electron in a magnetic field executes a finite motion (its trajectory in momentum space being a closed curve), whereas in crossed fields it executes an infinite one, since the trajectory (2) is an open curve.

The explicit dependence of the period on the electric field can be obtained only for a definite law of dispersion. However, if $E/H \ll 1$, it is possible to obtain the result

$$T^* \approx T\left\{1 - (cv_0/eHT)\oint v_\perp^{-2}\,dl\,(\mathbf{n} + \mathbf{p}/R)\right\}. \qquad (6)$$

Here T is the period of revolution in a magnetic field, $\mathbf{n} = \mathbf{v}_\perp/|\mathbf{v}_\perp|$ is the normal to the trajectory of the electron in a magnetic field, and R is the radius of curvature of the trajectory. The integration extends over the trajectory in a magnetic field. Thus $\Delta T/T \sim (c/v)(E/H)$.

Once we know the frequency of revolution of the electron $(\omega^* = 2\pi/T^*)$, it is easy to write down the distance between quantum energy levels in the classical approximation:[4,5]

$$\Delta\varepsilon^* = \hbar\omega^* = 2\pi|e|\hbar H/c\,(\partial S^*/\partial\varepsilon^*).$$

In connection with the dependence of the frequency of revolution of an electron in crossed fields on the size of the electric field, an interesting peculiarity should apparently occur in diamagnetic resonance in those semiconductors in which the dependence of the energy of the current carriers on the quasimomentum is appreciably nonquadratic: the resonance frequency should depend on the electric current passed through the specimen.

A nonquadratic dependence of the energy on the components of the quasi-momentum occurs not infrequently near the edge of the conduction band. Often it is a consequence of the crystal symmetry. Here the quadratic dependence on the magnitude of the momentum is retained near the edge of the band, but the angular dependence becomes complicated. Thus the energy spectrum of "holes" in Ge and Si crystals has the form[6]

$$\varepsilon = Ap^2 \pm [B^2p^4 + C^2\,(p_x^2p_y^2 + p_x^2p_z^2 + p_y^2p_z^2)]^{1/2},$$

where A, B, and C are constants.

To observe such effects in metals is in all probability impossible, since in a metal (in consequence of the large electrical conductivity) it is impossible to produce any appreciable electric field. To estimate the order of magnitude of the effect, we must start from formula (6), remembering however that the resonance frequencies are determined not by all the electrons but by those that have extremal effective masses.[7] It can be shown that for these electrons no effect linear in the electric field is present because of the symmetry of the trajectory. Therefore, apparently, $\Delta\omega/\omega \sim (c/v)^2(E/H)^2$.

*We have in mind the mean velocity in a plane perpendicular to the magnetic field.

†Except for an unimportant constant, ε* coincides with the total energy of the particle.

[1] L. D. Landau and E. M. Lifshitz, Теория поля (Field Theory), Gostekhizdat, 1948 [Transl: Addison-Wesley, 1951].

[2] Lifshitz, Azbel', and Kaganov, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 63 (1956), Soviet Phys. JETP **4**, 41 (1957).

[3] W. Shockley, Phys. Rev. **79**, 191 (1950).

[4] I. M. Lifshitz, Report at a session of the physics-mathematics section, Academy of Sciences, Ukr. S.S.R., 1951; I. M. Lifshitz and A. M. Kosevich, J. Exptl. Theoret. Phys. (U.S.S.R.) **29**, 730 (1955), Soviet Phys. JETP **2**, 636 (1956).

[5] L. Onsager, Phil. Mag. **43**, 1006 (1952).

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

[7] M. Ya. Azbel' and É. A. Kaner, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 896 (1957), Soviet Phys. JETP **5**, 730 (1957).

Translated by W. F. Brown, Jr.
100

IDENTIFICATION OF PARTICLES IN HIGH ENERGY STARS

G. I. KOPYLOV

Joint Institute for Nuclear Research

Submitted to JETP editor April 17, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 557-558 (August, 1959)

THE identification of particles in high energy stars* is often made by comparing the measurements of the momentum p_1 of one of the particles with its possible limiting values under predetermined assumptions about the mass and the number of remaining particles 2, 3, ... , n. These last are united into one composite particle having some effective mass m_{eff}. The formula for the momentum of particle 1 at an angle of observation θ_1 under the assumption that the other particle has a mass m_{eff} gives the limiting possible values of the momentum of particle 1.[1,2,3] Ordinarily the value $\overline{m} = m_2 + m_3 + \ldots + m_n$ is taken for m_{eff}, a result which considers the velocities of particles $2, 3, \ldots, n$ to be equal in magnitude and direction.[2]

We shall show that the solution for the bounds $p_{1\,max}$, $p_{1\,min}$ of the momentum p_1 of particle 1 can be restricted if one takes into account the angles θ_{ij} between the other charged particles i and j $(i, j = 2, 3, \ldots, n')$ and if the lower limit $\tilde{p}_i$ of their momenta p_i is estimated.

An attempt has been made earlier[4] to take into account information about the angles and momenta of the particles for purposes of identification. Unlike reference 4, the present work includes this information directly in m_{eff}. In this way only knowledge of the lower bounds of the momenta is required (in reference 4, knowledge of the values of p_i themselves is required, which is difficult for large p_i and leads to an indeterminacy in the limiting values for p_1).

To deduce a necessary formula, we note that the equation for the momentum p_1 (or energy E_1) of one of the secondary particles having the total energy E and momentum P coincides with the equation for p_1 in the decay of a particle with energy E and momentum P into two particles with masses m_1 and m_{eff}, if we take

$$m_{eff}^2 = (E_2 + \ldots + E_n)^2 - (\mathbf{p}_2 + \ldots + \mathbf{p}_n)^2. \quad (1)$$

It is easy to show that the roots of the equation above for p_1 have the characteristic

$$dp_{1max}/dm_{eff} < 0, \; dp_{1min}/dm_{eff} \geqslant 0.$$

This means that increasing the estimate for m_{eff} shrinks the region of solutions for the value p_1.

To increase this estimate, we write (1) as three positive terms

$$m_{eff}^2 \equiv \sum_{i=2}^{n} m_i^2 + 2\sum_{i<j}^{n} (E_iE_j - p_ip_j) + 2\sum_{i<j}^{n} p_ip_j(1 - \cos\vartheta_{ij}). \quad (2)$$

Taking into account $E_iE_j - p_ip_j \geq m_im_j$ and $p_i > \tilde{p}_i$ (where $\tilde{p}_i$ is the lower bound of p_i),† we immediately get the following estimate:

$$m_{eff}^2 \geqslant \tilde{m}^2 \equiv \overline{m}^2 + \Delta^2 \equiv \overline{m}^2 + 2\sum_{2\leqslant i<j}^{n'} \tilde{p}_i\tilde{p}_j(1 - \cos\vartheta_{ij}). \quad (3)$$

Here the sum is carried out over all pairs of charged particles, except particle 1. The masses of the neutral particles are included in $\overline{m}$.

Thus, if we take $\tilde{m}$ instead of $\overline{m}$ for the value of m_{eff}, p_{1min} and p_{1max} come closer and closer together as $\tilde{p}_i$ increases and θ_{ij} becomes larger. For narrow beams of secondary particles the use of formula (3) gives no effect.

If for some particles i and j not only $\tilde{p}$ but also p is known, $\tilde{p}$ can be changed to p in the equations and the term $E_iE_j - p_ip_j - m_im_j$ can be added. This makes $p_{1\,max}$ and $p_{1\,min}$ converge even more.

The most probable contribution from neutral particles to m_{eff} can be taken into account by adding to Δ^2 the term $\frac{1}{2}n'(\frac{1}{2}n' - 1)\overline{p^2}(1 - \cos\overline{\theta})$, where $\overline{p}$ and $\overline{\theta}$ are the average values of p_i and θ_{ij} in the given interaction.

The results of this work are given in more detail in reference 5.

The author takes this opportunity to thank I. M. Gramenitskiĭ and M. I. Podgoretskiĭ for their valuable comments.

*We consider high energy stars to be those in which there are tracks of relativistic particles.

†For gray tracks, for example, one can take $\tilde{p}_i = m_i$; for neutral particles, $\tilde{p}_i = 0$ is taken.

[1] I. L. Rozental', Usp. Fiz. Nauk **54**, 405 (1954).

[2] R. M. Sternheimer, Phys. Rev. **93**, 642 (1954).

[3] G. I. Kopylov, "On Estimating the Number of Secondary Particles Near Limiting Angles," preprint, Joint Inst. Nuc. Res. R-166 (1958).

[4] Birger, Grigorrov, Guseva, Zhdanov, Slavatinskiĭ, and Stashkov, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 971 (1956), Soviet Phys. JETP **4**, 872 (1957).

[5] G. I. Kopylov, preprint, Joint Inst. Nuc. Res., R-341 (1959).

Translated by William Ramsay
101

NOTE ON A BARYON SCHEME

H. OIGLANE

Institute of Physics and Astronomy, Academy of Sciences, Estonian S.S.R.

Submitted to JETP editor April 16, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 558-559 (August, 1959)

LET us assume that each of the eight known baryons is described by a four-component wave function. The general equation for all the baryons is in this case an equation for a 32-component spinor. A 32-dimensional spinor space can be treated as a rep-