No.	S							
	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
1	0.4	0.1						
2	≪0.01	0.05	≪0.01					
3	0.01	0.7	0.4					
4		0.2	0.6	0.15				
5		0.01	0.1	0.01				
6		0.05	0.5	0.05				
7			0.01	0.15	0.01			
8			0.01	0.5	0.02			
9			0.1	0.3	0.1			
10			≪0.01	0.5	0.1			
11				0.15	0.9	0.2		
12				0.01	0.25	0.05		
13				0.35	0.75	0.15		
14				<0.01	0.15	<0.01		
15				0.03	0.15	<0.01		
16				0.05	0.25	<0.01		
17					<0.01	0.4	<0.01	
18					0.15	0.6	0.01	
19					0.15	0.9	0.01	
20					0.15	0.45	<0.01	
21					0.01	0.1	0.01	
22					0.15	0.4	0.02	
23					0.1	0.5	0.05	
24					≪0.01	0.2	0.1	
25						0.3	0.8	0.1
26						<0.01	0.4	0.02

particle flux density be investigated in this range of distances with good accuracy.

The experimental charged-particle lateral distribution functions obtained for each of the selected showers were compared with the theoretical functions, calculated by Nishimura and Kamata[2] for various values of the cascade parameter S. The theoretical curves were normalized here to the number of particles experimentally observed in a circle of radius 25 m. The Pierson matching criterion was used to choose the theoretical curve corresponding to the experimental data. The results [the Pierson function $P(\chi^2)$] are listed in the table, which shows which values of the parameter S characterize the charged-particle flux density lateral distribution functions in the registered showers with different particle numbers N.

The experimental data given indicate the existence of extensive atmospheric showers of various ages near sea level.

[1] Vernov, Goryunov, Zatsepin, Kulikov, Nechin, Strugal'skiĭ, and Khristiansen, JETP **36**, 669 (1959), Soviet Phys. JETP **9**, 468 (1959).

[2] J. G. Wilson, ed. Progress in Cosmic Ray Physics, (Russ. Transl.), vol. 3, 1959, p. 7.

Translated by J. G. Adashko
68

A MEASUREMENT OF THE SURFACE TENSION AT THE BOUNDARY BETWEEN THE SUPERCONDUCTING AND NORMAL PHASES OF INDIUM

Yu. V. SHARVIN

Institute of Physical Problems, Academy of Sciences, U.S.S.R.

Submitted to JETP editor October 21, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **38**, 298-300 (January, 1960)

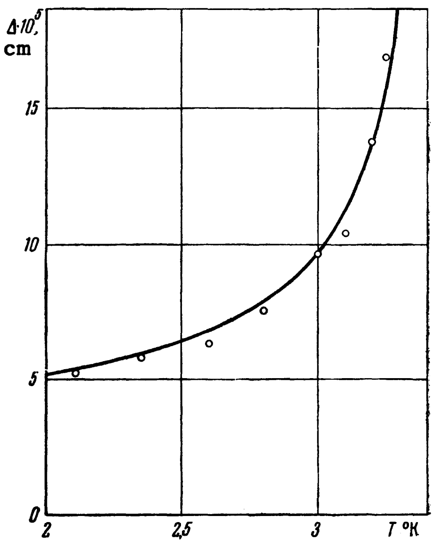
THE value of the surface tension σ_{ns} at the boundary between the superconducting and normal phases of indium has been measured by a method described previously.[1]

A single-crystal disc with diameter 50 mm and thickness 2.06 mm, fabricated of indium with impurity content ~ 0.002%, was placed in a magnetic field directed at an angle of 15° to the specimen surface. The structures observed were completely analogous to those observed in tin[1] at the same values of H/H_c. The period of the structure was measured for various fields and temperatures and the quantity $\Delta(T) = \sigma_{ns}(8\pi/H_c^2)$ was calculated.*

In the figure are given the results of measurements on Δ made in the range 2.11 to 3.245° K with an accuracy of 8 — 10%. In this range the results can be described within the limits of error by the relationship

$$\Delta_{In} = 3.3 \cdot 10^{-5} (1 - T/T_c)^{-1/2} \text{ cm}$$

(where $T_c = 3.40°K$), to which the curve in the figure corresponds.



We did not attempt to study the anisotropy of Δ by the method described. Trial measurements with various positions of the disc relative to the magnetic field showed that the anisotropy is small and lies within the limits of accuracy quoted above.

The values of Δ close to T_c can be compared with other quantities characterizing the superconductor by means of a relationship from the phenomenological Ginzburg-Landau theory.[2,3] In reference 1 a marked discrepance was pointed out between the experimental value of Δ and that calculated from the G.-L. theory using the quantities δ and H_c; the latter exceeds by a factor of about 1.5. Recently Gor'kov[4] showed, however, that the charge entering into the relationship of the G.-L. theory is two electronic charges and not one, as was assumed previously. This correction changed the relationship between Δ and δ in the required direction, but a small discrepancy of the opposite sign now appeared. In the table are given values of the constant C_Δ occurring in the asymptotic law $\Delta = C_\Delta(1 - T/T_c)^{-1/2}$ for $T \to T_c$, the values of the analogous constant C_δ for the penetration depth, the limiting values of the quantity H_{c1}/H_c for $T \to T_c$, where H_{c1} is the supercooling field, and also the results of calculating these quantities following G.-L. (see references 2—5). In the last column are given the values of $C_H = (dH_c/dT)T_c$ used in the calculations.

The values of C_δ for tin are quite reliable, since the measurements of δ were made by a number of investigators sufficiently close to T_c (down to $T_c - T = 0.017°$ in reference 6). Measurements on δ for single-crystal indium were recently made by Dheer[7] for $T_c - T \geq 0.46$. Thus, extrapolation of this data in order to obtain C_δ is less reliable than for tin. However, the values of C_δ and the data from supercooling agree with one another surprisingly well, as they do also for tin (columns 6 and 7 of the table). The discrepancy between Δ and δ for both metals amounts to 25—30% in terms of C_Δ (or 15—20% in terms of C_δ).

In the last row of the table are given data for aluminum obtained by Faber and Pippard.[8–10] The values of C_δ here are in general less satisfactory, since in this case δ should be studied with $T_c - T \sim 0.001°$ (see reference 11), but the existing measurements[8] were only made down to $T_c - T = 0.12°$. Comparison of the data on Δ and H_{c1}/H_c can be made also in the case of aluminum.[11] Here the relationship of the data is the opposite of that observed for tin and indium (see columns 3 and 4 or 6 and 7). The supercooling obtained experimentally is much larger than follows from the data for Δ.

It seems to us that the difference in this respect of the data for aluminum from the results for tin and indium is associated with some inaccuracy in the method used by Faber[10] for determining Δ. The use of the complicated meandering

	$C_\delta \cdot 10^6$, cm exptl	$C_\Delta \cdot 10^5$, cm			ϰ ***			H_{c1}/H_c	C_H, oersted
		from δ	exptl	from H_{c1}/H_c	from δ	from Δ	from H_{c1}/H_c		
	1	2	3	4	5	6	7	8	
Sn	2.55 *	1.63	2.3	1.6	0.16	0.108	0.164	0.232[9]	570
In	2.25 **	2.44	3.3	2.38	0.108	0.076	0.112	0.158[9]	495
Al	(2.46) [8]	(6.5)	9[10] (12—14)	10.3	(0.054)	0.032 (0.02——0.015)	0.0257	0.0363[9]	206

*Value averaged from references 6, 8, 12, and 13.

**The value taken for the calculation was averaged over the angle α between the current and the tetragonal axis of indium using Dheer's data[7] ($C_\delta = 2.35$ for $\alpha = 90°$, $C_\delta = 2.11$ for $\alpha = 0°$).

*** ϰ is the dimensionless parameter of the G.–L. theory; $H_{c1}/H_c = \sqrt{2}\varkappa$.

structure of the intermediate state in Faber's method is less reliable than the use of the inclined field method, in which one is able to observe the simplest layer structure. Faber also presents data obtained at one temperature using the inclined field method (see reference 10, Fig. 10), which, however, he does not use in the final results. Approximate treatment of this data using our formulae leads to the value $C_\Delta \times 10^5 = 12 - 14$, which is given in the table in brackets. The relationship between Δ and the value of the supercooling is then close to the case of Sn and In.

It is difficult at present to propose definite reasons for this small but systematic discrepancy. However, it would be stretching matters to ascribe it to accidental experimental errors.

I express my sincere gratitude to Acad. P. L. Kapitza for interest in the work, and to A. I. Shal'nikov and L. P. Gor'kov for detailed discussion of the results.

---

*During the calculation we attempted to estimate the effect of the specimen edges, i.e., the difference between the specimen and an infinite plate. The values of Δ, calculated using the formula for an ellipsoid inscribed in the specimen, are approximately 10% smaller than those obtained using the formula for an infinite plate (see reference 1). The true values will apparantly lie somewhere inside this range. Because accurate calculation is difficult for a disc, we used for calculation the formula for a flat ellipsoid of rotation having the same volume as our specimen (with axes 2.06 and 61.2 mm). The difference from the infinite case amounted in this instance to 8%. Introducing this correction into the results of reference 1, we obtained for tin

$$\Delta_{Sn} = 2.3 \cdot 10^{-5} (1 - T/T_c)^{-1/2} \text{ cm for } 2.16° < T < 3.5°.$$

---

[1] Yu. V. Sharvin, JETP **33**, 1341 (1957), Soviet Phys. JETP **6**, 1031 (1958).

[2] V. L. Ginzburg and L. D. Landau, JETP **20**, 1064 (1950).

[3] V. L. Ginzburg, JETP **30**, 593 (1956), Soviet Phys. JETP **3**, 621 (1956).

[4] L. P. Gor'kov, JETP **36**, 1918 (1959), Soviet Phys. JETP **9**, 1364 (1959).

[5] V. L. Ginzburg, JETP **31**, 541 (1956), Soviet Phys. JETP **4**, 593 (1957).

[6] Yu. V. Sharvin, JETP **22**, 367 (1952).

[7] P. N. Dheer, Superconductivity, Conf. Roy. Soc. Mond Laboratory, Cambridge, (1959).

[8] T. E. Faber and A. B. Pippard, Proc. Roy. Soc. **A231**, 336 (1955).

[9] T. E. Faber, Proc. Roy. Soc. **A241**, 531 (1957).

[10] T. E. Faber, Proc. Roy. Soc. **A248**, 460 (1958).

[11] V. L. Ginzburg, JETP **36**, 1930 (1959), Soviet Phys. JETP **9**, 1372 (1959).

[12] E. Laurmann and D. Shoenberg, Proc. Roy. Soc. **A198**, 560 (1949).

[13] A. L. Schawlow and G. E. Devlin, Phys. Rev. **113**, 120 (1959).

Translated by K. F. Hulme
69

SEVERAL POSSIBLE APPLICATIONS FOR THE RESONANT SCATTERING OF GAMMA RAYS

I. Ya. BARIT, M. I. PODGORETSKIĬ, and F. L. SHAPIRO

P. N. Lebedev Physics Institute, U.S.S.R. Academy of Sciences

Submitted to JETP editor November 4, 1949

J. Exptl. Theoret. Phys. (U.S.S.R.) 38, 301-302 (January, 1960)

BECAUSE of recoil during the emission of a gamma quantum by a free nucleus, the energy of the quantum is always less than the difference between the energy levels of the radiating nucleus. An analogous shift occurs in the absorption of a gamma quantum. This circumstance greatly hinders the observation of resonant scattering of gamma rays, which must occur with a large probability if this shift is absent or compensated.

Recently, however, Mössbauer[1,2] and others[3] have shown that at low temperatures the entire crystal takes up the recoil momentum in an observable fraction of the emissions and absorptions of low-energy gamma quanta. Under the indicated conditions the displacement of the gamma lines (as also the Doppler broadening) practically disappears, which makes possible the direct observation of resonant absorption. This was particularly clearly demonstrated by Mössbauer[2] and by Craig et al.,[3] who observed the dependence of the resonant-absorption cross section on the rate of change of the distance between source and absorber (Doppler effect). The experiments were performed with the 129-kev gamma rays of Ir-191. The lifetime of the excited state was shown to be equal to about 10^{-10} sec, which corresponds to a width $\Gamma = 10^{-5}$ ev and to a fractional width of about 10^{-10}. The influence of the Doppler effect manifests itself already at velocities of the order of 1 cm/sec.

In the work of Mössbauer[2] the described method is proposed for measuring the widths of gamma