Repeating the same considerations, we find that the quantity $T_{2n+1}(A)$ cannot be positive.

Considering only general inversion, we have shown that in the case of a spinor field the energy density cannot be positive definite, and in the case of a tensor field the energy density cannot be positive definite. From these premises and from the expressions, Eqs. (8) and (10), Pauli constructed the proof of his theorem.

[1]W. Pauli, Phys. Rev. 58, 716 (1940) (See *The Relativistic Theory of Elementary Particles* (Russian translation), IIL 1947, appendix)

[2]J. Schwinger, Phys. Rev. 82, 914 (1951) (See *Recent Developments in Quantum Electrodynamics* (Russian translation), IIL 1954, p. 133).

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A Possible Application of Cyclotron Resonance to Mass Spectrometry

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CYCLOTRON resonance, which was theoretically predicted by Dorfman[1] and has been observed experimentally in semiconductors,[2] consists of absorption of microwave power by an assemblage of electrons or holes upon which a magnetic field H is acting. The absorption takes place at a frequency

$$\nu = eH/2\pi mc, \qquad (1)$$

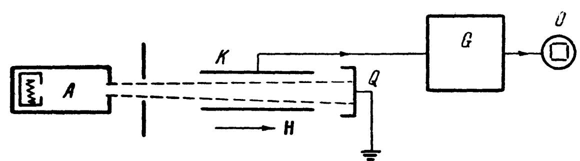
equal to the frequency of rotation of the carriers in the field H and is due to electric dipole transitions[3] whose possibility is controlled by the motion of the charges in quantum orbits. The electric dipole transitions are induced by the electric vector E_ν of the microwave field; the transition probability is a maximum when E_ν is perpendicular to H.

In comparison with paramagnetic resonance, cyclotron resonance absorption is distinguished by its remarkably large intensity. The electric dipole transition probability is approximately 10^{12} times larger than the probability of the magnetic dipole transitions in paramagnetic resonance.[4] Consequently the observation of cyclotron resonance requires a carrier concentration 10^{12} times smaller than is necessary for the observation of paramagnetic resonance. In view of the sensitivity of modern radiospectroscopic techniques it should be possible[4] to observe cyclotron resonance in a gas of free electrons at about 10^4 electrons per cm^3. Cyclotron resonance absorption must occur also in the space charge formed by ions of this or that substance; the relative magnitude of this absorption[3] must be 10^3 to 10^4 times less than for an electron gas under the same conditions of concentration and supplied *rf* power.

The condition that the effect be observable is that $\omega\tau > 1$. It follows from the requirement that the carrier be able to execute at least one complete rotation in the time between successive collisions.

Cyclotron resonance may find application in gas analysis, in studying the properties of plasma (e.g., in measuring ion mobilities and collision times), and in mass spectrometry.

The principle of operation of a possible mass spectrometer is similar to that of the *rf* mass spectrometer propsed by Hipple *et al.*[6] and consists of measuring the cyclotron frequencies of ions of the various masses and subsequently computing *m* by formula (1). A schematic diagram



Schematic diagram of apparatus.

of the apparatus is shown in Fig. 1. The ion source *A* sends an unfocused ion beam of low energy into the condenser *K* which forms part of the resonant circuit of the high-frequency tunable oscillator *G*. In the field H, parallel to the faces of the condenser, the ions move along helical paths, whose projections upon a plane perpendicular to H are circles of radius $\rho = mcv_\perp / eH$, where $v_\perp$ is the projection of the ion velocity upon this same plane. Even if an ion executes only a single rotation during its flight through the condenser absorption of high-frequency power must be observable at the frequency (1). By modulating the field or the oscillator frequency it is possible by the usual means to display the resonance curve on an oscilloscope or to register it with a recorder. After traversing the condenser the ions are discharged by the collector Q.

The sensitivity of the instrument is determined from the ratio of the number N of ions per cm^3 and the minimum density n required for detecting absorption, i.e., $N/n \approx N/10^4$. Thus the sensitivity will be the higher, the larger the ion current and the lower the ion energy. It is not difficult to see that in principle it is possible to raise this quantity to values of the order of 10^6 to 10^7 ; thus the possibility is disclosed of detecting isotopes having a natural abundance of a part in ten million.

The dispersion of the instrument is linear and according to formula (1) is obtained from the relation

$$D = (eH/2\pi mc)\,(1/100m) \qquad (2)$$

for a 1 percent change of mass. For elements of the center of the periodic table D will be about 10^4cps.

The resolving power is given by $R = m^*/\Delta m = \nu/\Delta\nu$, where $\Delta\nu$ is the error in the frequency measurement. Since $\Delta\nu = 10^{-5}\,\nu$ is easily attained, it is possible to hope for the creation of an instrument with a resolving power of about 10^5 and higher.

Thus experiments with cyclotron resonance on ion beams may prove to be useful in measuring nuclear masses. Such an experiment is easier to carry out for light elements.

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[2] Dresselhaus, Kip and Kittel, Phys. Rev. 92, 827, (1953).

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[6] Dresselhaus, Kip and Kittel, Phys. Rev. 98, 368 (1955).

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[8] Hipple, Sommer and Thomas, Phys. Rev. 76, 1877 (1949).

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Scattering Lengths of Slow Neutrons on Deuterons

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THE scattering of slow neutrons on free deuterons is completely specified by the two scattering lengths a_4 and a_2 that are associated with the two possible spin states of the system composed of two neutrons and one proton. From the experimental values of the total and coherent scattering cross sections for neutrons on deuterons it is possible to establish[1,2] that a_4 and a_2 are given by either α) $a_4 = 6.2 \times 10^{-13}$ cm and $a_2 = 0.8 \times 10^{-13}$ cm or β) $a_4 = 2.4 \times 10^{-13}$ cm and $a_2 = 8.3 \times 10^{-13}$ cm. Since the choice between these two possibilities cannot be made without experiments with polarized particles, it has to be based on theory. The theoretical solution of the problem of scattering in a three-body system has been carried out only under considerable simplifications. According to the theoretical work of some[3,4] one had to give a preference to the values β because according to theory $a_2 > a_4$. Others[5,6] obtained the opposite inequality $a_2 < a_4$, and one had to consider the values α as being the correct ones.

In the present note qualitative considerations in favor of the values α are pointed out.

The potential energy of the system composed of two neutrons and one proton depends only upon three "internal" coordinates, for which one may choose the distances ξ and η of the two neutrons from the proton and the cosine μ of the angle between them. The wave function of the S-states of such a system will depend only on the internal variables ξ, η, and μ and on the spin variables σ_1, σ_2 and σ_3 of all three particles. In particular, the wave function of the quartet state may be represented in the form

$$\Psi^{(s)}_{3/2\,M} = \varphi_{3/2}(\xi, \eta, \mu)\,\chi_{3/2\,M}(\sigma_1, \sigma_2, \sigma_3),$$
$$M = \pm 1/2, \pm 3/2,$$

where $\chi_{3/2\,M}$ is the spin wave function symmetric in an interchange of the spin coordinates of any pair of particles. Because of the identity of the