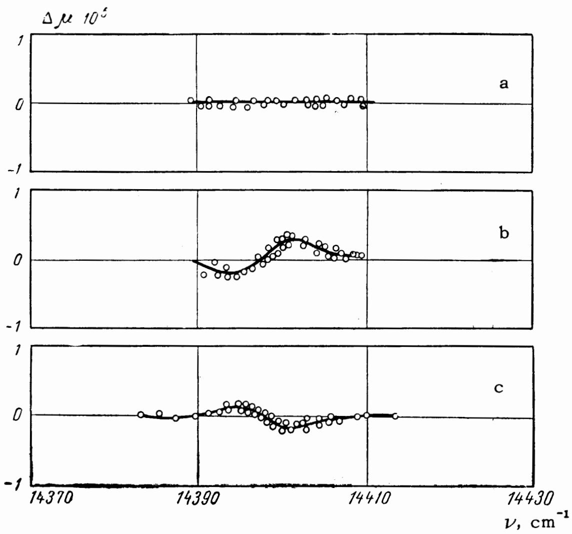

FIG. 4. Dispersion curves: a) without pumping; b) with optical pumping (negative dispersion in ruby P_1); c) dispersion curve of ruby P_2 without pumping and with a quartz plate in place of crystal P_1.

ferogram of Fig. 3 (the negative dispersion of the crystal P_1), and the curve of the anomalous dispersion of crystal P_2. The excursion of the dispersion curves, i.e., the separation between the maximum and the minimum ordinates of the dispersion curve under the conditions of pumping illumination are about 36% of the spread of the anomalous dispersion curve in the crystal P_2; this corresponds to a change of 3.7×10^{-6} in the index of refraction with respect to the unexcited ruby. The accuracy in measuring these dispersion curves was 86%. The population inversion, i.e., the quantity $(n_2 - n_1)/(n_2 + n_1)$, corresponds to the excursion of the measured negative dispersion curve and therefore to 36%. This is in agreement with the magnitude of the inversion measured in[5] for luminescence under approximately the same conditions. The measurements of negative dispersion give a method for direct determination of population inversion.

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ANNIHILATION OF ANTIBARYONS AND UNITARY SYMMETRY

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In this letter we investigate relations among amplitudes for the production of baryon-antibaryon pairs (which belong to the irreducible representation of SU(3) of dimension 10) in the annihilation of $\bar{p}$ and $\bar{\Sigma}^+$ on protons. The processes have the form

$$\begin{aligned}
&f_1 \quad \bar{p} + p \to \bar{\Omega}^- + \Omega^-, &&f_5 \quad \bar{\Sigma}^+ + p \to \bar{\Omega}^- + \Xi^{*-},\\
&f_2 \quad \bar{p} + p \to \bar{\Xi}^{*-} + \Xi^{*-}, &&f_6 \quad \bar{\Sigma}^+ + p \to \bar{\Xi}^{*-} + Y_1^{*-},\\
&f_3 \quad \bar{p} + p \to \bar{Y}_1^{*-} + Y_1^{*-}, &&f_7 \quad \bar{\Sigma}^+ + p \to \bar{Y}_1^{*-} + N^{*-}.\\
&f_4 \quad \bar{p} + p \to \bar{N}^{*-} + N^{*-}, && \qquad (1)
\end{aligned}$$

The relations among these amplitudes resulting from unitary symmetry have already been discussed in detail [1]. However, in view of the success of the Okubo mass formula [2] it is interesting to try to derive these relations also with account of those symmetry-breaking interactions which preserve isotopic spin and hypercharge (medium strong interactions).

When account is taken of the medium strong interactions up to first order in perturbation theory, the amplitudes satisfy the following relations[1)]

$$f_1 + f_4 + 3(f_2 + f_3) = 0,$$

$$f_5 + \sqrt{3} f_6 + f_7 = 0, \quad \sqrt{3}\,(f_1 + f_2 - f_3 - f_4) = 2(f_5 - f_7), \qquad (2)$$

leading to the following inequalities between the cross sections:

$$\sqrt{\sigma(\bar{\Omega}^-\Omega^-)} \leqslant 3\left(\sqrt{\sigma(\bar{\Xi}^{*-}\Xi^{*-})} + \sqrt{\sigma(\bar{Y}_1^{*-}Y_1^{*-})}\right) + \sqrt{\sigma(\bar{N}^{*-}N^{*-})},$$

$$\sqrt{\sigma(\bar{\Omega}^-\Omega^-)} \geqslant \left|\sqrt{\sigma(\bar{N}^{*-}N^{*-})} - 3\left(\sqrt{\sigma(\bar{\Xi}^{*-}\Xi^{*-})} + \sqrt{\sigma(\bar{Y}_1^{*-}Y_1^{*-})}\right)\right|.$$

Relation (2) does not depend on the detailed dynamics of the involved processes. Under certain conditions it is possible to apply the peripheral model, in which a system with a definite value of U-spin [4] is exchanged, and then one finds additional relations among the amplitudes.

The production of a final baryon with the same momentum direction as that of the initial proton (in the center-of-mass system) may proceed through a peripheral collision, consisting of the exchange of a meson system of charge two. Since such a meson has not been observed, one would expect a vanishing of the amplitude at small angles. Among the observed processes [5] $\bar{p} + p \to \bar{Y}_1^{*-} + Y_1^{*-}$, the greatest number of $\bar{Y}_1^{*-}$ were observed in the direction of the momentum of $\bar{p}$. In addition the greatest number of cases observed in the process $\bar{p} + p \to \bar{Y}_1^{*+} + Y_1^{*+}$ was in the forward direction. If we assume that the reactions $\bar{p} + p \to \bar{Y}_1^{*\mp} + Y_1^{*\mp}$ both proceed through the mechanism of the exchange of a meson state with $T = 3/2$, we find that $\sigma(\bar{Y}_1^{*-} Y_1^{*-})/\sigma(\bar{Y}_1^{*+} Y_1^{*+}) = 9$, which agrees with the experimental result, 7.

The relations among the f_i for such a peripheral mechanism depend on the value of the U-spin of the intermediate state:

$$f_1 = 0, \quad f_2 = -f_3/2 = f_4/3 = f_5/\sqrt{3} = -f_6/2 = f_7/\sqrt{3}, \quad \text{if} \quad U = 1,$$

$$-f_1/4 = f_2/3 = -f_3/2 = f_4 = -f_5/\sqrt{3} = f_6/2 = -f_7/\sqrt{3}, \quad \text{if} \quad U = 2, \qquad (3)$$

where the medium strong interactions have been included. From this it is evident that $\sigma(\bar{N}^{*-}N^{*-})$ and $\sigma(\bar{Y}_1^{*-} Y_1^{*-})$ must be equal if such a mechanism is valid. There are no experimental data concerning the process $\bar{p} + p \to \bar{N}^{*-} + N^{*-}$. If we assume, as was done above, that the processes $\bar{p} + p \to \bar{N}^{*-} + N^{*-}$ and $\bar{p} + p \to \bar{N}^{*++} + N^{*++}$ both proceed through the same pole mechanism, namely the exchange of a meson state with T = 2, we find that $\sigma(\bar{N}^{*-} N^{*-})/\sigma(\bar{N}^{*++} N^{*++}) = 16$. This result together with (3) contradicts the experimental result [6] obtained at an antiproton momentum of 3.25 Bev/c

$$[\sigma(\bar{Y}_1^{*-}Y_1^{*-}) + \sigma(\bar{Y}_1^{*+}Y_1^{*+})]\,/\,\sigma(\bar{N}^{*++}N^{*++}) = 10^{-2}.$$

Thus we may conclude that different peripheral mechanisms, operate in the processes $\bar{p} + p \to \bar{N}^{*-} + N^{*-}$ and $\bar{p} + p \to \bar{N}^{*++} + N^{*++}$ and that therefore we can not compare them in this manner. For this reason it is desirable that the process $\bar{p} + p \to \bar{N}^{*-} + N^{*-}$ be measured. The present data are completely insufficient for a test of Eq. (2).

Miller [7] presented at the Dubna conference an estimate of the upper bound for the formation of Ω^- in $\bar{p} + p$ annihilation: $\sigma < 3$ mb. This figure, together with the value of the cross section $\sigma(\bar{Y}_1^{*-} Y_1^{*-})$, is not in disagreement with the results of a peripheral mechanism with U = 1.

The production of a final baryon with momentum direction the same as that of the initial antibaryon may proceed through the exchange of a state such as a deuteron with baryon number 2. Assuming that these deuteron systems belong to a representation of SU(3) with dimension 10[8] we find for the U-spin the value 0 or 1. If the exchange is of U-spin zero, then all amplitudes are zero on the basis of unitary symmetry. If the exchange is of U-spin 1, then

$$f_1/3 = -f_2/2 = f_3 = f_5/\sqrt{3} = -f_6/\sqrt{2} = f_7/\sqrt{3}, \quad f_4 = 0. \qquad (4)$$

Such a mechanism is no longer compatible with the experimental ratio of the cross-sections for the production of $\bar{\Omega}^-\Omega^-$ and $\bar{Y}_1^{*-} Y_1^{*-}$ in $\bar{p} + p$ annihilation.

In conclusion the author thanks A. I. Akhiezer for a discussion of the results.

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METALLIZATION OF SOLID ARGON UNDER COMPRESSION

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THE present author is currently investigating theoretically the behavior of various elements under compression, using the solution of the Hartree equation for crystals.

The method of making such quantum-mechanical calculations was described earlier.[1] In an investigation of the behavior of the electron bands of solid argon, it was found possible to observe the metallization of the sample when it is subjected to a compression given by the factor $\delta = 3.2$ (the initial density of the solid argon was $\rho_0 = 1.9\ g/cm^3$).

In its normal state, solid argon is a typical atomic crystal whose binding energy is due to van der Waals' forces. The quantum-mechanical method used here does not describe van der Waals' forces. With this method, only the close packed structure of argon is considered and there should be a small pressure at $\delta = 1$. Calculations do indeed give a very small pressure in the initial state at $\delta = 1$. Under subsequent compression, the van der Waal's forces are unimportant and the results from the pressure calculations represent the real situation in the compression of argon. According to those calculations, the pressure (in megabars) is $p = 0.027$ at $\delta = 1$; $p = 0.324$ at $\delta = 2$; $p = 1.062$ at $\delta = 3$; $p = 2.721$ at $\delta = 4$. The rearrangement of the electron bands under compression is of special interest. In the region

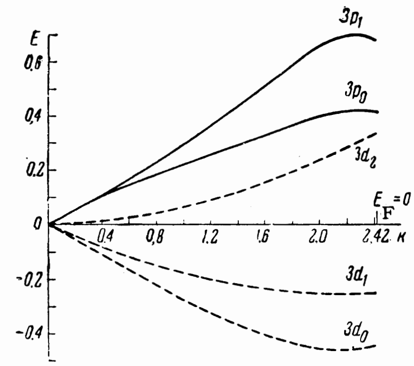

FIG. 1

$\delta < 3.2$, the upper filled band is the 3p-band. It is filled completely and contains six electrons: two electrons in the sub-band $3p_0$, and four electrons in the sub-band $3p_1$ (the latter number is the projection of the moment along the crystal momentum vector). The 3d-band lies higher and has no electrons at all.

This state of the crystal is the direct consequence of the well-known state of a free argon atom $(1s)^2(2s)^2(2p)^6(3s)^2(3p)^6$. The experimentally determined excitation energy of the argon atom $(3p)^6 \rightarrow (3p)^5 4s$ is 11.5 eV. The 3d-level in the atom lies close to 4s, but above it. In solid argon, the 3d-band lies below 4s. The present author is not aware of any measurements of the excitation threshold in solid argon. According to our calculations at $\delta = 1$, the gap between the 3p and 3d-bands is equal to 6 eV. Under compression, this gap becomes smaller. At $\delta = 3.2$, the gap is equal to zero and the bands 3p and 3d originate at the same point at $k = 0$ (Fig. 1). (The energy in Figs. 1 and 2 is given in atomic units; 1 atomic unit equals 27.23 eV.) Here, we actually have argon in the metallic state. It is evident from the figure that only the subbands $3d_0$ and $3d_1$, directed downwards, are

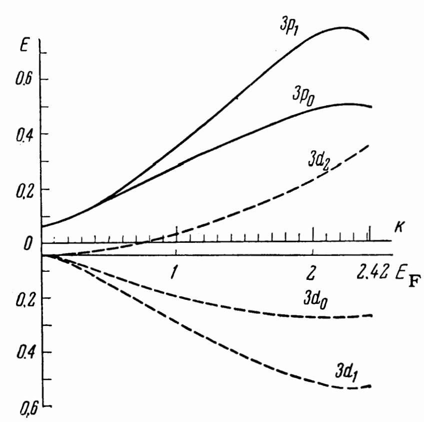

FIG. 2