] Christy has recently emphasized[3] that the use of the *average* rather than the *most probable* energy loss for charged particles can lead to as much as 20 to 30 percent error in the case of moderately energetic electrons. The most probable loss has been calculated most recently by Landau[4] who obtained the energy loss distribution in the form of a universal numerical function, and thereby an expression for the most probable loss. In the result there is a characteristic non-linear dependence of the probable loss on the thickness of the material traversed. This is also true of a classical expression[5] in which, however, the velocity dependence is slightly different and which has a different range of validity. Landau's expression is

$$\Delta E_{\text{prob}}=\xi[\ln(\xi/\epsilon)+0.37], \tag{1}$$

where

$$\xi=nZ(2\pi e^4/mc^2\beta^2) \quad \text{and} \quad \epsilon=[I^2(1-\beta^2)/2mc^2\beta^2]\exp(\beta^2),$$

and $n$ is the number of atoms, with $Z$ electrons each, per cm² of the foil material, $\beta$ is the velocity of the incident electron in units of the velocity of light $c$, and $m$ is the electronic mass. The mean excitation potential $I$ is given by Mano.[6] The classical result[5] differs from this only by the introduction of a factor $2(k/K)^2$ in the argument of the logarithm, where $k=1.123$, $K=2v_e/v$ and $v_e=e^2/\hbar$ cm/sec. For $K\ll 1$ Bohr[7] has shown that the quantum treatment is the more appropriate.

The non-linear dependence of the loss on the thickness of stopping material becomes appreciable when foils thicker than some minimum are used, this minimum being defined by the condition of compound scattering.[8] To satisfy this condition while still keeping the thickness much less than the range of electrons in the material is, however, not difficult. For the $\beta$-particles from the $K$-conversion line in Ba 137 (624 kev) traversing aluminum foils, it is required that the thickness be in the middle portion of the range between 0.2 and 260 mg/cm². Hence a direct measurement of the probable loss with a foil thickness from about 5 to 40 mg/cm² of aluminum may be used to verify Landau's expression. The resulting curve of loss *versus* foil thickness should show a small but observable curvature. Our preliminary measurements were made on the shift of the $Ba^{137}$ $K$-line for various thicknesses of both aluminum and tin. A double thin lens $\beta$-ray spectrometer, which is described elsewhere,[9] was used. The stopping material was mounted on a supporting frame which was then placed immediately in front of the conventional thin source holder. With the spectrometer set for 2.1 percent resolution and with 100 microcuries of $Cs^{137}$ as the source, the transmission curve of the $K$-conversion line was measured as a function of foil thickness and the maxima of these curves were taken to correspond to the most probable final momentum in each case. A comparison of the peak shifts, on an energy scale, with Landau's expression (Eq. (1)) for the cases of both aluminum and tin, is given in Fig. 1, with the