Wheeler,[2] that g_μ and g_e are likely to be equal, the ratio (3) is approximately equal to 4. If, on the other hand, we adopt their best observational values $g_\mu \cong 10^{-49}$ erg-cm^3 and $g_e \cong 2.2\times 10^{-49}$ erg-cm^3, the ratio is approximately equal to 20. In both cases, there is clear disagreement with recent results at Berkeley,[4] which indicate that the ratio (3) is substantially less than unity.

An estimate for the magnitude of the integral in (2) can be obtained by taking its upper limit to be roughly equal to Mc; this is equivalent to assuming that nucleon theory is valid in the non-relativistic domain, and that relativistic intermediate states can be ignored. Alternatively, the self-energy of a π-meson at rest due to intermediate nucleons can be calculated, and set equal to mc^2. The same integral appears (again with neglect of a factor $-mc$ in the energy denominator), and the values obtained for it in the two ways are approximately the same. When the latter evaluation of the integral is used, and g_μ is taken equal to 10^{-49} erg-cm^3 in order to obtain agreement with the rate of nuclear capture of negative μ-mesons, we obtain $\tau_{\pi\mu}\cong 2.3\times 10^{-9}$ sec., which is in fair qualitative agreement with the observed value.[5] This makes the computed mean life for $\pi-e$ decay much too small to agree with experiment; while the discrepancy could be removed by the assumption of a direct $\pi-e$ coupling that largely cancels the second-order contribution, this is a rather unlikely possibility. Thus, it would seem that the rate of nuclear beta-decay is too large to be consistent with the small rate of $\pi-e$ decay, if either $\pi-e$ coupling[1] or nucleon-electron coupling is assumed by itself.

The interaction (1) also leads to $\mu-e$ decay as a second-order process, but the rate computed in this way is far too small to agree with experiment.

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Production of π-Mesons by High Energy Nucleons*

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IN connection with the programs of accelerators under way in this country, it seemed useful to collect as many data as possible about the production of mesons by high energy particles. When looking through the literature we found that for the case where the bombarding particle is a high energy nucleon, two different results had been obtained. Using straightforward third-order perturbation methods, Urban and Schwarzl[1] obtained for the cross section σ:

$$\sigma = 4(g^2/\hbar c)^3(M/\mu)^2(Mc^2/E_0)^2(\hbar/Mc)^2\log(M/\mu), \tag{1}$$

where g is the coupling constant, M the mass of a nucleon, μ the mass of the π-meson, and E_0 the energy of the bombarding nucleon. Equation (1) and also the following equations give only the first terms in a series expansion in inverse powers of E_0. This paper was essentially a corrected version of the paper of Nordheim and Nordheim[2] who had arrived at practically the same result, although using an incorrect expression for the perturbation matrix element. As in the following, a charged scalar field was assumed. Independently, the result of Eq. (1) was obtained by us[3] making the same simplifying assumptions.

A different result, however, was obtained by Wang[4] using the Weizsäcker-Williams method. His result was

$$\sigma = K(g^2/\hbar c)^3(M/\mu)(Mc^2/E_0)(\hbar/Mc)^2, \tag{2}$$

where K is a constant of the order of magnitude unity.

Since it seemed to us that the Weizsäcker-Williams method should give reliable results for high energies, we have performed the third-order perturbation calculations, now retaining all terms. It then turned out that the final result is essentially identical with Wang's formula. Our final result is

$$\sigma = (\pi/8)(g^2/\hbar c)^3(M/\mu)(Mc^2/E_0)(\hbar/Mc)^2. \tag{3}$$

It is interesting to note that formula (3) does not give an E_0^{-2} dependence as one might expect from dimensional considerations,[5,6] thus indicating a dependence of the matrix element on energy. The difference between formulas (1) and (3) arises from the fact that in the evaluation of the matrix elements, Urban and Schwarzl,[1] as well as the present authors in their preliminary calculations,[3] neglected terms arising from the momentum of the virtual meson which were taken into consideration in the calculations leading to formula (3). Recoil was also taken into account, but this did not influence the final result.

We should like to express our sincere thanks to Professor H. Wergeland for discussions on the subject of this letter. Detailed calculations will be published in a report of the Purdue Synchrotron Project to the ONR.

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Note on the Resistivity of Gold at Low Temperatures

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AS is well known, the wave function of an electron in a perfectly periodic potential field consists of a plane non-attenuated wave, modulated with the period of the potential. In Bloch's model of a solid, the periodicity of this potential is equal to the periodicity of the lattice ions. It follows, therefore, that in such an ideal solid an electron would experience no scattering or in other words the electrical resistivity should be zero.

The above is a fundamental property of an ideal (i.e., rigorously periodic) lattice and is deduced from quantum mechanics without any approximation being involved. If one now inquires as to how closely any real crystal approximates this model, the following modes of departure may be envisaged:

(1) If the situation is such that the states in the lowest Brillouin zone are completely occupied by electrons, and an energy gap between it and the next higher zone exists (no overlap), we should, in the vicinity of absolute zero, have no net current, i.e., the crystal would be an insulator with an infinite resistivity at 0°K.

(2) In the more pertinent case of a monovalent metal such as gold with a half-occupied first zone, departures of the lattice from perfect periodicity can be due to the following: (a) Finite excitation of the Debye waves. This is temperature dependent and will vanish at the absolute zero. (b) Strains and impurities. (c) Crystallite boundaries in polycrystalline material.

These last three will, of course, be temperature independent at low temperatures. Accordingly, as the temperature approaches absolute zero, the resistivity of a conductor should approach zero or at most become temperature independent due to (b) and (c).

In view of all this, the observation made by de Haas, de Boer, and van den Berg[1-3] some years ago that the resistivity of pure gold increased as the temperature was lowered below about 3°K seems exceedingly strange. While all their measurements were made with polycrystalline specimens, even their purest sample (impurity $\sim 10^{-4}$ percent, mainly Cu and Ag) showed a definite minimum in the resistance-temperature curve, although it is true that less pure material gave a more pronounced effect. The resistance of one specimen continued to rise at temperatures as low as 0.4°K, and, in fact, seemed to be approaching infinity at absolute zero. These authors concluded that the minimum is not due to spurious causes such as gas absorption or unavoidable disturbances caused by the current and potential leads to the specimens.

The only other published measurements on gold appear to be those of Meissner.[4] Here, measurements on gold monocrystals (impurities $\sim 10^{-3}$ percent) showed no minimum down to 1.3°K, a temperature well below the minimum temperature found necessary by the Leiden investigators.

If the effect reported by the Leiden group should prove to be real (i.e., not due to impurities or some similar cause), then it appears that a rather fundamental violation of the basic quantum theory of solids has appeared. Thus, a monovalent substance like gold, where the Fermi surface in the first zone is presumably nearly spherical and far from a zone boundary, approaches the ideal Bloch model closely—the conduction electrons are nearly "free." Presumably, one would then have to go a step further than the present theory of solids and consider the possibility of electron interaction—a mechanism which has sometimes been suggested as responsible for superconductivity.

It seems more plausible to suppose that the effect is of a secondary nature, and in some way connected with the crystallite boundaries in the polycrystalline material. Thus, Meissner's single crystals do not show the effect even though the impurity content of his material was about ten times as large as that used by de Haas and collaborators. It may, of course, be that in the process of growing single crystals, Meissner automatically purified his material—such a process has been used for refining, the impurities being "flushed" to one end of the crystal, and this end then rejected.

It might, therefore, be of interest to re-examine this matter, making use of both single crystal and polycrystalline specimens fabricated from the same material and each having the same impurity content.

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Magnetic Effects of a Rotating Superconductor*

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IT was discovered by Meissner[1] that when a substance goes superconducting in a small magnetic field, the magnetic induction vector $B=0$. What is often observed is a Meissner effect varying anywhere from no effect at all to the complete effect, and this seems to depend on the degree of impurity, geometrical shape, and whether or not the specimen is a single crystal.[2] We have studied the frozen-in magnetic flux of superconducting tin whose total impurity is 0.012 percent. The tin was melted in a vacuum furnace and allowed to cool slowly after the manner of forming a single crystal. Ultrasonic pulses at 10 megacycles per second showed no evidence of flaws. The specimen was in the shape of a cylinder with well-rounded edges, approximately an ellipsoid, and mounted in Textolite such that it could be rotated about its long axis. The rotor of tin was enclosed in a lead shield so that with the lead superconducting, the magnetic field around the tin was not changed by external effects. With the lead housing superconducting, the magnetic field between the lead wall and the normal conducting tin rotor was about 0.01 gauss and remained unchanged (± 0.00005 gauss) with variation in the angular position of the tin rotor. Cooling further, the magnetic field detector, which was placed between the tin rotor and the lead housing, showed the Meissner effect as the tin rotor became superconducting and flux was pushed out of it.

The superconducting tin rotor showed a very pronounced frozen-in flux (incomplete Meissner effect) in that the magnetic field at the detector now varied sinusoidally with the angular position of the rotor. The frozen-in flux threaded through the superconducting tin in an orientation determined by the magnetic field within the lead housing. That is to say, the magnetic moment locked into the superconducting tin was independent of the angular orientation of the rotor with respect to the lead housing when the transition temperature was passed. Thus, there was no special path of impurities or structure flaws through the tin rotor for the frozen flux to choose. The frozen magnetic flux showed no observable relaxation effects over a period of five minutes.

A Meissner effect has been observed when the specimen has been cooled while rotating at 5000 revolutions per minute. On the stopping rotation the specimen showed no frozen flux. The magnetic field was observed to penetrate the rotor (reverse Meissner effect) when the temperature was then raised through the transition point. Magnetic fields were detected by the "magnetic airborne detector," AN-ASQ-3, kindly supplied by the Office of Naval Research.

We may conclude that when a solid ellipsoid of pure tin goes superconducting it may do two things with the magnetic flux which existed within its body. It may eject part of the flux, corresponding to the Meissner effect, by setting up macroscopic currents described by the theory of F. and H. London,[3] and this current does not move with the rotor as it is turned but stays fixed with respect to the external field. The remainder exhibits the intermediate state proposed by Gorter and Casimir[4] wherein magnetic flux is crowded into small regions where the critical field is exceeded, and this flux is supported by annular superconducting currents which we have observed to stay fixed with respect to the rotor. The earlier experiments by Onnes and Tuyn[5] support these conclusions. The authors acknowledge with pleasure the directing guidance of Professor C. F. Squire and the many helpful discussions with Professor W. V. Houston.

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The Viscosity and Thermal Conductivity of Mixtures of He^3 and He^4

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RECENTLY Ter Haar and Wergeland,[1] using Tisza's phenomenological picture of the viscosity of He^4, have estimated the influence of an admixture of He^3 to the He^4 liquid. Their expression for the increase in viscosity due to a fraction x of He^3 in He^4 liquid is

$$\Delta\eta = x(\eta_3{}^{\mathrm{kin}} - \eta_4{}^{\mathrm{kin}}) \approx x\eta_3{}^{\mathrm{kin}}. \quad (1)$$

In deducing (1) the kinetic viscosity of He^4 is neglected in comparison to that of He^3, and also the dynamic viscosity of both He^3 and He^4 is assumed to be the same.

In calculating η^{kin} from the well-known expression

$$\eta^{\mathrm{kin}} = \tfrac{1}{3}\rho\bar{c}\Lambda,$$

these authors have assumed that the mean free path Λ is equal to $m/\sqrt{2}\pi d^2$. This, however, is not justified, since in a degenerate Fermi-Dirac gas the mean free path Λ increases with decreasing temperature because the number of possible collisions is greatly reduced because of the exclusion principle. Indeed, at a temperature T, the possible transitions are limited to the states of the "Maxwell tail" beyond the maximum zero point energy $E_m = (h^2/2M)(3\rho/8\pi M)^{\frac{2}{3}}$: In velocity space such cells roughly fill a spherical cell of radius $v_m = (2E_m/M)^{\frac{1}{2}}$ and thickness