erators. This effect is due to the fact that the electric dipole moment for the transition in the case of cyclotron resonance exceeds approximately by a factor of 10^6 the magnetic moment of the electron, and by a factor of 10^4 the electric dipole moment of the molecule.

An important advantage of cyclotron resonance in comparison with paramagnetic resonance is the possibility of generating microwaves of shorter wavelengths, in the millimeter and the submillimeter ranges, since the low values for the effective mass of the carriers compared to the electron rest mass m_0 allow us to use lower magnetic fields. Thus, for example, in Ge $m_h^* \approx 0.04\,m_0$, and at a frequency of 1×10^{12} cps, the resonance value of the magnetic field is approximately 1.4×10^4 Oe instead of the 3.5×10^5 Oe in paramagnetic resonance.

If the anharmonicity of cyclotron oscillations of the carriers is not strongly pronounced or is completely absent, it is possible to achieve amplification or frequency conversion of the oscillations by the following method. A linearly polarized electromagnetic wave of frequency $\omega_p = 2\omega_c/n$, in which the vector $\mathbf{H}_p$ is oriented parallel to the constant field while its amplitude is somewhat less than H_0, is incident on a semiconductor sample situated in the constant magnetic field H_0. Such a system is potentially unstable with respect to the high-frequency signal of cyclotron frequency polarized in the plane perpendicular to the constant magnetic field. Parametric amplification or generation of high frequency oscillations is possible at this frequency. The power of the "pumping" signal depends on the value of m^*. In the case $\omega_c = 2\pi \times 3 \times 10^9$ cycles/sec and $m^* \approx 0.01\,m_0$ (for example, in the case of InSb) the resonance value of the magnetic field is given by $H_0 \approx 10$ Oe and $P_p \approx 10^4/Q_p$ watts.

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

[2] Dexter, Zeiger, and Lax, Phys. Rev. **104**, 637 (1956).

[3] Zeiger, Lax, and Dexter, Phys. Rev. **105**, 495 (1957).

[4] N. G. Basov and A. M. Prokhorov, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 431 (1954).

[5] Dresselhaus, Kip, and Kittel, Phys. Rev. **98**, 556 (1955).

Translated by G. Volkoff
168

SEVERAL POSSIBILITIES ASSOCIATED WITH THE SEPARATION OF CHARGED PARTICLES IN AN INHOMOGENEOUS HIGH-FREQUENCY ELECTROMAGNETIC FIELD

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THE nonrelativistic motion of charged particles in an inhomogeneous electromagnetic field $\mathbf{E}(\mathbf{r})e^{i\omega t}$, $\mathbf{H}(\mathbf{r})e^{i\omega t}$ has been investigated,[1-5] and it was shown that by means of high-frequency potential wells

$$\Phi(\mathbf{r}) = (\eta/2\omega)^2 |\mathbf{E}(\mathbf{r})|^2$$

(η is the ratio of charge to mass) it is possible to control within wide limits the average (over the period $2\pi/\omega$) motion of the particles: reflection from potential barriers, focusing of beams, acceleration of plasma blobs, confinement in a bounded region of space, and so forth. The field, however, had been considered as given, i.e., the reaction of the motion of the particles upon the magnitude and shape of the potential $\Phi(\mathbf{r})$ had been ignored, which is permissible only for low charge densities and if the particles do not leave the interaction region. Taking into account the finite charge density leads to the introduction of the effective dielectric constant of the region occupied by charges, which can markedly change the structure[6] of the potential $\Phi(\mathbf{r})$. Sometimes the second factor is also important; associated with it are a series of interesting new possibilities which are illustrated below on a simple example of sufficient generality.

Let a rectilinear beam of particles move with velocity $z = v_0$ into the side of a potential $\Phi(z)$, monotonically increasing from zero and produced by an inhomogeneous high-frequency field. If the period $2\pi/\omega$ of this field is much less than the particle transit time over a distance $L \sim E/|\nabla E|$, along which the amplitude of E changes substantially, then the kinetic energy of a particle, being composed of the energy of the average (over the period $2\pi/\omega$) motion and of the average energy of the oscillatory motion (of frequency ω), remain constant.[1,2] Consequently the particles advance only up to the plane $z = z_0$, such that $\Phi(z_0) = v_0^2/2$, whereupon in the turning point of the beam the energy of forward motion is completely transformed into energy of oscillatory motion: $|\dot{r}_1|^2/4 = \Phi(z)$, $\dot{r}_1 = -(\eta/\omega^2)Ee^{i\omega t}$. Now we assume that the particles leave the interaction region when the total velocity vanishes $[\dot{z}(t) + \dot{r}_1(t) = 0]$ at the plane $z = z_0$. Such a separation of particles can be achieved, for example, with an arrangement of conducting walls at a distance $r_{1\,max} = |\eta E(\dot{r}_0)|/\omega^2$ from the average trajectory of the beam. Then the kinetic energy of the particles is returned completely to the field. Moreover, if the system forming the high-frequency field is tuned to resonance and has a high Q, then, as is not difficult to show,[7] a stable oscillatory regime is always attained for a specific choice of the parameters.

Thus it appears to be possible to use the separation of particles for maintaining a given level of high-frequency power in a system. For instance, in containing a plasma blob in a high-frequency potential well inside a resonant cavity, the separation of fast particles at the walls can ensure the required level of high-frequency field for confining the slower particles, if the plasma temperature is kept constant (i.e. if the plasma is heated by some external source). For these purposes it is also possible to introduce an auxiliary beam of particles, i.e., to combine within a single cavity a source of high-frequency oscillations and a confined plasma blob. A similar combination might prove to be useful for several types of the accelerators that employ a high-frequency electromagnetic field to transfer energy from one beam to another.

The separation of particles interacting with an inhomogeneous field also has a quite independent importance as one of the possible methods of generating and amplifying microwaves.

[1] M. A. Miller, Report at the Second Conference MVO on Radioelectronics, Saratov, 1957; Изв. высших учебных заведений, Радиофизика (News of Higher Educational Institutions, Radiophysics) No. 3, 1958 (in press).

[2] A. V. Gaponov and M. A. Miller, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 242 (1958), Soviet Phys. JETP **7**, 168 (1958).

[3] H. A. H. Boot and R. B. R.-S.-Harvie, Nature **180**, 1187 (1957).

[4] M. A. Miller, Dokl. Akad. Nauk SSSR **119**, 478 (1958), Soviet Phys. "Doklady" **3**, 322 (1958); J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 299 (1958), Soviet Phys. JETP **8**, 206 (1959).

[5] A. V. Gaponov and M. A. Miller, J. Exptl. Theoret. Phys. **34**, 751 (1958), Soviet Phys. JETP **7**, 515 (1958).

[6] F. B. Knox, Austral. J. Phys. **10**, 565 (1957).

[7] M. A. Miller, Изв. высших учебных заведений, Радиофизика (News of the Higher Educational Institutions, Radiophysics) No. 4, 1958 (in press).

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169

CIRCULAR POLARIZATION OF INTERNAL γ-BREMSSTRAHLUNG IN β-DECAY AND TIME REVERSAL INVARIANCE

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THE continuous γ-radiation which accompanies β-decay is of current interest in connection with parity nonconservation in weak interactions. A number of authors[1-3] have indicated that instead of observing the electron polarization it may be possible to observe the circular polarization of the γ-photons. The experiments which have been carried out[4] verify parity nonconservation in weak interactions.

In the present note, we present a theoretical analysis of the bremsstrahlung effect in β-decay in connection with the problem of invariance under time reversal.

A pseudoscalar with respect to time reversal can be formed from the electron momentum, the photon momentum, and the neutrino momentum (using the recoil of the nucleus) or from the electron momentum, the photon momentum and the angular momentum of the nucleus. In the first case we obtain the following