

### Experiments on the Periodic Deviation From the "Schottky Line"

Measurements made with extreme care have verified the discovery made by Seifert and Phipps<sup>1</sup> that the thermionic emission from a heated filament does not increase linearly with the square root of the electric intensity as called for by the Schottky mirror image theory. The maxima and minima which have been checked are near 25.6, 40, 65.5, 121 and 255 kv per cm (italicized numbers for minima). Seifert and Phipps<sup>1</sup> state that "the heights of the maxima and minima for a given filament decrease slightly with increasing temperature" while Turnbull and Phipps<sup>2</sup> state that "the magnitude of the percent deviation,  $\delta$ , increases with temperature." There is agreement that within experimental error the location of the maxima and minima is independent of the temperature. My observations show that the amplitude of the deviations are *independent* of the temperature except at the lower fields where the non-periodic deviations are greater the lower the temperature, as has already been pointed out.<sup>3</sup>

The principal object of this letter is to stress the importance of this temperature independence of both the amplitude of the effect and the position of the maxima and minima on the electric intensity scale. The results impose serious limitations on any theory which tries to explain the periodic deviations observed as a change in the transmission properties of the surface barrier unless the theory incorporates a temperature factor exactly compensating for the difference in the electron energy distribution which is a necessary consequence of the change in temperature or else the transmission function must change with the electric field in such a way that its alteration is independent of the energy of the electron transmitted through the surface of the metal. It does not appear that either of the theories<sup>4</sup> so far suggested are capable of explaining the observed facts.

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<sup>1</sup> R. L. E. Seifert and T. E. Phipps, Phys. Rev. **56**, 652 (1939).

<sup>2</sup> D. Turnbull and T. E. Phipps, Phys. Rev. **56**, 663 (1939).

<sup>3</sup> W. B. Nottingham, Phys. Rev. **49**, 78 (1936).

<sup>4</sup> H. M. Mott-Smith, Phys. Rev. **56**, 668 (1939); C. J. Mullin and E. Guth, Phys. Rev. **57**, 349 (1940).

### Erratum: On the Yield of Nuclear Reactions with Heavy Elements

(Phys. Rev. **57**, 472 (1940))

The relations given in the caption of Fig. 1 of the above-named paper contain an error in exponent of the numerical factors,  $10^{26}$  appearing instead of  $10^{24}$ . They should read:  $(2m\epsilon/\pi\hbar^2)S_p = 1.52 \times 10^{24} S_p$  for protons and  $(2m\epsilon/\pi\hbar^2)S_\alpha = 6.08 \times 10^{24} S_\alpha$  for  $\alpha$ -particles. The other two relations in the caption remain unchanged.

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### Notes on the Separation of Alloys and Isotopes by the Centrifuge

Density differences of two percent were produced by Joly and Poole<sup>1</sup> in liquid alloys of lead, tin, and bismuth by use of a centrifuge. With a Beams ultracentrifuge I have changed the density of liquid Wood's metal by as much as 13 percent.

The centrifuge consisted of two hardened steel rotors held together by a bolt as indicated in Fig. 1. Opposite faces of the rotors were ground and polished to almost optical flatness. Four radial slots in the lower rotor held ingots of the alloy. The vacuum chamber containing the rotor was heated to 100°C and then the rotor run at 500 r.p.s. The hydrostatic pressure at this speed forced the rotors apart slightly so that some metal leaked out. With the removal of material, the pressure was reduced and the leakage stopped. The remaining metal (about 25 percent) in the four slots had densities of 8.40, 8.33, 8.29, and 8.33 g/cc. The original material (Pb 50 percent, Bi 25 percent, Sn 12.5 percent, Cd 12.5 percent) had a density of 9.57 g/cc.

Separation by use of the centrifuge of the constituents of an alloy in the liquid state is possible but any attempt to separate isotopes in a liquid, without counter-currents, seems futile because of the slowness of the molecular sedimentation. This limitation exists even though vibrations and temperature inequalities, to which earlier failures have been attributed,<sup>1-4</sup> can be removed. For mercury, the sedimentation velocity under unit force is about  $10^{-14}$  cm/sec., if one calculates by the classical hydrodynamic method. With a force field as high as 500,000 g the velocity imposed on a heavy molecule,  $5 \times 10^{-9}$  cm/sec., is still negligible. If the "cage model" of a liquid<sup>5</sup> is used, the influence of the field on a single molecule is again found to be small in a force field of 500,000 g. The ratio of the energy an atom might acquire in moving freely as far as  $3 \times 10^{-8}$  cm under the influence of this field to its thermal energy is about  $7 \times 10^{-8}$ . So separation in the field would be negligible in comparison with mixing due to diffusion.

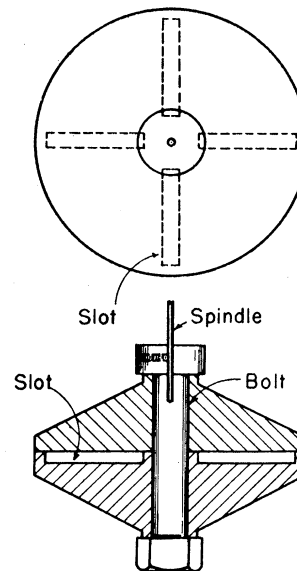


FIG. 1. Compound rotor.

Separation of isotopes in the gas phase is possible by the method of "evaporative centrifuging" used by Beams and Skarstrom<sup>6</sup> and by Humphreys.<sup>4</sup> The Lindemann-Aston separation factor is proportional to  $\exp [1/T]$ . I have therefore attempted to obtain a relatively large separation of the chlorine isotopes by using hydrogen chloride just above its melting point in a Beams centrifuge. The rotor was cooled to  $-98^\circ\text{C}$  and the vapor from the liquid HCl was pumped through the hollow spindle which formed the axle. (See reference 6 for details.) Although no analysis by the mass spectrograph of the fractions was made, the operation of the centrifuge at low temperature was demonstrated. The theoretical isotopic separation coefficient which is 1.11 at room temperature, becomes 1.25 just above the solidification temperature of hydrogen chloride if the rotor velocity is  $5 \times 10^4$  cm/sec. at the boundary of the liquid-gas phase. This velocity is the highest practical in "evaporative centrifuging" with hollow rotors.

The substitution of hydrogen chloride for carbon tetrachloride results in a decrease in molecular mass and a three-hundred-fold increase in ratio of gas pressure at the rotor center to that at the gas-liquid boundary. Under these conditions the time for equilibrium across a radial sector of the rotor is reduced and an increased rate of removal seems practical. If then the centrifuge is employed to separate isotopes, it would appear advantageous to use the hydrogen halides near their melting points to effect a partial separation of large amounts of chlorine and bromine isotopes.

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<sup>1</sup> J. Joly and J. H. J. Poole, *Phil. Mag.* **39**, 372 (1920).

<sup>2</sup> R. S. Mulliken, *J. Am. Chem. Soc.* **44**, 1033 (1922); **44**, 1729 (1922).

<sup>3</sup> J. H. J. Poole, *Phil. Mag.* **41**, 818 (1921).

<sup>4</sup> R. F. Humphreys, *Phys. Rev.* **56**, 684 (1939).

<sup>5</sup> M. J. Polissar, *J. Chem. Phys.* **6**, 833 (1938).

<sup>6</sup> J. W. Beams and C. Skarstrom, *Phys. Rev.* **56**, 266 (1939).

#### Observations on the Dark Current of a Willemite Crystal

Some time ago the photoconductivity of a single crystal of willemite was investigated at low temperatures.<sup>1</sup> Several times during this study it was noticed that the dark current showed a sudden large increase at about  $-60^\circ\text{C}$  while the crystal was warming up with the field on, and then fell to its very low initial value. Subsequent studies on this crystal showed that this effect is obtained when the crystal is illuminated with ultraviolet light at low temperatures with field on (in our case 2000 volts/cm) and then allowed to warm up in the dark. However, if the crystal is depolarized and then warmed up in the dark with the field on, the effect observed was only about 1/100 of that obtained when the crystal was initially illuminated as described above. This small effect is probably due to the fact that the crystal was not completely depolarized. Since the rate of warming up could not be controlled conveniently with the present arrangement for cooling the crystal, no quantitative measurements were made concerning the dependence of dark current on temperature, time, and exposure to ultraviolet light. This phenomenon was observed for both  $\lambda$  2537Å and  $\lambda$  3125Å. It would doubtless

occur for the whole range of wave-lengths for which the crystal exhibits photoconductivity. Similar results were found when electrical contact was made with either gold (sputtered) or Aquadag electrodes.

We feel that this dark current effect is probably connected with the emission of trapped light reported by Johnson.<sup>2</sup> Further experiments are indicated, such as simultaneous observations of dark current and fluorescence.

We hope to publish a more detailed account of experiments on photoconductivity and absorption of crystalline willemite in the near future.

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<sup>1</sup> R. Hofstadter and R. C. Herman, *Phys. Rev.* **56**, 212 (1939).

<sup>2</sup> R. P. Johnson, *J. Opt. Soc. Am.* **29**, 387 (1939).

#### Resonance Scattering of Neutrons in Helium

Experiments of Staub and Stephens<sup>1</sup> on the scattering of neutrons in helium have shown that resonance occurs for neutrons of about one Mev, arising from the existence of a virtual  $P$  level of  $\text{He}^5$ .<sup>2</sup> This resonance raises the ratio of the forward scattering cross sections of helium and hydrogen from 1.4 to 2.5 Mev to about 9 at 1 Mev. We have investigated the resonance scattering more closely by using a continuous neutron spectrum. This was produced by allowing the monochromatic neutrons of a  $dd$  generator to strike a paraffin howitzer of suitable shape, where, by elastic collision the neutrons lost part of their original energy. The howitzer was shaped so as to give a continuous neutron distribution which was almost uniform from 0.6 to 2.0 Mev. This distribution was determined by the scattering of the neutrons in a cloud chamber filled with methane. The shape of the resonance curve over this region has been measured in 0.1-Mev intervals by using the same cloud chamber technique as described by Staub and Stephens. From our results we conclude that the level of  $\text{He}^5$  has a width at half-maximum of 0.4 Mev. The shape of the resonance peak of the scattering cross-section curve indicates a doublet structure of the two levels  $J = \frac{3}{2}$  and  $J = \frac{1}{2}$  with a splitting of  $0.24 \pm 0.1$  Mev. Since the more intense peak occurs at the lower energy and corresponds to  $J = \frac{3}{2}$  the doublet is inverted. The  $\frac{3}{2}$  level is unstable against decay into a neutron and an  $\alpha$ -particle by 0.76 Mev and the  $\frac{1}{2}$  level by 1.0 Mev. The shape and the absolute values of the resonance scattering cross-section curve are within the experimental error in agreement with the predictions of the dispersion theory derived for this particular case by Bloch.<sup>3</sup> The previous experimental data of Staub and Stephens fit into the present curve within the statistical error. A full account of the experiments will be published shortly.

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<sup>1</sup> H. Staub and W. E. Stephens, *Phys. Rev.* **55**, 131 (1939).

<sup>2</sup> J. H. Williams, W. G. Shepherd and R. O. Haxby, *Phys. Rev.* **52**, 390 (1937).

<sup>3</sup> F. Bloch, to be published soon.