current in the electron beam $I \simeq 10$ kA.

The electron pressure under such conditions will act on a layer of thickness $\simeq 0.3$ cm surrounding the target.

We note finally that the Rosseland free path of the equilibrium quanta in the volume considered by us corresponds to $\ell = 10^{-6}$ cm even at $T \sim 15$ eV; the free path of electrons of energy 30 - 50 eV is of the order of 10^{-5} cm. Therefore the effective process of radiative recombination is possible on the surface of the volume and does not play an important role in the balance of the ionization of the target atoms by the electron beam. The radiation power from the surface of the target is negligibly small compared with the power of the electron beam. For the same reason, a negligible role is played by triple recombinations resulting in the formation of high-energy electrons capable of again ionizing the atoms of the substance.

One of the possibilities of using the high pressure produced in a solid by an electron beam, from our point of view, is that of obtaining metallic hydrogen. According to contemporary theoretical notions [1], molecular hydrogen goes over at pressures on the order of $\sim 10^6$ bar into a new phase state, which may turn out to be metastable and have superconducting properties. The Debye temperature of superconducting hydrogen amounts, according to theoretical estimates, to $\Theta \gtrsim 0.3 - 1$, and the critical temperature is $T_c \gtrsim 90°K$. Owing to these parameters, the production of superconducting hydrogen is an enticing problem. Obviously, in order to obtain it, the working medium for producing the high pressure must be a readily-ionized material, placed in the form of a small granule in liquid hydrogen near its surface, and on which an electron beam is focused. If the temperature of the electron gas in multiple ionization of the target atom by the electron beam constitutes a small fraction of the average ionization energy, then the proposed method of obtaining metallic hydrogen may turn out to be promising. Under conditions when the ionization of the atoms occurs in a medium of a degenerate electron gas with a Fermi energy on the order of 15 - 20 eV, the formation of such a low-temperature electronic plasma seems to us quite probable. To verify this assumption, we are attempting to solve numerically the problem of determining the average thermal energy of electrons produced as a result of cascade ionization of atoms by an electron beam.

In conclusion, the authors are grateful to S. Darznik for a discussion.

[1] T. Schaider, Helv. Phys. Acta 42, 957 (1969).

ELECTROMAGNETIC CONTRIBUTIONS TO THE TOTAL CROSS SECTION OF HADRON SCATTERING

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If we extrapolate the old data on the total cross section for the scattering of hadrons in the Regge-pole model [1], then the cross section should still decrease at $E \gtrsim 30$ GeV. At the same time, the experimental [2] cross section σ^{exp} is practically constant starting with 25 - 30 GeV. With increasing energy, it deviates more and more from the extrapolation of [1], and exceeds it at 60 GeV (for π^-p and K^-p scattering) by approximately 1 mb. In addition, the data of [2] point to violation of the Pomeranchuk and Okun'-Pomeranchuk theorems, if the observed constant value is indeed the asymptotic value of the cross section.

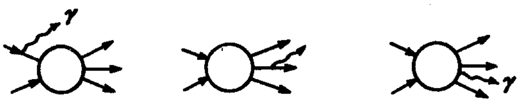

Fig. 1

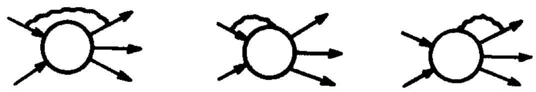

Fig. 2

These data are customarily explained as being due to rescattering in different variants of eikonal models (see, e.g., [3]). At the same time, all the theoretical analyses are devoted to purely hadronic cross sections σ^h. The measured σ^{exp}, on the other hand, receive contributions also from the electromagnetic interaction. It is usually assumed that the relative magnitude of this contribution is $\sim\alpha$, and that it can be ignored in the interpretation of contemporary experiments. We shall show below that actually these contributions can reach 1 mb (at 60 GeV). (One cannot exclude the possibility that these values differ somewhat in experiments performed by different procedures.)

An appreciable contribution to σ^{exp} is made by bremsstrahlung (Fig. 1). The main contribution is connected with the small k^2 [4] (when the momenta of the photon and one of the hadrons are almost parallel and the angular distribution of the produced hadrons is not deformed in practice):

$$\sigma_\gamma^{(1)} \approx \frac{2\alpha}{\pi}\sigma^h \ln\gamma \frac{d\omega}{\omega} \quad (\gamma = s/2m_1m_2). \tag{1}$$

At E = 60 GeV, the cross section for the emission of a photon with energy $\omega > m_\pi$ is $\sim$2 mb.

It would be incorrect, however, to obtain the purely hadronic cross sections by simply subtracting from σ^{exp} the result of the integration of (1). The correction σ_2^γ is of the same order, compensates to a considerable degree the contribution of the bramsstrahlung, and results from the interference between the purely hadronic amplitude with the diagrams of Fig. 2, which contain electromagnetic vertices. The possibility of such a compensation makes the calculation very strongly dependent on the model. In the general case

$$\sigma^\gamma = \sigma_1^\gamma + \sigma_2^\gamma = \frac{\alpha}{\pi}\sigma^h(C_2\ln^2\gamma + C_1\ln\gamma + C_0); \quad C_i \sim 1. \tag{2}$$

Corrections of this type are significant in the study of deep inelastic ep scattering (see, e.g., [5]). For hadronic cross sections, the assumption that the amplitudes decrease reapidly on going off the mass shell and with increasing |t| leads to a complete cancellation of the doubly-logarithmic terms, $C_2 = 0$ [6]. It is impossible here to say anything concerning the value of C_1. If we assume $C_2 = 0$ and $C_1 = 2$, then we get $\sigma^\gamma = 0.7$ mb for πp scattering at 60 GeV. The contributions of σ_γ for different processes (e.g., π^-p and π^-n),

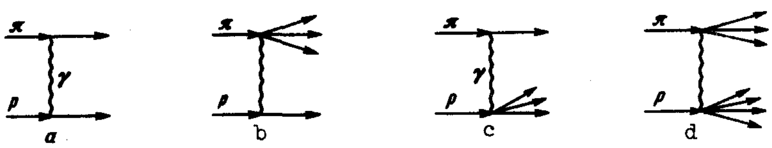

Fig. 3

are different both because of the difference in the summary charge of the produced particles, and because by virtue of (1) σ_i^{γ} contains an integral of the hadronic cross section σ^h at lower energies, where they differ quite strongly.

A second important mechanism is connected with the peripheral single-photon processes (Fig. 3). Assuming the total cross section of $\gamma\pi$ scattering to be constant and equal to the asymptotic value $\sigma_{as}^{\gamma\pi} = \sigma^{\gamma p}\sigma^{\pi p}/\sigma^{pp}$, and neglecting the magnetic contributions, we obtain for the process of Fig. 3b (the final hadrons are concentrated here in not too narrow a cone about the initial direction, and the contribution of the temporal photons are discarded):

$$\sigma_{3b} \sim \sigma_{as}^{\gamma\pi} \frac{\alpha}{\pi} \ln^2 \gamma \text{ (for } E = 60 \text{ GeV}, \sigma_{3b} \sim 0.01 \text{ mb).} \quad (3)$$

The cross sections of the remaining processes of Fig. 3 are approximately the same (for elastic scattering with allowance for the experimental limitation $|t| \geq 0.014$). The net result is $\sigma_3 \sim 0.04$ mb. Let us assume that the phase relations at small transfers are close everywhere to those holding for forward scattering at $E \sim 20$ GeV, where Re f/Im f = cot $\delta \sim 0.2$ for πp scattering. (If cot $\delta \neq 0$ owing to the contribution of Regge poles other than the pomeranchon, it should decrease like $E^{-1/2}$ and cot $\delta > 0.1$ at $E \sim 60$ GeV. We assume cot $\delta \sim 0.15$). Then the contribution made to the cross section by the interference between the purely hadronic amplitudes and the amplitudes of the processes of Fig. 3 is of the order of

$$\sigma_i \sim 2\text{ctg}\,\delta \sqrt{\sigma_{\pi p}^h \sigma_3} \sim 2\cdot 0.15\sqrt{25\cdot 0.04} = 0.3 \text{ mb} . \quad (4)$$

The quantity σ_i can be represented in the form of a sum of the isoscalar σ_i^0 and isovector σ_i^1 contributions. Apparently $\sigma_i^1 \gg \sigma_i^0$. As a result we have, say for πN scattering,

$$\sigma_{i\pm p}^{exp} = \sigma_{\pi\pm p}^h + \sigma_{\pi\pm p}^{\gamma} \pm \sigma_i^1 + \sigma_i^0; \quad \sigma_{\pi^- n}^{exp} = \sigma_{\pi^- n}^h + \sigma_{\pi^- n}^{\gamma} + \tilde{\sigma}_i. \quad (5)$$

The values of σ^{γ} increase logarithmically. They may be connected with electromagnetic corrections to the Regge trajectories, and make practically no contribution to the difference of the cross sections. However, their presence causes a logarithmic growth of the cross sections (more rapid than in different variants of the eikonal approximation), and is capable of causing the observed "break" in the total cross sections. The difference $\sigma_{\pi^- p} - \sigma_{\pi^+ p} \sim 2\sigma_i^1$ apparently decreases asymptotically, but at the contemporary energies we have $2\sigma_i^1 \sim 0.6$ mb (4). In calculating the cross section with the aid of the optical theorem, we can attempt to estimate these contributions by generalizing the Bethe formula, which takes into account both the difference of the diffraction cones for different trajectories [7] (with different signature factors) and the large contribution of the inelastic channels.

Thus, at the present time we cannot identify the cross section σ^{exp} with the purely hadronic σ^h with accuracy better than 1 mb. In the absence of a consistent generally accepted model, the separation of σ^h from σ^{exp} is impossible. It seems reasonable to us to use the following method of solving the problem: calculate the electromagnetic corrections $\sigma^i + \sigma^{\gamma}$ in different strong-interaction models, and take into account all the terms of the expansion of type (2), as well as Re f/Im f and the cross sections of the physical processes with emission of a photon (bremsstrahlung and elastic and inelastic scattering). If some universal relations appear between the corresponding coefficients, then σ^{γ} and Re f/Im f can be determined from bremsstrahlung experiments.

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[1] V. Barger, M. Olsson, and D.D. Reeder, Nucl. Phys. 5B, 411 (1968): K.A. Ter-Martirosyan, ZhETF Pis. Red. 10, 445 (1969) [JETP Lett. 10, 1285 (1969)].
[2] IHEP-CERN Collab. Phys. Lett. 30B, 500 (1969).
[3] A.N. Tavkhelidze, Rapporteur's Paper at 15th Internat. Conference on High-energy Physics, Kiev, 1970.
[4] V.N. Gribov, Yad. Fiz. 5, 399 (1967) [Sov. J. Nucl. Phys. 5, 280 (1967)].
[5] L.W. Mo and Y.S. Tsai, Rev. Mod. Phys. 41, 205 (1969).
[6] V.G. Gorshkov et al., Paper at 15th Internat. Conference on High-energy Physics, Kiev, 1970.
[7] Yu.N. Kafiev, Yad. Fiz. 12, 562 (1970) [Sov. J. Nucl. Phys. 12, 308 (1971)].