energy. The upper curves a′ and a correspond to the calculations by Bhabha[5] as corrected by Block, King, and Wada[4] for the cases of no screening (a′) and complete screening (a). The two lower curves b′ and b (b′ — no screening, b — complete screening) were calculated by us from the results of Murota, Ueda, and Tanaka,[6] whose calculation is more exact than Bhabha's.

As can be seen from the figure, the totality of the experimental results on the determination of λ for an energy interval of primary electrons 1 — 100 Bev is in satisfactory agreement with the theory of Murota et al. A certain disagreement between experiment and the predictions of the above mentioned theory for electrons in the energy interval 0.1 — 1 Bev is apparently due to an illegitimate extrapolation into the indicated energy region of the correction calculated by Koshiba and Kaplon[7] for the number of false tridents, which should lead to a substantial underestimate of the true number of tridents.

Thus the experimental results on the determination of the cross section for direct electron-positron pair production by electrons should apparently be considered as being in agreement with the predictions of quantum electrodynamics up to 100 Bev energies for the primary electrons.

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*These events were found by A. A. Varfolomeev's group.

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CYCLOTRON ABSORPTION OF ELECTROMAGNETIC WAVES IN A PLASMA

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THE propagation of electromagnetic waves in a magnetoactive plasma at frequencies ω, close to $m\omega_H^{e,i}$ (m = 1, 2, ... ; where ω_H^e is the gyromagnetic frequency of the electron and ω_H^i is the gyromagnetic frequency of the ion) is characterized by strong absorption; this absorption is due to the thermal motion of the electrons and ions (cyclotron absorption)[1-5] and is of interest in connection with problems of microwave diagnostics and radiofrequency heating of plasmas.

The damping of waves characterized by $\omega \approx m\omega_H^e$, m = 2, 3, ... , is especially pronounced in the case of a double resonance, i.e., when $m\omega_H \approx \omega_+$, where ω_+ is the frequency given by the condition

$$A = 1 - u_e - v_e + u_e v_e \cos^2\theta = 0,$$

$$u_e = (\omega_H^e/\omega)^2, \quad v_e = (\Omega_e/\omega)^2,$$

Ω_e is the electron Langmuir frequency, and θ is the angle between the direction of propagation of the wave and the direction of the magnetic field. As is well known,[2,6] when $\omega \approx \omega_+$ the index of refraction for the extraordinary wave n_2 become very large and a plasma wave can appear. When $\omega \approx m\omega_H^e \approx \omega_+$ and m = 3, 4 the complex indices of refraction for these waves, determined from the dispersion equation which has been reported earlier,[2] are

$$n' = n_{2,3} + i\varkappa_{2,3},$$

where

$$n_{2,3}^2 = \{-A_0 \pm (A_0^2 - 4\beta_e^2 B_0 A_1)^{1/2}\} / 2\beta_e^2 A_1 \gg 1,$$

$$\varkappa_{2,3} = \sigma_m^e \sin^2\theta\,(1 - u_e)\, n_{2,3}^3 (2B_0 + A_0 n_{2,3}^2)^{-1},$$

$$B_0 = (2 - v_e)\, u_e - 2(1 - v_e)^2 - u_e v_e \cos^2\theta,$$

$$A_1 = -v_e \{3\cos^4\theta\,(1 - u_e) + \cos^2\theta \sin^2\theta\,(6 - 3u_e + u_e^2) \times (1 - u_e)^{-2} + 3\sin^4\theta\,(1 - 4u_e)^{-1}\},$$

$$\sigma_m^e = \frac{\sqrt{\pi}\, m^{2m-2} \sin^{2m-2}\theta\,\Omega_e^2}{2^{m+3/2} m! \cos\theta\,\omega_H^{e2}} (\beta_e n_{2,3})^{2m-3} \exp(-z_m^{e2}),$$

$$z_m^e = (1 - m\omega_H^e/\omega)(\sqrt{2}\,\beta_e n_{2,3} \cos\theta)^{-1}, \qquad \beta_e = (T_e/m_e c^2)^{1/2}, \tag{1}$$

T_e is the temperature of the electron gas and m_e is the mass of the electron. If, however, $\omega \approx 2\omega_H^e \approx \omega_+$,

$\mathrm{Re}\, n' \sim \mathrm{Im}\, n' \sim \beta_e^{-1/3}$ for $|1 - 2\omega_H^e/\omega| \lesssim \beta_e^{2/3}$, $|A_0|^3 \lesssim \beta_e^2$.

We now consider cases of ion cyclotron resonance. If $\omega \approx \omega_H^i$, the indices of refraction for the ordinary and extraordinary waves (when $\beta_i c \ll V_A \ll c$) are given by the expressions

$$n_1^2 = N_+^2 = \frac{1+\cos^2\theta}{\cos^2\theta}\,\frac{c^2/V_A^2}{u_i - 1}, \quad n_2^2 = N_-^2 = \frac{c^2/V_A^2}{1+\cos^2\theta}, \tag{2}$$

where $c^2/V_A^2 = (\Omega_i/\omega_H^i)^2$ (the subscript i used in the quantity f_i denotes the quantity f_e with the electron mass replaced by the ion mass m_i and the temperature of electron gas replaced by the ion temperature T_i). The expression for n_1 given in (2) applies when $|1 - \omega_H^i/\omega| \gg \beta_i N_+ \cos\theta$; in this case the cyclotron damping of the ordinary wave is exponentially small. When $|1 - \omega_H^i/\omega| \ll \beta_i N_+ \cos\theta$ however, this wave is highly damped:

$$n_1' = n_1 + i\varkappa_1 = \frac{\sqrt{3}+i}{2}\left\{\sqrt{\frac{\pi}{8}}\,\frac{c^2(1+\cos^2\theta)}{V_A^2\beta_i\cos^3\theta}\right\}^{1/3}. \tag{3}$$

The extraordinary wave also experiences cyclotron absorption:

$$\varkappa_2 = \beta_i N_-^2 \cos\theta \sin^4\theta \exp(-z_1^{i2}) / \sqrt{8\pi}\,|w(z_1^i)|^2 (1+\cos^2\theta)^2, \tag{4}$$

where

$$z_1^i = (1 - \omega_H^i/\omega)(\sqrt{2}\beta_i N_- \cos\theta)^{-1},$$

$$w(z) = e^{-z^2}\left(1 + \frac{2i}{\sqrt{\pi}}\int_0^z e^{t^2}dt\right).$$

The extraordinary wave is weakly damped: $\kappa_2 \ll N_-$ since $\beta_i N_- \ll 1$. When $\beta_i c \sim V_A$ propagation of both waves is impossible because of the strong damping: $n_{1,2} \sim \kappa_{1,2} \sim 1/\beta_i$ if $\omega \sim \omega_H^i$.

In the case of multiple resonances

$$\omega \approx m\omega_H^i, \qquad m = 2, 3, \ldots, \qquad n_{1,2}' = N_\pm + i\varkappa_{1,2},$$

where

$$N_\pm^2 = \{\varepsilon_{11}(1+\cos^2\theta) \mp [\varepsilon_{11}^2(1+\cos^2\theta)^2 - 4\cos^2\theta(\varepsilon_{11}^2 + \varepsilon_{12}^2)]^{1/2}\} / 2\cos^2\theta, \tag{5}$$

$$\varkappa_{1,2} = \sigma_m^i N_\pm \{(1+\cos^2\theta)N_\pm^2 - 2\varepsilon_{11} - 2i\varepsilon_{12}\}\{2\cos^2\theta N_\pm^4 - \varepsilon_{11}(1+\cos^2\theta)N_\pm^2\}^{-1}, \tag{6}$$

$$\sigma_m^i = \frac{\sqrt{\pi}\, m^{2m-2}\sin^{2m-2}\theta c^2}{2^{m+1/2} m!\cos\theta V_A^2}(\beta_i N_\pm)^{2m-3}\exp(-z_m^{i2}),$$

$$z_m^i = (1 - m\omega_H^i/\omega)(\sqrt{2}\beta_i N_\pm \cos\theta)^{-1}, \quad \varepsilon_{11} = 1 - v_i/(1-u_i),$$

$$\varepsilon_{12} = -iv_i/\sqrt{u_i}(1-u_i).$$

If $|z_m^i| \lesssim 1$, then $\kappa_{1,2}/N_\pm \sim (\beta_i N_\pm)^{2m-3}$.

Waves characterized by frequencies $\omega \sim \omega_H^i$ (ω not necessarily close to $m\omega_H^i$) are also damped as a consequence of absorption in the electron gas (Landau damping). The refractive indices for these waves are given by Eq. (5) and the damping coefficients are

$$\varkappa_{2,3}/N_\pm = \mathrm{Im}\left\{\frac{1}{\varepsilon_{33}}[\varepsilon_{11}\sin^2\theta N_\pm^4 + (2\varepsilon_{12}\varepsilon_{23}\cos\theta\sin\theta - \varepsilon_{23}^2\cos^2\theta - (\varepsilon_{11}^2 + \varepsilon_{12}^2)\sin^2\theta)N_\pm^2 + \varepsilon_{11}\varepsilon_{23}^2] + \varepsilon_{22}'(\varepsilon_{11} - \cos^2\theta N_\pm^2)\right\} \times \{2\varepsilon_{11}(1+\cos^2\theta)N_\pm^2 - 4\cos^2\theta N_\pm^4\}^{-1}, \tag{7}$$

where

$$\varepsilon_{23} = -i\tan\theta v_i(1 + i\sqrt{\pi}z_0^e w(z_0^e))/\sqrt{u_i},$$

$$\varepsilon_{22}' = i2\sqrt{\pi}(m_e/m_i)\sin^2\theta v_i z_0^e w(z_0^e)\beta_e^2 N_\pm^2/u_i,$$

$$\varepsilon_{33} = (2m_i/m_e)v_i(z_0^e)^2(1 + i\sqrt{\pi}z_0^e w(z_0^e)),$$

$$z_0^e = (\sqrt{2}\beta_e N_\pm\cos\theta)^{-1}.$$

The damping (7) is small; $\kappa_{2,3} \ll N_\pm$. Even if $|z_0^e| \lesssim 1$, i.e., $V_A \sim \beta_e c$, we find $\kappa_{2,3}/N_\pm \sim m_e/m_i$.

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CURVES FOR THE PHOTOPROTON YIELD FROM THE C^{12} *NUCLEUS*

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A previously described[1] scintillation telescope was used to investigate the depencence of the photo-