

The data were corrected for the resolution of the instrument by the method of Owen and Primakoff<sup>1</sup> and a Fermi-Kurie plot made. Figure 2 shows the result as the upper curve. The line is quite

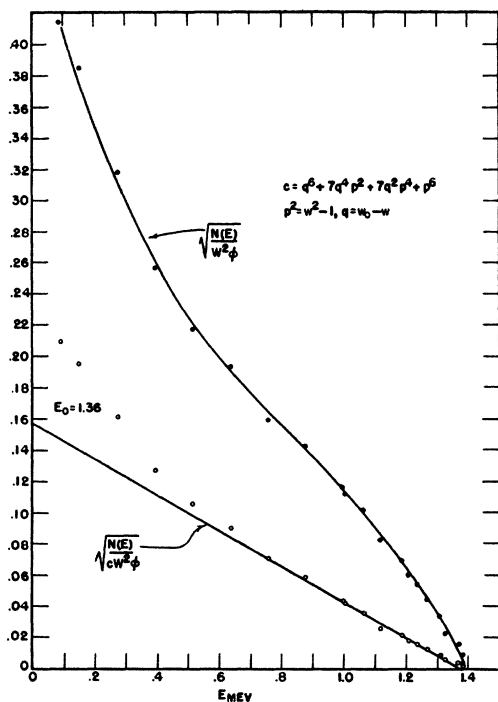


FIG. 2.  $K^0$  Kurie plot.

concave to the energy axis above 700 keV and the end point is  $1.36 \pm 0.05$  MeV.

The correction term for the third forbidden axial vector or tensor interaction produces the lower curve in Fig. 2 when applied to the data. This curve is about as good a fit to a straight line in the higher energy half of the spectrum as was obtained from  $P^{32}$  measured under the same conditions.

\* This document is based on work performed under Contract No. W-7405, eng. 26 for the Atomic Energy Project at Oak Ridge.

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<sup>1</sup> G. E. Owen and H. Primakoff, Phys. Rev. **74**, 1406 (1948).

### Phase Relations in He<sup>3</sup>-He<sup>4</sup> Solutions

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IN a previous letter the depression of the lambda-temperature of He<sup>4</sup> by the addition of He<sup>3</sup> was reported,<sup>1</sup> but the question of whether the lambda-transition remains second order, as proposed by Stout,<sup>2</sup> or becomes first order with the consequent existence of two liquid phases below the lambda-temperature, as proposed by de Boer,<sup>3</sup> remained unanswered. It is possible to decide between these two possibilities by means of vapor pressure measurements. To this end, the vapor pressures of 20.3 mole percent and 25.5 mole percent solutions of He<sup>3</sup> in He<sup>4</sup> have been measured.

Before examining the experimental results, consider the phase diagram for He<sup>3</sup>-He<sup>4</sup> solutions according to the calculations of

de Boer,<sup>3</sup> as shown in Fig. 1. In the regions labeled I and II a single liquid phase exists in equilibrium with the vapor; in the

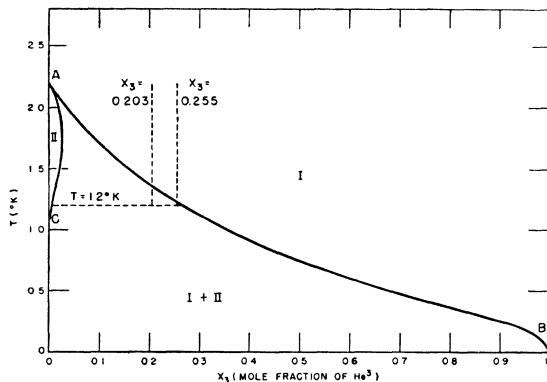


FIG. 1. Phase diagram of He<sup>3</sup>-He<sup>4</sup> solutions according to J. de Boer.

region labeled I+II two liquid phases are present in equilibrium with each other and with the vapor. If this diagram is correct, it can be seen that when a 20.3 percent He<sup>3</sup> solution is cooled to 1.2°K, a temperature below the lambda-temperature given by curve AB, two liquid phases are in equilibrium, and the compositions of the liquids are given by the intersection of the dashed horizontal line with the curves AB and AC. When a 25.5 percent He<sup>3</sup> solution is cooled to 1.2°K the same two liquid phases appear;

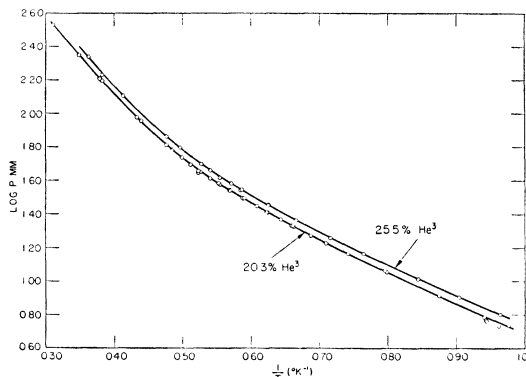


FIG. 2. Vapor pressures of 20.3 percent and 25.5 percent solutions of He<sup>3</sup> in He<sup>4</sup>.

their concentrations are the same as for the 20.3 percent solution, but their relative amounts are different. It follows that the vapor pressures of the 20.3 percent and of the 25.5 percent He<sup>3</sup> solutions must be equal at 1.2°K and indeed at any other temperature in the region I+II. The same conclusion can be reached directly by application of the phase rule, for if two liquid phases and a vapor phase are present in equilibrium in a two component system there is only one degree of freedom, and hence the vapor pressure must be a function of the temperature alone and independent of concentration.

The vapor pressure data are plotted in Fig. 2. It can be seen that the vapor pressures of the two solutions are not equal at any temperature down to the lowest temperature studied, 1.04°K, which is well below the lambda-temperatures previously measured, namely 1.65° and 1.56°K,<sup>1</sup> and also below the lambda-temperatures given by the curve AB in Fig. 1. These data eliminate the possibility that two liquid phases coexist in equilibrium with the vapor below the lambda-temperature, at least down to 1.04°K and in the concentration range 0 percent to 20 percent He<sup>3</sup>.\*

Since there is only one liquid phase present above and below the lambda-temperature, the concentration of He<sup>3</sup> in liquid I, which is stable above the lambda-temperature, must be equal to that in liquid II, which is stable below the lambda-temperature. Further, it can be deduced thermodynamically that the transition must remain second order. It can easily be shown that for any arbitrary variation  $dx$  in the He<sup>3</sup> concentration the condition for equilibrium between the two liquid phases is

$$\Delta SdT - \Delta VdP = 0, \quad (1)$$

where  $\Delta S$  and  $\Delta V$  are the differences in molal entropy and volume, respectively.<sup>4</sup> Hence,

$$\Delta V(dP/dx)_T = 0. \quad (2)$$

Since the experimental data show that  $(dP/dx)_T$  is not zero,

$$\Delta V = 0, \quad (3)$$

and similarly from (1)

$$\Delta S = 0. \quad (4)$$

Equations (3) and (4) are the conditions for a second-order transition.

The vapor pressure measurements show these solutions deviate from ideality above their lambda-temperatures, in the sense that the vapor pressures are higher than given by Raoult's law. Below their lambda-temperatures the non-ideal behavior becomes more marked, increasing rapidly as the temperature is lowered. The latter observation is in qualitative agreement with the model suggested by Taconis, Beenakker, Nier, and Aldrich,<sup>5</sup> although the quantitative behavior appears to be different. These measurements will be extended and reported in greater detail in a subsequent paper.

The authors are indebted to Professors J. W. Stout and Lester Guttman for many stimulating discussions on this problem.

\* It should be remarked that a narrow temperature region with two liquid phases, on the order of a few hundredths of a degree wide, is not ruled out by the data, but this possibility is considered to be unlikely. In any case, such a situation would be practically indistinguishable from a second-order transition.

<sup>1</sup> Abraham, Weinstock, and Osborne, Phys. Rev. **76**, 864 (1949).

<sup>2</sup> J. W. Stout, Phys. Rev. **76**, 864 (1949).

<sup>3</sup> J. de Boer, Phys. Rev. **76**, 852 (1949).

<sup>4</sup> See for example J. W. Stout, Phys. Rev. **74**, 605 (1948), Eq. (8), or E. A. Guggenheim, *Thermodynamics* (North-Holland Publishing Company, Amsterdam, 1949), pp. 188-9.

<sup>5</sup> Taconis, Beenakker, Nier, and Aldrich, Phys. Rev. **75**, 1966 (1949).

## Effects of Electrical Forming on the Rectifying Barriers of *n*- and *p*-Germanium Transistors

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THE amplifying properties of transistors made with *n*- or *p*-germanium can be improved by an electrical forming or power treatment of one of the point electrodes. W. H. Brattain<sup>1</sup> discovered that transistor action in *n*-type germanium having a resistivity of the order of one to ten ohm-centimeters can generally be improved by passing large reverse currents through the collector. Later, it was discovered that transistor action in *p*-type germanium could be greatly enhanced by passing a large forward current through the emitter.<sup>2</sup> Since this initial work, other members of the Bell Telephone Laboratories' staff have contributed to our knowledge of the effects of various forming treatments. The purpose of the present note is to present some qualitative data on forming and to give a tentative interpretation of the results in terms of modifications of the rectifying barrier layer at the contact.

The forming treatments which we shall describe involve appli-

cations of direct current in either the forward or reverse direction for times of the order of seconds or less. The extent of the changes caused by forming depends in part on the surface treatment of the germanium and in part on the material used for the point contact. We have used phosphor bronze points on surfaces which were ground and etched.

Transistor action depends on the presence of an inversion layer or change of conductivity type in the barrier layer of the emitter contact. In the case of *n*-germanium, there is evidence that such a barrier layer exists at the free surface, independent of the contact, and hence effective emitter action is obtained without electrical forming. Such a barrier layer is shown schematically in the energy level diagram of Fig. 1a. The position of the Fermi level at the surface, closer to the filled band than to the conduction band, is determined by the energy levels of electrons in surface states.

Since the same surface treatment has been used for both *n*- and *p*-germanium, the surface states and position of the Fermi level at the free surface of *p*-germanium are expected to be similar to those for *n*-germanium, as shown in Fig. 1b. Unless a barrier layer is formed by the metal contact, little or no rectification to *p*-germanium is to be expected. It is, indeed, found that a metal point contact to *p*-germanium makes a poor rectifier unless there is some electrical forming or power treatment.

Forming may affect the surface layers, and thus the height of the barrier layer,  $\phi_s$ , as well as the distribution of donor and acceptor ions in depth in the vicinity of the contact. While it is believed that both effects occur, we shall be concerned with forming methods in which the principal results can be interpreted in terms of changes in  $\phi_s$ . Changes in ion concentrations may predominate with heavy forming such as may be produced by large current pulses. That the germanium and its surface layers are affected is indicated by the fact that a formed point may be replaced by another point, with little change of characteristics.<sup>3</sup>

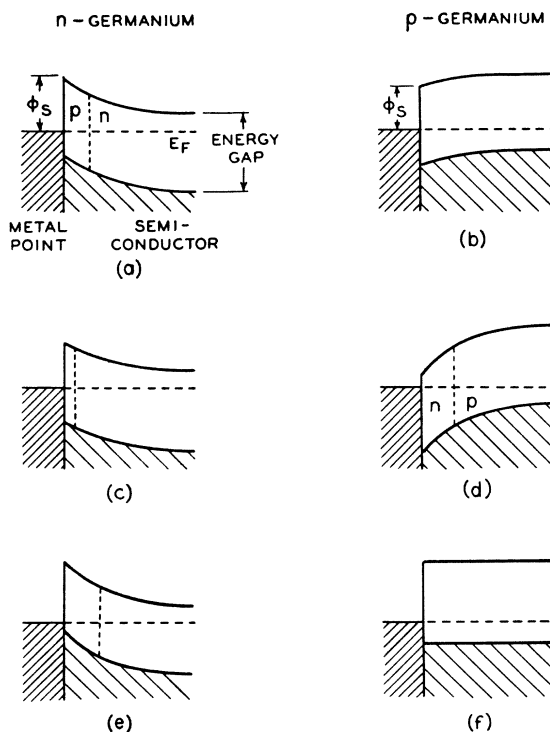


FIG. 1. Energy level diagrams showing effects of electrical forming on the rectifying barriers at contacts with *n*- and *p*-germanium: (a, b)—unformed; (c, d)—formed by negative current; (e, f)—formed by positive current.