discussed here. The values of the form factors A_n do not depend on the medium.

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IS THE EQUALITY OF THE ELECTRIC AND MAGNETIC PROTON FORM FACTORS EXACT?

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It is known that the experimentally determined proton form factors satisfy the following rule [1]:

$$G_E^p(q^2) = G_M^p(q^2) / \mu_p. \quad (1)$$

This equality is accurate to 2 - 3%. So good an agreement between the electric and magnetic form factors is quite surprising.* It is therefore of interest to assume that for some unknown reason relation (1) is exact for arbitrary q^2, and consider the experimental consequences that ensure from this assumption. We shall show below that the experimental data on $\bar{p}p$ annihilation at rest agree with this assumption.

1. If the vertex part describing the interaction between a proton and a γ quantum is written in the form $F_1(q^2)\gamma_\mu + F_2(q^2)\sigma_{\mu\nu}q_\nu/2M$ (M = proton mass), then the form factors G_E and G_M are connected with F_1 and F_2 as follows:

$$G_M = F_1 + F_2, \; G_E = (F_1 + F_2)q^2/4M^2,$$

i.e., $G_M(4M^2) = G_E(4M^2)$. It then follows from (1) that

$$G_M(4M^2) = G_E(4M^2) = 0.$$

(Using the unitarity condition, we can show that as $q^2 \to 4M^2$ these form factors should tend to zero like $q^2 - 4M^2$ or faster.) This leads to the following behavior of the cross sections of the processes $\bar{p}p \to e^+e^-$, $\mu^+\mu^-$, and $e^+e^- \to \bar{p}p$: they are equal to zero when $q^2 = 4M^2$, increase, and then begin to drop again (at large q^2 the form factors tend to zero). If we assume that $|F_i(4M^2)| \approx |F_i(-4M^2)|$, then we can estimate the position of the maximum in these cross sections. It appears when $q \approx 5.5 - 6.0$. To observe the growth of these cross sections it is necessary to increase the accuracy by one and one-half orders of magnitude compared with that obtainable at present [1].

2. Equation (1) leads to relations between certain amplitudes of the proton annihilation process and the proton-antiproton annihilation process. Let us consider, for example, the $\bar{p}p \to 2\pi$ transition amplitude in the state $J^P = 1^-$, the form of which is $(f_1\gamma_\mu + f_2\sigma_{\mu\nu}q_\nu/2M)(k_1 - k_2)_\mu$ (where k_i are the pion momenta). The functions $f_1(q^2)$ and $f_2(q^2)$ enter

into the expression for the imaginary parts F_1 and F_2 when $4\mu^2 < q^2 < 9\mu^2$ (μ is the pion mass):

$$\mathrm{Im} F_i(q^2) = (q^2 - 4\mu^2)^{3/2} f^*_{2\pi}(q^2) f_i(q^2)$$

($f_{2\pi}(q^2)$ is the $\pi\pi\gamma$ vertex part). It follows therefore that f_1 and f_2 are connected by the same relations as F_1 and F_2:

$$[f_1(q^2) + f_2(q^2)]/[f_1(q^2) + f_2(q^2) q^2/4M^2] = \mu_p. \tag{2}$$

This equality is satified not only in the region $4\mu^2 < q^2 < 9\mu^2$ but also by virtue of the analyticity of $f_1(q^2)$ and $f_2(q^2)$ for arbitrary q^2, particularly when $q^2 \geq 4M^2$. An important factor in the derivation of (2) is that the $\pi\pi\gamma$ vertex is expressed only in terms of one form factor, which has dropped out of this equation. If the $\pi\pi\gamma$ vertex were to be expressed in terms of several form factors, then the relation obtained with $q^2 > 9\mu^2$ would contain these form factors on the second (unphysical) sheet connected with the cut drawn from the point $q^2 = 4\mu^2$.

Equations of exactly the same kind as for the amplitude of the $p\bar{p} \to 2\pi$ transition hold also for the amplitudes of the transitions $p\bar{p} \to k\bar{k}$, $\pi\omega$, $\eta\rho$, $\pi\rho$ in the state $J^P = 1^-$ (the amplitude of $p\bar{p} \to k\bar{k}$ with $J^P = 1^-$ has the same structure as the amplitude of $p\bar{p} \to 2\pi$, and the amplitudes of $p\bar{p} \to \pi\omega$, $\eta\rho$, $\pi\rho$ have the form $\epsilon_{\mu\nu\lambda\rho} k_{1\mu} k_{2\nu} I_\lambda (f_1\gamma_\rho + f_2\sigma_\rho \xi(q\xi/2M)$, where k_1 and k_2 are the meson momenta, and I_λ is the polarization of the vector meson). It follows therefore that the amplitudes of the transitions $p\bar{p} \to 2\pi$, $k\bar{k}$, $\eta\rho$, $\pi\omega$ in the state $J^P = 1^-$ are equal to zero at the point $q^2 = 4M^2$. This agrees with the available experimental data on $p\bar{p}$ annihilation at rest. The transitions $p\bar{p} \to 2\pi$, $k\bar{k}$, $\eta\rho$, $\pi\omega$ are possible only from the state $J^P = 1^-$, and the transition $p\bar{p} \to \pi\rho$ is possible both from the 1^- state and from 0^-. Therefore the transitions $p\bar{p} \to 2\pi$, kk, $\eta\rho$, $\pi\omega$ should be suppressed compared with the transition $p\bar{p} \to \pi\rho$.**

The experimental data are as follows [4]: the transitions $p\bar{p} \to 2\pi$, $k\bar{k}$, $\eta\rho$ constitute 0.3, 0.2, and 0.2% of the total number of annihilations, respectively (the $p\bar{p} \to \pi\omega$ transition was not observed), and the transition $p\bar{p} \to \pi\rho$ is larger by one order of magnitude and amounts to 4.3%.

At higher energies (when $q^2 \geq 6$ GeV^2) there are no special reasons for the suppression of the reactions $p\bar{p} \to 2\pi$, $k\bar{k}$, $\eta\rho$, $\omega\pi$ and therefore the cross sections of these reactions should in general be of the same order as the cross section of the process $p\bar{p} \to \pi\rho$. At present there are only upper-bound estimates of the cross sections of some of these reactions at high energies.

3. Besides (1) there exist also experimental relations for the neutron form factors

$$\text{a) } G_E^n(q^2) = 0, \quad \text{б) } G_M^n(q^2)/\mu_n = G_E^p(q^2), \tag{3}$$

which have been verified in the interval $-q^2 < 1.5$ GeV^2 with much lower accuracy than (1). It should be noted that simultaneous satisfaction of (1) and (3b) in the entire region of q^2 is apparently unattainable. The reason is that the form factors G^n and G^p have different isotropic structures, and, in particular, they are different in different isotopic states when $q^2 > 0$. It is seen from these considerations that (3a) cannot be satisfied exactly in the entire range of q^2, if only the contributions from the singularities which do not coincide in states with zero and unity isospin do not vanish.

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* The equality (1) was obtained theoretically in a number of papers (see [2]). It should be noted, however, that it is satisfied experimentally with an accuracy higher than expected from these models.

** Considerations based on the simple quark model and leading to the suppression of two-meson ionization pertain to an equal degree to the suppression of annihilation in the pair $p\bar{p} \rightarrow \pi\rho$ [3].

CYCLOTRON INSTABILITY OF MONOENERGETIC IONS IN A CURVILINEAR MAGNETIC FIELD

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It is known that instabilities with characteristic frequency on the order of or higher than the ion cyclotron frequency can develop in a plasma with monoenergetic ions (see [1], and also the review [2] and the literature cited there). As a rule, these instabilities are analyzed in an approximation where a homogeneous magnetic field is assumed.

We shall show in this paper that allowance for the curvature of the magnetic field leads to one more version of cyclotron instability in a plasma with monoenergetic ions. This instability develops near the ion cyclotron frequency and its harmonics, and is remarkable in that it can exist at parameters for which other types of cyclotron instability are impossible.

To take into account the curvature of the magnetic field, let us consider the model of a helical field with cylindrical symmetry with zero shear. Assuming the oscillations to be small-scale compared with the dimension of the plasma instability, we obtain in the well-known manner (see [3]) the following dispersion equation