

for the 2-gauss field and for the difference between the "1929" and "1949" scales gives a zero field transition on the "1949" scale of $3.731(\pm 0.006)^{\circ}\text{K}$, a value in perfect agreement with that which can be deduced for natural tin from recent, precise isotope measurements based on the "1949" scale.^{7,8}

Employing the above assumption, the pertinent KCl and Ag calorimetric data^{2,3} were corrected to the "1949" scale (below 4.3°K). The results for KCl are shown in Fig. 1B, the original uncorrected data being reproduced for comparison in Fig. 1A. What appeared to be a significant "anomaly" in the original data has been essentially removed. Some recent data⁹ have also been included in Fig. 1B and are in excellent agreement with the older corrected data. The result for Ag was practically equivalent to that for KCl, a strikingly similar "anomaly" in the characteristic temperatures being effectively removed.¹⁰

Finally it may be noted that the Debye characteristic temperatures obtained by Keesom and Pearlman⁹ for KCl (using the "1949" scale) show a sharp rise below 2.2°K . The data on which

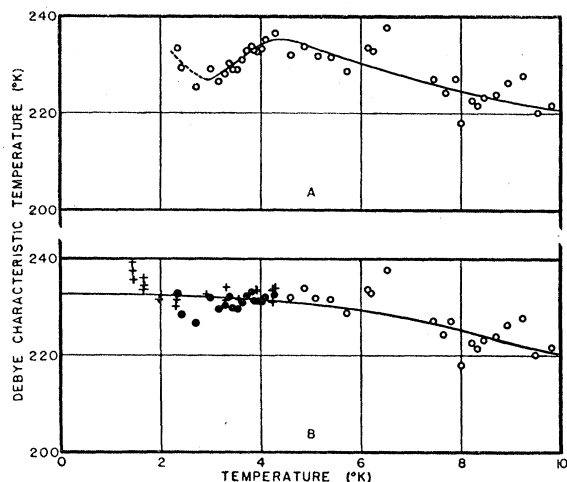


FIG. 1. Debye characteristic temperature of KCl. O Uncorrected data of Keesom and Clark (see reference 2); ● data of Keesom and Clark (see reference 2); corrected to "1949" scale; + data of Keesom and Pearlman (see reference 2) ("1949" scale).

the "1949" scale is based have been questioned by Kistemaker,¹¹ and it is interesting to note that if Kistemaker's results are used to determine a new vapor pressure scale and the KCl data of Keesom and Pearlman corrected to this new scale, the sudden rise in their characteristic temperatures is substantially reduced.

The principal conclusion to be drawn here is that systematic differences between an actual temperature scale and the true thermodynamic scale may cause apparently significant "anomalies" in calorimetric results, so that the presence of systematic errors in temperature scale should at least be investigated as a possible source of small "anomalies" when they occur.

¹ M. Blackman, Repts. Progr. Phys. **8**, 11 (1941).

² W. H. Keesom and C. W. Clark, Physica **2**, 698 (1935).

³ W. H. Keesom and J. A. Kok, Proc. Amsterdam Acad. Sci. **35**, 301 (1932); Physica **1**, 770 (1934).

⁴ See, e.g., P. H. Keesom and N. Pearlman, Phys. Rev. **88**, 140 (1953).

⁵ These scales are: "1924," "1929," "1932" [see W. H. Keesom, Leiden Comm. Suppl. 71d (1932)], "1937" [G. Schmidt and W. H. Keesom, Physica **4**, 971 (1937)], "1939" [R. Bleaney and F. Simon, Trans. Faraday Soc. **35**, 1205 (1939)], and "1949" [H. van Dijk and D. Schoenberg, Nature **164**, 151 (1949)]. See also W. H. Keesom, *Helium* (Elsevier Publishing Company, Amsterdam, 1942), pp. 186-201.

⁶ W. H. Keesom and J. A. Kok, Proc. Amsterdam Acad. Sci. **35**, 743 (1932).

⁷ E. Maxwell, Phys. Rev. **86**, 235 (1952).

⁸ Lock, Pippard, and Shoenberg, Proc. Cambridge Phil. Soc. **47**, 811 (1951).

⁹ P. H. Keesom and N. Pearlman, Phys. Rev. **91**, 1354 (1953).

¹⁰ Compare Debye characteristic temperature curves given by Keesom and Clark (see reference 2).

¹¹ J. Kistemaker, Physica **12**, 272, 281 (1946).

Further Evidence for the Energy Gap of Lead Sulfide*

GEORGE R. MITCHELL AND ARTHUR E. GOLDBERG
Chicago Midway Laboratories, Chicago, Illinois
(Received February 1, 1954)

THERE has been some question regarding the value of the energy gap for PbS. The thermal activation energy (1.17 ev) disagrees with the adsorption edge of single crystals and the long-wavelength limit of photoresponse of PbS thin films.¹⁻³ Recently, Moss published curves showing the wavelength dependence of the photoelectromagnetic effect in natural galena and gave evidence that the quantum efficiency of the photoresponse is of the order of unity.⁴ He concluded that the energy gap is very close to 0.41 ev.

In the course of growing PbS single crystals from the vapor phase, a *p-n* junction was found that exhibited a small photovoltaic effect. The response time was not greater than 150μ sec, thus ruling out the possibility of a thermal effect. According to present theory the photovoltage results mainly from the production of minority carriers.⁵ It is most probable that the minority carriers are produced by band-to-band transitions. Conceivably, minority carriers could be produced by photoexcitation of impurity centers. Since the activation energy for impurity ionization is very small, the energy required to produce a minority carrier in this way is virtually that required for a transition between full and conduction bands. Compared in Fig. 1 are the equal-energy spec-

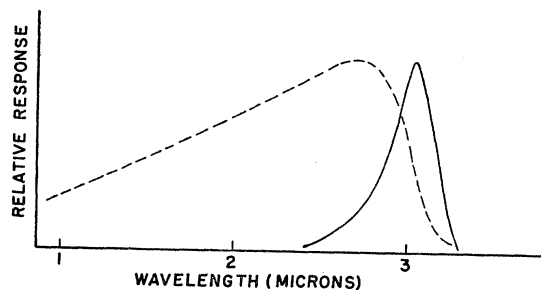


FIG. 1. Photoeffects in PbS: dashed curve, photoelectromagnetic effect in galena from data of Moss (see reference 4); solid curve, photovoltaic effect in *p-n* junction in synthetic single crystal.

tral responses of the photoelectromagnetic effect in galena and the photovoltaic effect in the junction at room temperature. The good agreement between the long-wavelength cutoffs supplies further confirmation that the energy gap is 0.4 ev.

* This research was supported in whole by a contract with the United States Air Force.

¹ E. H. Putley, Proc. Phys. Soc. (London) **B65**, 388 (1952).

² A. F. Gibson, Proc. Phys. Soc. (London) **B65**, 378 (1952).

³ M. A. Clark and R. J. Cashman, Phys. Rev. **85**, 1043 (1952).

⁴ T. S. Moss, Proc. Phys. Soc. (London) **B66**, 993 (1953).

⁵ T. S. Moss, *Photoconductivity in the Elements* (Academic Press, Inc., New York, 1952), p. 50.

Temperature Dependence of Periodic Deviations from the Schottky Line*

G. A. HAAS† AND E. A. COOMES
University of Notre Dame, Notre Dame, Indiana
(Received February 1, 1954)

ALTHOUGH the importance of the $1/T$ dependence of the amplitude in periodic Schottky deviations to electron emission theory has been stressed,¹ a completely satisfactory experimental study of this effect has been hindered by patch effects. Recent Schottky data taken on a specimen of polished molybdenum wire revealed a long patch-free region $100 < \xi < 300$ (volts cm^{-1})². This allowed a precise separation of deviations from

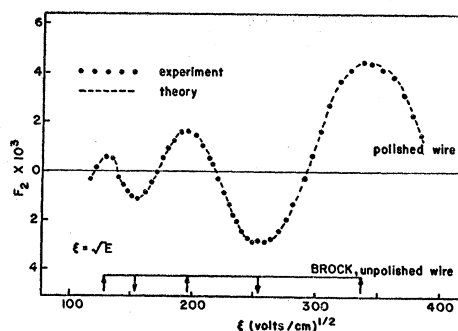


FIG. 1. Periodic deviations in the Schottky effect for a polished molybdenum filament, at 1600°K.

which accurate amplitude determinations could be made, an example of which is given in Fig. 1. In this figure the points are experimental, the dotted curve theoretical,² while the arrows along the axis of abscissas mark experimental extrema obtained for unpolished molybdenum filaments.³ The amplitude maximum taken at $\xi=200$ from deviation curves for various temperatures is plotted against $1/T$ in Fig. 2. While some uncertainty is involved

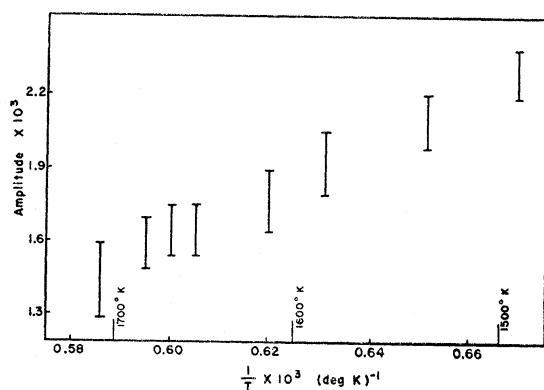


FIG. 2. Periodic deviation amplitude maximum at $\xi=200$, plotted against $1/T$. The range in amplitude indicates uncertainty in locating extrema on the deviation plot. (See Fig. 1.)

in locating the exact maximum of deviations, as indicated by the range at a given temperature, the tendency to increase with $1/T$ seems definitely apparent.

* Sponsored by the U. S. Navy Bureau of Ships.
 † Now at the U. S. Naval Research Laboratory, Washington, D.C.
 ‡ W. B. Nottingham, Phys. Rev. 57, 935 (1940); E. Guth and C. Mullin, Phys. Rev. 60, 535 (1941).
 § Juenker, Colladay, and Coomes, Phys. Rev. 90, 772 (1953).
 ¶ Brock, Houde, and Coomes, Phys. Rev. 89, 851 (1953).

Radioactive Isotope Separation by Nuclear Recoil*

H. MORINAGA† AND D. J. ZAFFARANO
 Institute for Atomic Research and Department of Physics,
 Iowa State College, Ames, Iowa
 (Received January 13, 1954)

NUCLEAR reactions such as (γ, n) , (d, p) , and $(\alpha, 2p)$ lead to product nuclides with the same atomic number as the initial nuclides. Unless the Szilard-Chalmers process¹ is practicable, it is usually difficult to achieve high specific activity for the product isotope. With light nuclei, however, the recoil momentum of the product nucleus can afford sufficient range to allow physical separation, as is clearly visible in nuclear emulsions.² When the ranges of the product nuclei are of the order of a micron, i.e., the

size of colloidal particles, one may expect that in a fine powder mixture or in a colloidal suspension one phase or element can act as donor and the other as catcher. If the grain size of the donor is comparable to or smaller than the range of the recoiling product nucleus, the probability of stopping the radioactive nucleus within the "catcher phase" becomes high. Therefore, radioactive atoms will be transferred to the catcher phase from the donor phase.

To verify this experimentally, a preliminary experiment has been done using the $C^{12}(\gamma, n)C^{11}$ reaction in colloidal graphite solution. "Aquadag" solution of about 0.5-percent carbon by weight was bombarded by x-rays from the 70-Mev bremsstrahlung beam from the Iowa State College synchrotron, together with a control sample of powdered carbon. The colloid was precipitated and identical counting samples were prepared from the two target materials. It was found that the carbon bombarded as a colloid lost as much as 80 percent of its activity into the water phase. This result is understandable, since the carbon particles in "Aquadag" consist of small slabs with an approximate diameter of $\frac{1}{10}$ micron and much smaller thickness. The energies of recoiling C^{11} nuclei are expected to be of the order of a fraction of a Mev, corresponding to ranges of a fraction of a micron in carbon.

This method of separating isotopes may have importance in the production of Mg^{28} by $Mg^{26}(\alpha, 2p)$.³ For Mg^{28} production, a compressed powder of mixed Mg and some catcher metal such as tungsten might be used for good heat dissipation and ease of chemical separation. In the case of alpha-particle bombardment, particle sizes need not be less than one micron because of the high recoil momentum available.

The advice of Dr. R. S. Hansen is gratefully acknowledged.

* Work was performed in part in the Ames Laboratory of the U. S. Atomic Energy Commission.

† On leave from the University of Tokyo, Tokyo, Japan.

‡ L. Szilard and T. A. Chalmers, Nature 134, 462 (1934).

§ For example, C. Millar and A. Cameron, Phys. Rev. 78, 78 (1950).

¶ R. K. Shelton and N. R. Johnson, Phys. Rev. 89, 520 (1953).

Mass Assignments by Isotope Separation*

M. C. MICHEL AND D. H. TEMPLETON
 Radiation Laboratory and Department of Chemistry,
 University of California, Berkeley, California
 (Received January 19, 1954)

A TIME-OF-FLIGHT isotope separator constructed in this laboratory¹ has been used to assign mass numbers to several radioactive isotopes produced in cyclotron bombardments. Atoms of the mass numbers in question have been separated and the corresponding activity observed with a Geiger counter or other counting equipment.

The essential features of the instrument are high transmission (about 20 percent) at a resolution such that the separation factor between adjacent isotopes in the mass range 100–250 is about 100 or larger. In addition, the instrument is calibrated absolutely so that any desired mass number can be selected without the necessity of observing ion currents due either to the isotope being separated or to added stable isotopes.

Several isotopes of cesium (formed by α, n reactions on iodine) have been separated in the course of work on their decay properties. Chemically separated carrier-free cesium sulfate fractions were ionized from a surface ionization source for this work. The previous assignments² of Cs^{127} and Cs^{129} were verified, with sufficient activity separated to establish the half-life of Cs^{127} as 6.1 ± 0.2 hours instead of the previously reported 5.5 hours. In addition, Cs^{130} has been separated and its half-life observed to be 30 minutes, in agreement with the previous result.²

A new isotope of cesium found by Mathur and Hyde of this laboratory, has been assigned to mass 125 and its half-life observed (from separated samples) to be 45 ± 1 minutes.

In connection with an investigation of the decay scheme of Cs^{136} by Olsen and O'Kelley³ a large quantity of this isotope was separated for use in a beta spectrometer study of its decay. On the basis of the decay of part of the separated sample over nine half-