Karnaukhov, and L. A. Petrov, Proc. 23rd Conf. on Nuclear Spectroscopy and Atomic Structure, Tbilisi 1973, p. 63.
[5] A. B. Migdal, Teoriya konechnykh fermi-sistem i svoistva atomnykh yader (Theory of Finite Fermi Systems and Properties of Atomic Nuclei), Nauka, 1965.
[6] Yu. V. Gaponov and Yu. S. Lyutostanskii, Yad. Fiz. 16, 484 (1972) [Sov. J. Nuc. Phys. 16, 270 (1973)].
[7] E. F. Wigner, Phys. Rev. 51, 106 (1937).
[8] P. Franzini and L. A. Radicati, Phys. Lett. 6, 322 (1963).

ELECTROMAGNETIC CONTRIBUTIONS TO TOTAL HADRON CROSS SECTIONS AT HIGH ENERGIES

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A large electromagnetic correction ($\sim\alpha \ln^2(s/s_0)$) can appear in processes with large multiplicity. This correction may explain the observed growth of the cross sections in ISR experiments.

1. In hadron collisions, an increase in energy leads to a rapid growth of the multiplicity, $\langle n_{ch}\rangle \gtrsim a \ln s + b$. Prompt production of a large number of charged particles is accompanied by strong electromagnetic radiation.

It is know that the relative momenta of the produced hadrons are not small on the average. The electromagnetic radiation of individual hadrons is therefore incoherent in the mean. This can be verified, for example, by considering the fluctuations of the squared change of a charge moving to the right in the c.m.s. In sum, the cross section of the accompanying radiation increases in the principal approximation in proportion to $\langle n_{ch}\rangle$. A simple calculation by means of the usual formulas (see, e.g., [1]) yields [2]

$$d\sigma_\gamma = \frac{\alpha}{2\pi}\frac{dk_\perp^2}{k_\perp^2}\frac{d\omega}{\omega}\langle n_{ch}\rangle\sigma_{tot}. \tag{1}$$

Here ω and $k_\perp$ are the frequency and transverse momentum of the photon.

Allowance for the correlations, if their radius is finite, does not change the principal conclusion that $d\sigma_\gamma$ is proportional to $\langle n_{ch}\rangle$. Thus, if the hadrons are produced in clusters (fireballs) with mean-squared charge $\langle Q^2\rangle$, and if the number of clusters is N, then the quantity $\langle n_{ch}\rangle$ in (1) is replaced by $N\langle Q^2\rangle \sim \langle n_{ch}\rangle$.

2. Integration of the cross section (1) leads to the usual expression containing $\langle \ln^2 q_i q_j\rangle$ (q_i and q_j are the momenta of the produced hadrons). When calculating the correction to the total cross section, it is necessary to add here the compensating contributions due to exchange of virtual photons. The assumption that the amplitudes decrease rapidly on going off the mass shell and with increasing $|t|$ lead to a complete cancellation of the doubly-logarithmic terms [3]. It is natural to assume, however, that at least one logarithm remains in the sum. One of the causes of its preservation may be (in the language of [3]) the numerical difference between the electromagnetic and strong radii of the hadron[1]. Under this assumption, the correction to the total cross section is

$$\alpha C_1 \left\langle \ln\frac{q_i q_j}{m_i m_j}\right\rangle\langle n_{ch}\rangle\sigma_{tot}.$$

Making furthermore the assumption of equipartition in rapidity space, we readily obtain $\langle \ln(q_i q_j/m_i m_j)\rangle = (1/3)\ln(s/m_p^2)$. As a final result, the measured total cross section σ_{tot}^{exp} is expressed in terms of the purely hadronic σ_{tot} by the following relation:

$$\sigma_{tot}^{exp} = \left(1 + \alpha\frac{C_1}{3}\ln\frac{s}{m_p^2}\langle n_{ch}\rangle\right)\sigma_{tot}. \tag{2}$$

If we use for the multiplicity the usual approximation $\langle n_{ch}\rangle = a \ln s + b$, $a = 1.65$, then we obtain from (2)[2]

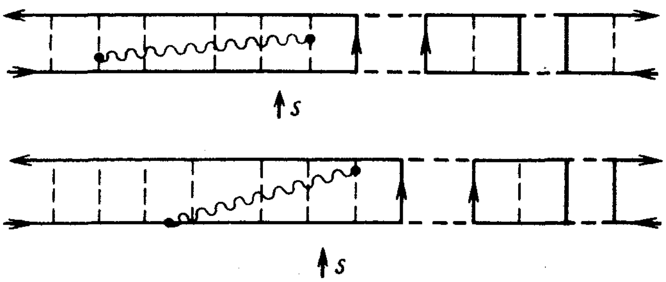

Fig. 1

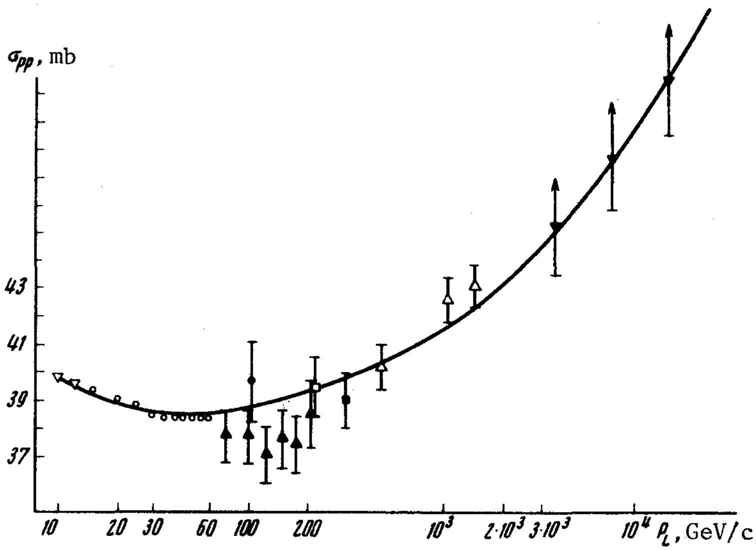

Fig. 2. Data of: ∇ Foley [10], o Gorin [9], ▲ Bartenov [11], ● J.W. Chapman [12], □ G. Charlton [13], ■ F. T. Dao [14], Δ U. Amaldi and S. R. Amendolia [7], and ▼ G. B. Yodh [8].

$$\sigma_{tot}^{exp} = (1 + C\alpha \ln^2 s/s_0)\sigma_{tot}\,; \quad C = \frac{1}{3}C_1\alpha \,. \tag{3}$$

The coefficient C should not depend on the type of the reaction considered (pp, $\bar{p}p$, $K^{\pm}p$, $\pi^{\pm}p$, γp, ...). Allowance for singly-logarithmic terms in (3) reduces simply to a change of the value of s_0, which can differ noticeably in different reactions.

We note that in multiperipheral models, where the total cross section is described by a sum of diagrams of the ladder type, the effect considered here corresponds to inclusion of the diagrams shown in Fig. 1. With respect to a diagram without photons, each such diagram yields, according to [5], an extra factor A(n)ln s.

3. Even if the pure hadron cross section is constant or slowly varying, the measured cross section (3) can increase quite rapidly. This may explain the growth of the total cross sections, observed at s ≳ 500 GeV [7, 8]. By way of illustration, Fig. 2 compares the data on the total pp-scattering cross sections in the p_L interval from 10 to 3×10^4 GeV/c with a simple approximation corresponding to allowance for the contributions of the P, P', and ω trajectories[3)]

$$\sigma_{pp}^{exp} = 36{,}5\left(1 + \frac{3\alpha}{\pi}\ln^2\frac{s}{s_0}\right)\text{mb} + a s^{-1/2}; \quad s_0 = 20\ \text{GeV}^2; \tag{4}$$

$$a = 14{,}7\ \text{mb/Gev}\,.$$

To describe $\bar{p}p$ scattering it is necessary to change only the coefficient a, which is connected with allowance for the contributions of P' and ω. A good approximation is obtained at a = 84 mb/GeV. For $K^{\pm}p$ scattering we have a = 0 and $\sigma_{tot}^{exp} = [1 + (3\alpha/\pi)\ln(s/s_0')]\sigma_{tot}$. As stated above, s_0 and s_0' may differ. The choice $s_0' = 10$ GeV ensures here the cross-section growth observed in Serpukhov [9].

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1) We note that the result of Lee and Nauenberg [4] cannot be applied directly to the total hadron scattering cross sections. Inasmuch as $\sigma_{tot} \sim m_h^{-2}$, the transitions $s \to \infty$ and $m_h \to 0$ are not equivalent here.

2) Of course, the cross section includes also other electromagnetic corrections, for example those connected with interference between strong and Coulomb amplitudes in elastic and inelastic scattering. They can become appreciable at moderately high energies, but decrease with increasing s [6].

3) We did not try here to obtain the best approximation, bearing in mind only a demonstration of the effect.

[1] V. N. Gribov, Yad. Fiz. 5, 399 (1967) [Sov. J. Nuc. Phys. 5, 280 (1967)]; F. E. Low, Phys. Rev. 110, 974 (1958).
[2] R. N. Cahn, Phys. Rev. Lett. 29, 1481 (1972).
[3] V. G. Gorshkov, Zh. Eksp. Teor. Fiz. 56, 597 (1969) [Sov. Phys.-JETP 29, 329 (1969)].
[4] T. D. Lee and M. Nauenberg, Phys. Rev. 133B, 1549 (1964).
[5] A. V. Efremov, Dissertation, Dubna, 1970.
[6] V. M. Budnev, I. F. Ginzburg, ZhETF Pis. Red. 13, 519 (1971)[JETP Lett. 13, 370 (1971)]; L. A. Kondratyuk and V. B. Kopeliovich, ibid. 16, 201 (1972) [16, 142 (1972)].
[7] U. Amaldi et al., CERN Preprint, 1973; S. R. Amendolia et al., CERN Preprint, 1973; Phys. Lett., in print.
[8] G. B. Yodh, Y. Pal, and J. S. Trefil, Phys. Rev. Lett. 28, 1005 (1972).
[9] Yu. P. Gorin et al., Yad. Fiz. 14, 998 (1971) [Sov. J. Nuc. Phys. 14, 560 (1972)].
[10] K. J. Foley et al., Phys. Rev. Lett. 19, 857 (1967).
[11] V. Bartenev et al., ibid. 29, 1755 (1972).
[12] J. W. Chapman et al., ibid. 29, 1686 (1972).
[13] G. Charlton et al., ibid. 29, 515 (1972).
[14] F. T. Dao et al., ibid. 29, 1622 (1972).

EXCITED STATES OF p-SHELL HYPERNUCLEI

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We calculate the excitation energies of p-shell hypernuclei with ΛN potentials having strong repulsion in odd states.

A few recent papers [1 - 3] report the existence of excited states of the hypernuclei C_Λ^{12} and N_Λ^{14} with approximate excitation energy and width 11 and 0.5 MeV, respectively, which are stable against Λ-particle emission (see also [4]). There are two possibilities for excited-state production, excitation of the core nucleus and excitation of the Λ particle. According to the Dalitz hypothesis [5], the Λ particle in the observed excited states is in the p-state relative to the mass center.

A theoretical analysis of the excited states of p-shell hypernuclei is of interest for the following reasons: With further progress in the physics of hypernuclei, our ideas concerning the ΛN interaction are altered appreciably and, unfortunately, still remain unsatisfactory at present. The failure to describe the binding energies of hypernuclei with mass number A > 5 on the basis of a paired central ΛN potential has stimulated investigations of other possible components of lambda-nucleon interaction (three-particle ΛNN forces, effects of ΛΣ suppression, etc.). The excited states of p-shell hypernuclei yield new data, which make it possible to verify the correctness of our notions concerning ΛN interactions.

One of the possible methods of eliminating the overestimate of the binding energies of hypernuclei with A > 5 is to introduce Majorana ΛN forces. Assuming equality of the singlet and triplet ΛN potentials and taking the Majorana forces into account, the paired ΛN potential takes the form

$$V_{\Lambda N} = \frac{1}{2} V_0 (1 + P_x) + \frac{1}{2} V_1 (1 - P_x),$$