possible pairs: 1) the 3.3913-μ line of the He-Ne laser coincides with the 2947.906 cm^{-1} absorption line of CH_4 within 0.003 cm^{-1}, at an absorption coefficient k = 0.17 cm^{-1}/Torr and $\Delta\omega_{col}$ = 5 MHz/Torr [5]; 2) the 3.5070-μ line of the He-Xe laser coincides with the 2850.608 cm^{-1} absorption line of the H_2CO molecule, accurate to 0.007 cm^{-1}, with k ≈ 0.1 cm^{-1}/Torr [6]. At a gas pressure 10^{-2} Torr it is possible to obtain a deep "dip" with width $\Delta\omega_b \approx 5 \times 10^4$ Hz by using a field of intensity 10^{-2} W/cm^2.

In a number of cases the absorbing molecules can be those of the active medium in the absence of excitation, for in this case the condition that the gain and absorption frequencies coincide are automatically satisfied.

The foregoing examples of absorbing molecules are far from optimal, for in their case $A_{21}^b \approx$ sec^{-1}. The most suitable atoms or molecules have $A_{21}^b \approx 10^3 - 10^5$ sec^{-1}. At these values of A_{21}^b it is possible to use very low absorbing-gas pressures ($\sim 10^{-4}$ Torr), which guarantees high stability of the position ω_b of the absorption line. At such low pressures, the mean free path amounts to several times ten centimeters, and consequently, by passing the beam many times through the absorbing gas and maintaining strict parallelism of the beam it is possible to obtain, by having the molecules cross several rays in succession, a narrow "dip" of width $\Delta\omega_b \approx 10^3$ Hz. In addition, with $A_{21}^b \approx 10^3 = 10^5$ sec^{-1}, an appreciable decrease takes place in the power needed for the production of the "dip."

5. Perfectly realistic values are a width $\Delta\omega_b \approx 10^5$ Hz for the absorption "dip" and an accuracy 10^{-9} for the stabilization of the resonator frequency Ω and of the gain line α_a. With $p_b \approx 0.1 - 0.3$ and $\Delta\omega_a$, kc $\lesssim 10^8$ Hz we can expect in this case a stability of the generation frequency ω, relative to ω_b, on the order of 10^{-11}. The absolute stability of the generation frequency will therefore be determined by the stability of the absorption-line frequency ω_b. At low gas pressures ($10^{-3} - 10^{-4}$ Torr) the stability of the center of the absorption line will be determined by the interaction of the molecules with the cell walls, and can apparently be no worse than 10^{-11}.

The author is deeply grateful to N. G. Basov for a discussion and support of this work.

[1] N. G. Basov and A. N. Prokhorov, Zh. Eksp. Teor. Fiz. 27, 431 (1954); J. P. Gordon, K. J. Zeiger, and C. H. Townes, Phys. Rev. 95, 282 (1954).
[2] H. M. Goldenberg, D. Kleppner, and N. F. Ramsey, Phys. Rev. Lett. 5, 361 (1960).
[3] N. G. Basov and V. S. Letokhov, ZhETF Pis. Red. 2, 6 (1965), JETP Lett. 2, 3 (1965).
[4] W. E. Lamb Jr., Phys. Rev. 134A, 1429 (1964).
[5] B. N. Edwards and D. E. Burch, JOSA 55, 174 (1965).
[6] K. Sakurai, K. Shimoda, M. Takami, J. Phys. Soc. Japan 21, 1838 (1966).

*The results for the case of strong saturation, as well as the stability conditions, will be treated in a detailed paper.

ρ-MESON PRODUCTION IN πN COLLISION AND THE HYPOTHESIS OF THE CONNECTION BETWEEN THE ρ MESON AND AND A CONSERVED CURRENT

N. N. Achasov, V. I. Belinicher, and L. M. Samkov
Mathematics Institute, Siberian Division, USSR Academy of Sciences
Submitted 16 June 1967
ZhETF Pis'ma 6, No. 4, 600-604 (15 August 1967)

In the study of ρ-meson production in πN collisions one usually starts from the one-pion exchange model [1], assuming the contribution of the peripheral diagram (Fig. 2a) to the amplitude of the process to be the predominating one, owing to the closeness of the pion pole to the physical region of the momentum transfer. In this paper we consider the same process assuming, following Sakurai [2], that the ρ meson is connected with the conserved isovector vector current:

$$(\Box - m^2)\,\rho_n^\alpha(x) = j_n^\alpha(x); \quad \partial_n j_n^\alpha(x) = 0. \tag{1}$$

The matrix element of the πN - ρN reaction can be written in the form:

$$ {}_{out}\langle k\alpha; p_2 | p_1; q\beta\rangle_{in} = -i(2\pi)^{-3/2}(2k_0)^{-1/2}\int e^{ikx}\, E_n \, {}_{out}\langle p_2 | j_n^\alpha(x) | p_1; q\beta\rangle_{in}\, dx, \tag{2}$$

where $\vec{E}$ is the ρ-meson polarization vector. It follows from (1) and (2) that the isotopic-current conservation condition for the matrix element is

$$(p_2 - p_1 - q)_n \, {}_{out}\langle p_2 | j_n^\alpha(o) | p_1; q\beta\rangle_{in} = 0. \tag{3}$$

We shall consider for concreteness the production of a ρ^+ meson, all the results being valid for the production of ρ^0 and ρ^- mesons. A detailed exposition of the results will be published in [3].

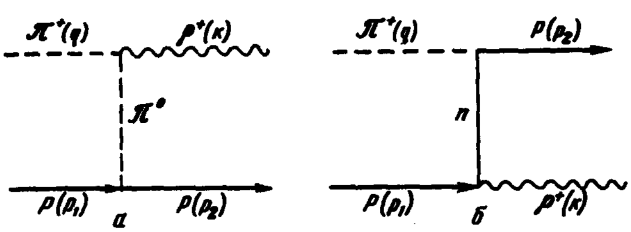

Fig. 1

It is easy to verify that condition (3) is not fulfilled for a peripheral diagram (Fig. 1a). In order to satisfy condition (3), we consider a diagram with "radiation of a ρ meson by a nucleon (Fig. 1b). In calculating these diagrams, we use the effective Lagrangian

$$L_{int} = g\bar{N}\gamma^5\tau^\alpha N\pi^\alpha + f_\rho \bar{N}\gamma^n \frac{\tau^\alpha}{2} N\rho^\alpha + f_\rho \rho_n^\alpha \pi^\beta \partial_n \pi^\gamma \epsilon^{\alpha\beta\gamma}\,; \tag{4}$$

Contributions of the type of "strong magnetic" term are disregarded. The differential cross section of the reaction πN → ρN → ππN, summed over the spin states of the final nucleon and averaged over the spin states of the initial one, is given by

$$\frac{d^3\sigma}{d\omega^2\,dt\,d\Omega} = 2\left(\frac{g^2}{4\pi}\right)\left(\frac{f_\rho}{4\pi}\right)^2 \frac{\left(\frac{\omega^2}{4} - \mu^2\right)^{3/2}}{\omega[(S - M^2\mu^2)^2 - 4\mu^2M^2][(m^2 - k^2)^2 + m^2\Gamma^2]} \times \frac{T^2 + U^2 + 2UT}{4\pi}, \tag{5}$$

where M is the nucleon mass, μ the pion mass, $t = (p_1 - p_2)^2$, $s = (p_1 + q)^2$, m the ρ-meson m mass, $\omega^2 = (k_1 + k_2)^2 = k^2$, k_1 and k_2 are the momenta of the final pions, T^2 the contribution from diagram 1a, U^2 the contribution from diagram 1b, 2UT the interference term, Γ the width of the ρ meson, and Ω the solid ange of the final pion in the c.m.s. of the two produced pions.

We have investigated (5) for $0 \leq t \leq 10\mu^2$ and for practically arbitrary s.

It turns out that if we integrate (5) with respect to Ω, then the dependence of $d^2\sigma/d\omega^2dt$ on t is close to that obtained when only one-pion exchange is taken into account. It can be stated that this near-equality becomes stronger with increasing s, for not too small $|t|$ $(t < -\mu^2)$. Although the contribution from the diagram 1b is sometimes not small compared with the contribution from diagram 1a, $\overline{U^2}$ and $\overline{2UT}$ cancel each other ($\overline{U^2} = (1/4\pi)\int U^2 d\Omega$, $\overline{T^2} = (1/4\pi)\int T^2 d\Omega$, $\overline{2UT} = (1/4\pi)\int 2UTd\Omega$). When $s \to \infty$ and $t \to 0$ (ρ-meson production forward), the picture changes radically, the contribution from diagram 1a vanishes, and the principal role is played by the "radiation" of the ρ meson by the nucleon. This means that no definite conclusion can be drawn at present concerning the peripheral nature of the $\pi N \to \rho N$ reaction by investigating experimentally the dependence of $d^2\sigma/d\omega^2dt$ on t.

If we choose the z axis in the c.m.s. of the produced pions in the direction of the momentum of the incoming pion, then the dependence on the azimuthal angle ϕ is equivalent to the dependence on the Yang-Treiman angle. However, if we are intersted only in the distribution over the Yang-Treiman angle, and integrate with respect to the angle θ between the momenta of the incoming pion and the pion at the end of the reaction, then the dependence on the Yang-Treiman angle vanishes in practice.

Allowance for the "radiation" of the ρ meson by the nucleon makes it possible to explain the experimentally observed peak in the ρ-meson region at $|\cos\theta| \leq 0.3$ [5,6] without involving a resonance in the $\pi\pi$-scattering S-wave. Figures 2a and 2b show the following plots: $\overline{T^2}$ - dashed curve, $\overline{2UT} + \overline{U^2} + \overline{T^2}$ - curve I, $\overline{U^2}$ - II, $\overline{2UT}$ - III, $\overline{2UT} + U^2$ - IV, $(1/2\pi)\int(U^2 + 2UT + T^2)d\phi|_{\theta=90^\circ} = (1/2\pi)\int U^2 d\phi|_{\theta=90^\circ}$ - V (q_{lab} = incident-pion momentum in the lab.).

The authors thank I. F. Ginzburg, V. V. Serebryakov, and D. V. Shirkov for interesting remarks and for a discussion of the results. One of the authors (N.N.A.) is grateful to R. M. Muradyan and B. V. Struminskii for a discussion of the vector theory of strong interactions.

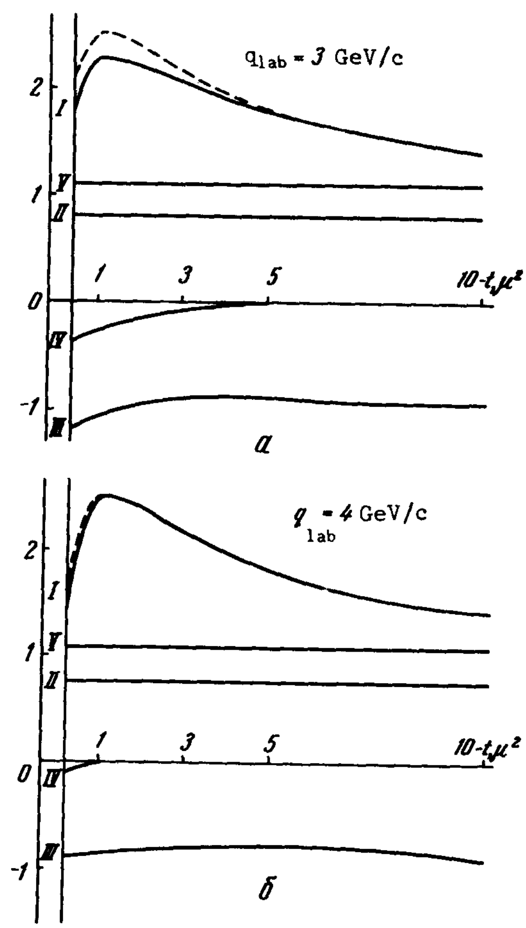

Fig. 2

[1] G. E. Chew, F. E. Low, Phys. Rev. 114,1640(1959).
[2] J. J. Sakurai, Ann. of Phys. 11, 1 (1960).
[3] N. N. Achasov, V. I. Belinicher, L. M. Samkov, Preprint IM SOAN USSR, Novosibirsk, 1967 (to be published).
[4] I. D. Jackson, Nuovo Cimento 34, 1644 (1964).
[5] V. Hagopian et al. Phys. Rev. Lett. 14, 1077 (1965).
[6] M. A. Jabiol, F. E. James, Nguyen Huu Khanh, Phys. Rev. Lett. 17, 1065 (1966).