sented in Fig. 1. The abscissa represents distance along the normal to the original shock with the origin at the corner, the scale being so arranged that the original shock has advanced a unit distance. The ordinate is the reduced pressure defect as determined by Lighthill, $P=(p_2-p)/\epsilon(p_2-p_1)$, where p is the pressure along the wall, p_1 and p_2 are respectively the pressures ahead of and behind the original shock and ϵ is the angle of the bend in the wall. The sign of the quantity P is observed to be positive for both concave and convex corners. The theoretical treatment shows a logarithmic infinity in the pressure at the corner. This, of course, would not be obtained experimentally, but a relative maximum in the pressure does exist there.

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Superconductivity of Lead

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NUMEROUS determinations of the zero-field transition temperature of lead have been made. A summary of these is given in Table I. All of these observations, except that of Daunt, were made by the direct measurement of electrical resistance. Daunt's method involved the shielding effect of persistent currents in a hollow cylinder.

In our work on columbium to be described in a forthcoming paper, an a.c. induction method[1] was used for the measurement of superconducting transitions. The superconductor was mounted as a cylindrical core of a coil which functioned as the secondary of a mutual inductance. The primary coil was actuated by an oscillator which provided a maximum a.c. field within the secondary of 1.5 oersteds at a frequency of 1000 cycles per second. The secondary e.m.f. which was dependent for its magnitude on the permeability of the core, was amplified, rectified, and observed on a recording potentiometer. During the application of this method to the study of columbium it appeared that a further check on the zero-field transition temperature of lead would be worth while, especially if agreement between results for very pure samples could be obtained using this method. Such a result would help in establishing the lead transition temperature as a reasonably reproducible reference point in the region between 4° and 10°K.

The lead used in the present investigation was made available to us through the courtesy of Dr. C. H. Hack and Mr. E. J. Dunn, Jr., of the National Lead Company. It had been analyzed as follows (No. A-586A):

Ag 0.00065%	Zn 0.0001%	As, Cd, Co, Ni, Sn: no perceptible amounts.
Cu 0.00022%	Bi 0.0002%	
Fe 0.00018%	Mn 0.00005%	

The samples were in the form of cylinders 1.5 mm in diameter and 5 cm long, attached by a copper rod to the desorption cryostat described in the forthcoming report on the superconductivity of columbium. Temperatures were determined to the nearest 0.01°K with the aid of a helium gas thermometer which was filled to 1 atmos. at 20.4°K. Corrections were applied for gas imperfection, room temperature volume, and temperature gradients in the capillary. The hydrogen triple point was checked within 0.02°K.

The collected results of the transition temperatures observed in the present experiments are given in Table II. The observations were made on two samples in a series of experiments in which the gas thermometer was refilled at the beginning of each run, usually to 1 atmos. but in one case to ½ atmos. to check the consistency of the thermometer corrections. A typical transition is shown in Fig. 1. Neither specimen showed hysteresis, but since thermometer response was more immediate on warming cycles, the data shown were taken on transitions proceeding from the superconducting to the normal state. Changes of oscillator frequency from 500 to 2000 cycles/sec. and of amplitude over the full range available did not affect the transitions.

As a further check on the magnetic purity of the material, observations were made of the $H-T$ curve in the vicinity of the zero-field transition temperature both in transverse and in longi-

Table I. Transition temperature of lead.

Investigators	Year	Source, purity	Temperature °K
Onnes, Tuyn[a]	1922	Kahlbaum: 99.99%	7.22; 7.26
de Haas, de Boer, van den Berg[b]	1934	Kahlbaum: 99.99%	7.19_3; 7.20_6
Daunt[c]	1937	Hilger: 99.999%	7.22
Bruksch, Ziegler[d]	1942	(evaporated films)	7.23 ±0.03
Bruksch, Ziegler, Hickman[e]	1942	Baker (thin wires)	7.20 ±0.01
van Itterbeck, de Greve, Lambeir, Celis[f]	1949	(sputtered films)	7.20
		Average:	7.216°

[a] K. Onnes and W. Tuyn, Leiden Comm. No. 160b (1922).
[b] de Haas, de Boer, and van den Berg, Leiden Comm. No. 233b.
[c] J. G. Daunt, Phil. Mag. 28, 24 (1939).
[d] W. F. Bruksch, Jr., and W. T. Ziegler, Phys. Rev. 62, 348 (1942).
[e] Bruksch, Ziegler, and Hickman, Phys. Rev. 62, 354 (1942).
[f] van Itterbeck, de Greve, Lambeir, and Celis, Physica 15, 962 (1949).

Table II. Zero-field transition temperatures of lead by a.c. induction method.

Transition temperature, °K	No. of separate observations
7.26	1
7.25	1
7.24	5
7.22	5
7.21	1
7.20	2
7.17	1
Average: 7.22_4°K	
Mean deviation: 0.02°K	

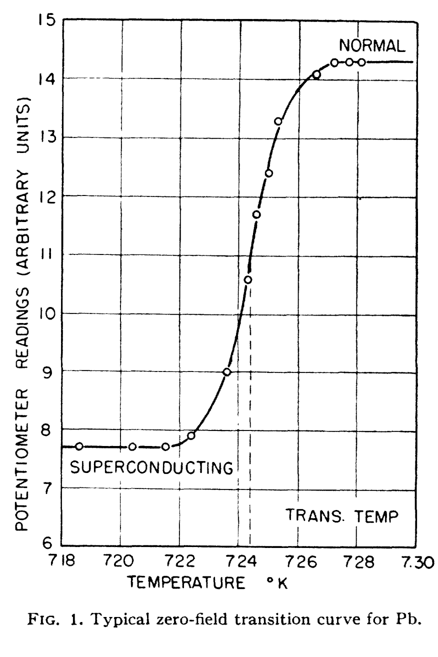

Fig. 1. Typical zero-field transition curve for Pb.

tudinal fields. The two types of transitions agreed with published values, the longitudinal field transitions showing the shape reported by Shoenberg.[2]

* Assisted by the ONR.
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A Lower Bound on the Range of the Triplet Neutron-Proton Interaction*

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IT has been pointed out by Schwinger[1] that the existence of a quadrupole electric moment for the deuteron requires that the triplet neutron-proton interaction be of finite range. On the basis of approximate expressions for the quadrupole moment and the percentage of D-state in the deuteron, Schwinger was able to derive an approximate relationship between the range and these two quantities and so make an estimate of a lower bound for the range assuming the experimental value for the quadrupole moment and that the percentage of D-state was less than 5 percent. Recently, Broyles and Kivel[2] have obtained a *rigorous* lower bound for the triplet range from the experimental quadrupole moment by a very simple argument. However, the value obtained, 1.1×10^{-13} cm, is very much lower than that estimated by Schwinger who found for the lower bound 2.5×10^{-13} cm. A large part of this difference can well be attributed to the rather severe, but justifiable, restriction placed by Schwinger on the percentage of D-state, which was not imposed in the calculation of Broyles and Kivel.

Since the experimentally determined magnetic moment of the deuteron makes it unlikely[3] that the percentage of D-state in the deuteron much exceeds about 5 percent, it is of interest to determine what influence this restriction has on the rigorous calculation of Broyles and Kivel. The procedure, following Broyles and Kivel, consists in maximizing the expression for the quadrupole moment with respect to the S- and D-wave functions, assuming that these have their asymptotic form outside of the interaction range, but now with the restriction that the percentage of D-state has a fixed value. Using Lagrange's method of undetermined multipliers, the procedure is essentially identical with that of Broyles and Kivel. The optimum choice of functions is again found to be S- and D-functions which vanish inside the interaction range, as is to be expected. The maximum value of the quadrupole moment is found to be given by the equation

$$Q_{\max}=\frac{1}{80\alpha^2}\{\beta'(2\alpha r_0)[\delta(1-\delta)/\gamma(2\alpha r_0)]^{\frac{1}{2}}-\delta\gamma'(2\alpha r_0)/\gamma(2\alpha r_0)\},$$

where r_0 is the range of the interaction, $\alpha=[ME_B/\hbar^2]^{\frac{1}{2}}$ where E_B is the binding energy of the deuteron, δ is the fraction of D-state, and the functions $\gamma(x)$, $\beta'(x)$, and $\gamma'(x)$ are defined by

$$\gamma(x)=e^x\int_x^\infty[1+6/x+12/x^2]^2e^{-x}dx$$

$$\beta'(x)=8^{\frac{1}{2}}e^x\int_x^\infty[x^2+6x+12]e^{-x}dx$$

$$\gamma'(x)=e^x\int_x^\infty[x+6+12/x]^2e^{-x}dx.$$

Equating $Q_{\max}$ to the experimental value for the deuteron quadrupole moment,[4] $Q_{\exp}=2.77\times10^{-27}$ cm^2, yields a lower limit to the range of interaction, r_0. In Fig. 1, the full curve shows the dependence of this lower limit on the percentage of D-state. The dotted line gives the lower limit found by Broyles and Kivel

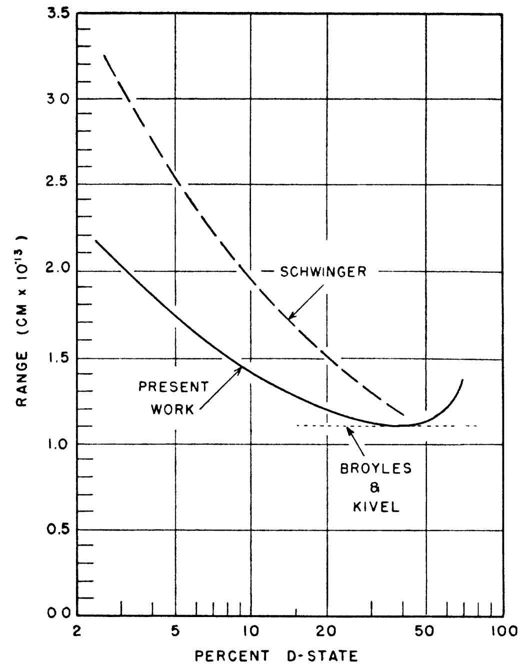

FIG. 1. Relations between range of triplet neutron-proton interaction and percentage of D-state in deuteron. *Full curve:* lower limit on range from present work; *dotted curve:* lower limit on range obtained by Broyles and Kivel; *dashed curve:* approximate relation between range and percentage of D-state obtained by Schwinger.

which is seen to correspond to about 35 percent D-state. The dashed curve represents the approximate relation between range and D-state percentage found by Schwinger. (The fact that this curve falls below our rigorous lower limit for more than 50 percent D-state shows that Schwinger's approximations break down for a high D-state percentage.) If the percentage of D-state in the deuteron is less than 5 percent, we may conclude that the triplet range is certainly greater than 1.75×10^{-13} cm. This is still considerably below Schwinger's approximate value.

We may also note that our curve becomes asymptotic to a vertical line at $\delta=8/9$ (89 percent D-state). For higher D-state percentage, the quadrupole moment is necessarily negative.

For a potential which cuts off sharply at a given range (such as a square well), the range for which the lower bound is obtained above is well defined. For a well with a "tail" (such as the Yukawa or exponential wells) the range referred to above is that at which the S- and D-functions take their asymptotic forms. This requires that the potential at the above range must be small in absolute value compared with the absolute value of the deuteron binding energy. It should be noted that it is not assumed that the central and tensor interactions have the same range; the range referred to is simply that of the longest range potential.

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