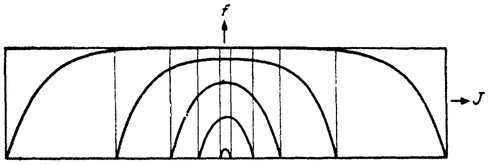

FIG. 1. f-values as a function of the position of the Hall sondes for some different shapes of the sample ("ideal" current electrodes).

The potential function satisfying these conditions is readily found to be

$$\varphi_{\text{Hall}}=A_H\frac{BJ}{d}\cdot\frac{4}{\pi}\sum_1^\infty\frac{1}{(2k-1)}\frac{\sinh[(2k-1)\pi z/l]}{\cosh[(2k-1)\pi b/2l]}\cdot\frac{\sin[(2k-1)\pi x/l]}{[(2k-1)\pi b/l]}.$$

The Hall potential between the probes A and B (on $z=+\frac{1}{2}b$ and $z=-\frac{1}{2}b$, respectively) is:

$$\overset{(A)}{\varphi_{\text{Hall}}}-\overset{(B)}{\varphi_{\text{Hall}}}=V_{\text{Hall}}=A_H(BJ/d)f(b/l,\ x/b),$$

in which f depends on the ratio of the length to the width of the sample and of the position of the probes along its sides. Some values of f are given in Table I. These results, which include those of Isenberg *et al.*[1] are plotted in Fig. 1. We determined experimentally the values of f for $x/l=0.5$, using samples with l/b values of about 0.5, 1, 2, and 8. We found them to be in agreement with the theory. When the problem of the Hall potential is treated in this way, no so-called "einge-prägte Kräfte" nor electrostatic charges are introduced, as was done by Isenberg. It is sufficient to consider the resistivity of the material as a tensor.

TABLE I. Values of the function $f(b/l,\ x/b)$.

x/l \ l/b	0.1	0.5	1.0	2.0	4.0	∞
00	0	0	0	0	0	0
0.125	0.04	0.20	0.39	0.62	0.83	1.00
0.250	0.06	0.30	0.56	0.82	0.98	1.00
0.500	0.075	0.37	0.68	0.94	1.00	1.00

Thus no appreciable Hall potential can be built up in the sample if the current electrodes are placed close to each other. Perrier,[2] in suggesting such an arrangement, has not taken into account this fact and therefore his suggestion pointing to very high Hall voltages is incorrect.

This point of view may be of some importance for the study of *inhomogeneous conductors*. Let us consider a material consisting of highly conducting grains separated by thin layers of lower conductivity, and let the picture in Fig. 2 be a consistent model of this situation. The macroscopic resistivity is to a good approximation: $\bar{\rho}=\rho_1+(l_2/l_1)\rho_2$. The most interesting case occurs if the third term dominates the second. Let this be so. Then approximately $i_1:i_2=l_1:l_2$, where i_1 and i_2 are the *mean* values of the components of the current densities in the direction of J. Now we have in each grain a Hall voltage of about $A_H^{(1)}l_1i_1B$ and in each longitudinal layer likewise $A_H^{(2)}l_2i_2B$, but in each perpendicular layer the Hall voltage cannot be higher than $0.75(l_2/l_1)A_H^{(2)}l_1i_1B$. We have used here the value of f for the middle of the layer and in the limit for small l_2, assuming that the conducting grains may be considered as electrodes for the layer, as was done above. We suppose $A_H^{(2)}>A_H^{(1)}$.

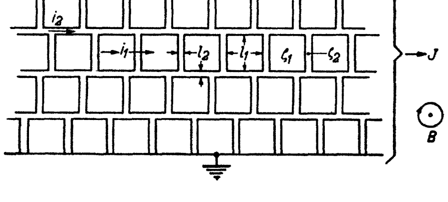

FIG. 2. A model for an inhomogeneous conductor.

For the sample as a whole we obtain approximately (with c being of the order of magnitude unity):

$$\bar{A}_H=A_H^{(1)}+c(l_2/l_1)^2\cdot A_H^{(2)}.$$

Generally $\bar{A}_H$ will not be very different from $A_H^{(1)}$; $\bar{\rho}$ on the other hand can be much greater than ρ_1. This means that, if the Hall effect and the resistivity of such an inhomogeneous conductor is to be explained in terms of electron density and mobility, no conclusion as to the mobility either in the highly conducting grains or in the badly conducting layers may be drawn.

We have in fact found in some samples of semiconducting materials very low values of the mobility, which, however, could be explained in the manner given.

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[1] Isenberg, Russell, and Greene, Rev. Sci. Inst. 19, 685 (1948).

[2] A. Perrier, Helv. Phys. Acta 19, 410 (1946).

The Thermodynamics of Liquid Helium of He³—He⁴ Solutions

O. K. RICE
Department of Chemistry, University of North Carolina,
Chapel Hill, North Carolina

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THE thermodynamics of liquid helium on the basis of the two-fluid theory of He II has been considered independently by Gorter[1] and the writer.[2] Though using different methods these treatments are in many respects similar. We differ, however, in one rather fundamental point. I assumed zero enthalpy of mixing of normal and superfluid, which allowed me to set the partial molal enthalpy of superfluid[3] $\bar{H}_{4s}$ equal to zero. I then obtained an approximate expression for the partial molal entropy $\bar{S}_{4s}$, which arises from an entropy of mixing of normal and superfluid, to be expected from the picture I developed in which the superfluid is separated from the normal fluid in ordinary space as well as momentum space.

On the other hand, Gorter based all his applications on Tisza's[4] assumption that the total molal entropy is equal to the molal entropy of normal fluid times its mole fraction. This is equivalent to $\bar{S}_{4s}=0$, or no entropy of mixing. On this basis $\bar{H}_{4s}$ must be finite; in fact, $-\bar{H}_{4s}/T$ will be given by an expression very similar to that found by me for $\bar{S}_{4s}$, and it plays much the same role in the theory, namely that of stabilizing the mixtures of normal and superfluid below the λ-point.

Either assumption is thermodynamically possible. We wish here to consider the possibility of distinguishing between them experimentally by means of the change of the λ-temperature T_λ with pressure or with mole fraction x_3 of He³ in a mixture of the isotopes.

If $\bar{S}_{4s}=0$, we obtain instead of Eq. (25) of reference 2 (1949)

$$dp/dT_\lambda=S_\lambda/(V_\lambda-\bar{V}_{4s,\lambda}) \tag{1}$$

which differs from Eq. (25) only by lacking the factor $r/(r+1)$ (roughly 0.85) on the right-hand side $[\bar{V}_{4s,\lambda}\equiv\bar{V}_{2,\lambda}$ of Eq. (25)$]$. This would upset the previously found good agreement with experiment somewhat, but hardly enough to be conclusive in view of the uncertainties involved. It offers, however, a possibility for future investigation.

The effect of He³ on the λ-point of He⁴ has recently been investigated theoretically[5–7] and experimentally.[8,9] Assuming $\bar{H}_{4s}=0$, and assuming that He³ and normal He⁴ form an ideal solution, with He³ insoluble in superfluid,[10] Engel and Rice showed that

$$dT_\lambda/dx_3=-RT_\lambda^2/\bar{H}_{4n,\lambda}(1-x_3) \tag{2}$$

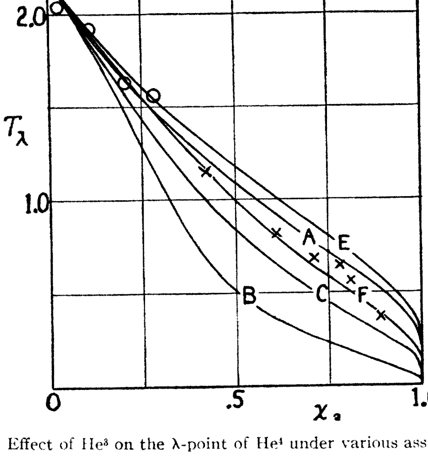

FIG. 1. Effect of He^3 on the λ-point of He^4 under various assumptions.

where it follows from $\bar{H}_{4s}=0$ that $\bar{H}_{4n,\lambda}=H_{4n}{}^0$, the latter being the enthalpy of *pure normal* He^4 at $T\lambda$ (metastable and unobtainable if $T\lambda<T\lambda_0$).

For the case $\bar{S}_{4s}=0$ we obtain

$$dT_\lambda/dx_3=-RT_\lambda/\bar{S}_{4n,\lambda}(1-x_3). \tag{3}$$

Since we assume always that $x_{4s}=0$ at T_λ for any given x_3 and that normal He^4 and He^3 form an ideal solution, $\bar{S}_{4n,\lambda}=S_{4n}{}^0-R\ln x_4$, where $x_4=1-x_3$, and Eq. (3) becomes

$$dT_\lambda/dx_4=RT_\lambda[x_4(S_{4n}{}^0-R\ln x_4)]^{-1}. \tag{4}$$

$S_{4n}{}^0$ like $H_{4n}{}^0$ cannot be measured below $T\lambda_0$. If we guess with Tisza that $S_{4n}{}^0=\text{constant}=S\lambda_0$, the integral of Eq. (4) is

$$RT\lambda\ln x_4=S\lambda_0(T\lambda-T\lambda_0). \tag{5}$$

This is identical with Eq. (34) of de Boer and Gorter[7] and curve B of Daunt and Heer.[9] The relationship between x_4 and $T\lambda$ is determined by $S\lambda_0$ and $T\lambda_0$, and is not clear to me how curve E of Daunt and Heer differs from curve B.

$S_{4n}{}^0$ is probably not exactly constant. If the specific heat is given by[6] $C_{p,4n}=aT$, so that $S_{4n}{}^0=S\lambda_0-a(T\lambda_0-T)$ we obtain

$$RT\lambda\ln x_4=S\lambda_0(T\lambda-T\lambda_0)+\tfrac{1}{2}a(T\lambda-T\lambda_0)^2. \tag{6}$$

This reduces to Eq. (5) if $a=0$.

In Fig. 1 we show curves calculated using $S\lambda_0=1.59$ cal. mole^{-1} deg.$^{-1}$ and $H\lambda_0=2.95$ cal. mole^{-1}. Of three curves for $\bar{H}_{4s}=0$, curve A has $H_{4n}{}^0$ and hence $S_{4n}{}^0$ constant ($a=0$), and curve C has $C_{p,4n}=aT$ with $a=0.725$ cal. mole^{-1} deg.$^{-2}$ (which makes $S_{4n}{}^0=0$ at 0°K); curve B has $C_{p,4n}$ constant for temperatures near $T\lambda_0$, then falling off to give $S_{4n}{}^0=0$ at 0°K. These are the curves of Engel and Rice[6] except for trivial differences in the parameters. Curves E and F are for $\bar{S}_{4s}=0$, with $a=0$ and 0.725, respectively.

The experimental points shown agree almost exactly with curve F. If it is believed that $S_{4n}{}^0$ should be zero at 0°K this might be supposed to be evidence in favor of taking $\bar{S}_{4s}=0$. The points are too close to curve A to allow much probability of $S_{4n}{}^0$ going to zero if $\bar{H}_{4s}=0$ is taken as the basis of the calculations, though perhaps it is not excluded. (Note the difference between curves B and C for both of which $S_{4n}{}^0$ goes to zero.) However, we have such a hazy idea of what normal He^4 should be like below the λ-point that we really cannot say whether its entropy should approach zero or not, and we have noted that Tisza assumed it to be constant. Furthermore, we must remember that the curves are based on the assumption that normal He^4 and He^3 form an ideal solution, which may not be strictly true. Therefore it appears that these data cannot help us to decide whether to take $\bar{H}_{4s}=0$ or $\bar{S}_{4s}=0$. However, extremely accurate measurements of dT_λ/dx_3 for very dilute solutions of He^3 might serve to resolve the question, for in this case all the quantities are known and there is a definite though small difference between Eqs. (2) and (3).

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[1] C. J. Gorter, Physica **15**, 523 (1949).
[2] O. K. Rice, Phys. Rev. **76**, 1701 (1949); **78**, 182 (1950).
[3] Subscripts: 4*n* refers to normal He^4, 4*s* to superfluid, 3 to He^3; λ means "at the λ-point;" λ_0 "at the λ-point of pure He^4." In general, the notation as in reference 2.
[4] L. Tisza, Phys. Rev. **72**, 838 (1947), and earlier papers.
[5] J. W. Stout, Phys. Rev. **76**, 864 (1949).
[6] O. G. Engel and O. K. Rice, Phys. Rev. **78**, 55 (1950).
[7] J. de Boer and C. J. Gorter, Physica **16**, 225 (1950).
[8] Abraham, Weinstock, and Osborne, Phys. Rev. **76**, 864 (1949), see circles, Fig. 1.
[9] J. G. Daunt and C. V. Heer, Phys. Rev. **79**, 46 (1950), see crosses, Fig. 1.
[10] Taconis, Beenakker, Nier, and Aldrich, Physica **15**, 733 (1949).

A Mixed Shower of Nuclear Origin

M. S. Sinha*
Bose Research Institute, Calcutta, India
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It has been noticed recently by several investigators that showers containing both soft and penetrating particles are definitely produced. The origin of many of these showers is not electromagnetic, and has been attributed by Rossi[1] to some nuclear interaction by particles other than ordinary mesons. As an example of this kind of shower a photograph has been reproduced by Rossi (see Fig. 3d of reference 1) in which a shower is produced with two separate cones whose axes are inclined at an angle of about 20°.

We reproduce herewith (Fig. 1) a photograph of a shower in which the axes of the two cones emerging from a point in the third lead plate (thickness 1 cm) are separated by an angle of about 180°. This is most unusual and a shower of this type has not so far come to our notice. A burst produced in a gas, previously observed by the author,[2] contained particles emitted in all directions, but few in the upward direction.

A fourfold coincidence counter system, two above and two below the chamber triggered the expansion of the cloud chamber, which had 10 cm of Pb above it and a total of 4 cm inside. The experiment was being performed to record showers of nuclear origin, produced in the lead placed above the lead plates inside the chamber serving to distinguish between the nature of the particles constituting the shower. The shower in Fig. 1 could not

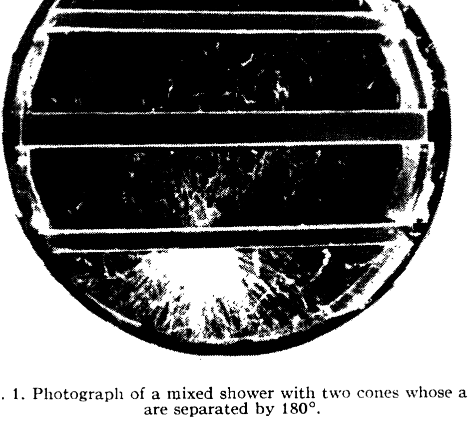

FIG. 1. Photograph of a mixed shower with two cones whose axes are separated by 180°.