SOVIET PHYSICS JETP VOLUME 3, NUMBER 3 OCTOBER, 1956

Formation of Negative Hydrogen Ions by Collision of Protons with Gas Molecules

IA. M. FOGEL' AND R. V. MITIN

Physical and Technical Institute, Academy of Sciences, Ukrainian SSSR

Kharkov State University

(Submitted to JETP editor February 7, 1955)

J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 450-457 (March, 1956)

Measurements were made of effective cross sections of two electron capture by collisions of protons of energies from 9.5 to 29 kev with molecules of H_2, N_2, O_2, He, Ne and A. The ratio of the number of negative hydrogen ions to the number of protons in the balanced beam formed after the proton beam has passed through the six mentioned gas targets, was determined as a function of energy. The effective cross section of capture of a single electron by collision of a fast hydrogen atom with a fast hydrogen atom with a hydrogen molecule was computed on the basis of the experimental results.

FORMATION of negative ions by single collisions of fast singly charged positive ions with gas molecules results from the exchange of two electrons between the colliding particles. Effective cross sections of two electron capture by positive oxygen ions upon collision with molecules of hydrogen, nitrogen and oxygen were given in the work of Fogel and Krupnik[1]. For protons colliding with hydrogen molecules initial measurements of double exchange of charges were presented in the work of Fogel, Krupnik and Safronov[2].

The process of two electron capture by triply charged ions of argon in neon, argon and nitrogen were studied by Fedorenko[3].

As is evident from this brief review, processes involving double exchanges (unlike atomic collisions involving exchange of single electrons) have been inadequately studied and therefore, in order to understand the mechanism of such processes, it is necessary to make further investigations for different ion-molecule pairs over a widest possible range of ion energies.

METHOD OF MEASUREMENTS

For the study of the process of double exchange of charge of protons we have constructed an experimental equipment basically similar to that used in Ref. 1 and will therefore not describe the equipment here. The basic difference between our experimental arrangement and that previously used was that the analysis of the beam, after it passed through the collision chamber, was performed by an electrostatic and not a magnetic analyzer. Measurements of the I^+ and I^- currents in the Faraday trap of the electrostatic analyzer were made simultaneously by a mirror galvanometer and a string electrometer so that errors caused by accidental fluctuations of the primary proton current were removed.

A liquid air trap was inserted in the collision chamber used in this work. The trap served to freeze out the condensed vapors and resulted in a considerable reduction of the number of negative ions produced by double ionization of the residual gas molecules in the collision chamber.

The electric potentials in the ion source, focusing lens and the accelerating tube were measured by a voltmeter calibrated with a resistance voltmeter similar to the one used in Refs. 1 and 2.

The content of the beam formed as a result of passage of protons through matter is represented by differential equations.

$$dN^+/d(nx) = -(\sigma_{10}+\sigma_{1-1})N^+ + \sigma_{01}N^0 + \sigma_{-11}N^-; \quad (1a)$$

$$dN^0/d(nx) = \sigma_{10}N^+ - (\sigma_{01}+\sigma_{0-1})N^0 + \sigma_{-10}N^-; \quad (1b)$$

$$dN^-/d(nx) = \sigma_{1-1}N^+ + \sigma_{0-1}N^0 - (\sigma_{-11}+\sigma_{-10})N, \quad (1c)$$

where N^+, N^0 and N^- are the number of protons,

[1] Ia. M. Fogel and L. I. Krupnik, J. Exptl. Theoret. Phys. (U.S.S.R.) 29, 209 (1955); Soviet Phys. JETP 2, 252 (1956).

[2] N. V. Fedorenko, J. Tech. Phys. (U.S.S.R.) 24, 769 (1954).

[3] Ia. M. Fogel', L. I. Krupnik and R. G. Safronov, J. Exptl. Theoret. Phys. (U.S.S.R.) 28, 589 (1955). Soviet Phys. JETP 1, 415 (1955).

neutral atoms of nydrogen and negative ions of hydrogen, respectively in the beam; σ_{ik} is the effective cross section of the process, as a result of which a particle with a charge i is converted into a particle with a charge k; n if the number of atoms per cc of the matter, x the length of path in matter.

By Eq. (1c) and by use of the initial conditions $nx = 0$, $N^+ = N_0^+$, $N^0 = 0$, $N^- = 0$, the following formula for determining the cross section for two electron capture by a proton is readily obtained:

$$\sigma_{1-1} = 1.08\times10^{-19}\,(T/L)\left[\frac{d(I^-/I_0^+)}{dp}\right]_{p=0}, \qquad (2)$$

where L is the effective length of the collision chamber, T the temperature of the gas in the chamber, I^- the current of negative hydrogen ions in the beam, I_0^+ the ion beam current entering the collision chamber.

The method of measuring the cross section σ_{1-1}, based on Eq. (2), consists of studying the dependence of the ratio I^-/I_0^+ on the gas pressure p in the collision chamber. The derivative in Eq. (2) is determined from the linear portion of this dependence ,the presence of which is conditioned by the formation of negative ions by single collisions of protons with the gas molecules.

The solutions of differential equations (1) have the following form:

$$N^- = a_0 + a_1 e^{-r_1 nx} + a_2 e^{-r_2 nx}, \qquad (3)$$
$$N^+ = b_0 + b_1 e^{-r_1 nx} + b_2 e^{-r_2 nx},$$
$$N^0 = c_0 + c_1 e^{-r_1 nx} + c_2 e^{-r_2 nx},$$

where the quantities r_1, r_2, a_0, a_1, a_2, etc. are the functions of the six cross sections entering into the differential equation (1). When $nx \to \infty$, $N^- \to a_0$, $N^+ \to b_0$, $N^0 \to c_0$, i.e., with sufficient increase of the thickness of the gas target, the composition of the beam no longer changes. The content of the beam is said to be in equilibrium. It can be shown that $(N^-/N^+)_p$ will have the following form:

$$\left(\frac{N^-}{N^+}\right)_p = \left(\frac{I^-}{I^+}\right)_p = \frac{\sigma_{10}\sigma_{0-1} + \sigma_{1-1}\sigma_{01} + \sigma_{1-1}\sigma_{0-1}}{\sigma_{01}\sigma_{-10} + \sigma_{-11}\sigma_{01} + \sigma_{-11}\sigma_{0-1}}. \qquad (4)$$

For sufficiently small values of nx, Eqs. (3) can be expanded into series. By neglecting all powers of nx higher than second we obtain:

$$I^-/I^+ = \sigma_{1-1}nx + {}^1/_2\,(\sigma_{10}\sigma_{0-1} + \sigma_{1-1}\sigma_{10} + \sigma_{1-1}^2 - \sigma_{1-1}\sigma_{-10} - \sigma_{1-1}\sigma_{-11})\,(nx)^2 \qquad (5)$$

Thus, in the region of gas pressures in the collision chamber when multiple collisions of the beam particles with gas molecules begin to appear and while these pressures are not yet too great, the dependence of the ratio I^-/I^+ on the pressure is expressed by the equation

$$I^-/I^+ = \gamma p + \delta p^2, \qquad (6)$$

where

$$\gamma = \sigma_{1-1}L/kT; \qquad (7)$$
$$\delta = {}^1/_2\,(\sigma_{10}\sigma_{0-1} + \sigma_{1-1}\sigma_{10} + \sigma_{1-1}^2 - \sigma_{1-1}\sigma_{-10} - \sigma_{1-1}\sigma_{-11})\,L^2/k^2T^2.$$

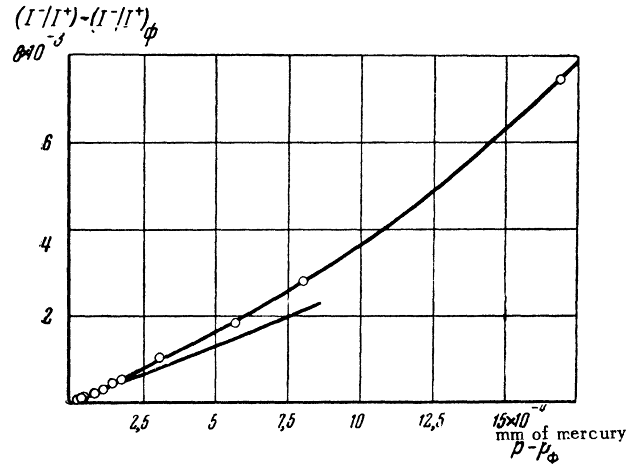

FIG. 1

In Fig. 1 is shown part of the curve of variation of I^-/I^+ with pressure for 29 kev protons passing through hydrogen. In constructing this graph the double charge transfers from the protons to the molecules of the residual gas in the collision chamber, were taken into consideration. This was done by making the values on the axes of abscissas and ordinates to correspond to $p - p_\Phi$ and $(I^-/I^+) - (I^-/I^+)_\Phi$ respectively, where p_Φ is the pressure of the residual gas and $(I^-/I^+)_\Phi$ the value of the ratio I^-/I^+ at the pressure of the residual gas. The pressure of the residual gas in the chamber was 5×10^{-5} mm of mercury. It should be noted that upon freezing of the condensed vapors in the collision chamber, the value of $(I^-/I^+)_\Phi$ decreases from 3×10^{-3} to 2×10^{-4}. As seen from Fig. 1, the dependence of I^-/I^+ on pressure appears linear up to a pressure $\sim 10^{-4}$ mm of mercury. At higher pressures there is observed a departure from linearity, resulting from the formation of negative hydrogen ions as a result of multiple collisions of the beam particles with the gas molecules.

It follows from the above that the dependence of I^-/I^+ on pressure at not too high pressures should be expressed by Eq. (6). From eleven experimental points in Fig. 1, using the method of least squares, we have determined the values of constants γ and δ in Eq. (6), which turned out to be 2.74 and 1.03×10^3, respectively. Application of the least square method to the 5 points of the linear portion of the curve gives for the value of $\gamma = 2.7$. The values of I^-/I^+ computed according to Eq. (6), with the indicated values of the constants γ and δ, differed from the experimental values by not more than 7.6%. This result indicates that, up to the pressure of 1.7×10^{-3} mm of mercury, the dependence of I^-/I^+ on the pressure follows Eq. (6).

In the following, for the determination of σ_{1-1}, the quantity γ was determined by the method of least squares from the linear portion of the graph of the dependence of I^-/I^+ on pressure.

The mass spectroscopy method used by us for the measurement of cross sections σ_{1-1} can yield sufficiently accurate values of these cross sections if the following factors which distort the results of measurements are corrected for or removed:

(a) Weakening of the proton beam in the collision chamber resulting from neutralization of protons by collision with gas molecules.*

(b) Unequal distribution of protons and negative hydrogen ions in the collision chamber.

(c) Unequal weakening of the proton and negative hydrogen ion beams in the path from the collision chamber exit to the cylinders of the Faraday analyzer.

The correction for the neutralization of protons can be readily computed if cross section σ_{10} is known. For protons in hydrogen and helium this correction does not exceed several percent and was therefore not introduced by us.

Certain experiments described below indicate that unequal distribution of protons and negative hydrogen ions in the gas of the collision chamber cannot substantially distort the results of measurements.

The correction for the unequal attenuation of the positive and negative beams in the analyzing chamber can only be computed for the case of hydrogen in the collision chamber since for this computation it is necessary to know (besides cross section σ_{10}) the cross section σ_{-10} which was measured in Ref. 4 for negative hydrogen ions in hydrogen. This correction did not exceed 0.2% and is therefore insignificant. Accidental errors in the measurement of cross section σ_{1-1} amounted to 30%. The errors in the measurements of the proton energy was of the order of 3%.

For the determination of the equilibrium value of the ratio I^-/I^+ the curve of I^-/I^+ in its dependence on pressure was plotted up to pressures corresponding to the equilibrium state of the beam. The equilibrium state of the beam is reached for all six gases at pressures of the order of 10^{-2} mm of mercury. Accidental errors in the measurements of $(I^-/I^+)_p$ amounted to 18%.

RESULTS OF MEASUREMENTS

Measurements were made of the effective cross sections of the double exchange of charge process for protons with energy from 9.5 to 29 kev in hydrogen, nitrogen, oxygen, helium, neon and argon. To fill the collision chamber we used hydrogen passed through a palladium filter, spectrally pure helium and neon, oxygen with 0.9% impurities, argon with 0.3% impurities and nitrogen obtained by evaporation of liquid nitrogen and purified from admixtures of oxygen (of the order of 4%) by passage through copper filings heated to 600°. In Fig. 2 is presented the dependence of the effective cross sections σ_{1-1} on the proton energy for all six gases investigated. The value of $\sigma_{1/1}$ for each energy was obtained by averaging two measurements. In the energy range investigated the effective cross section σ_{1-1} for protons in nitrogen, oxygen, argon and neon decreases with increase in energy; for protons in helium there is observed quite a shallow maximum around 14 kev and finally for protons in hydrogen there is a sharp maximum around 17.5 kev. The values of σ_{1-1} fall within the limits from 5×10^{-19} cm^2(neon, 29 kev) to 1.27×10^{-17} cm^2 (hydrogen, 17.5 kev).

Since the measurements of effective cross sections of double exchange of charge for protons are being made for the first time, it is not possible to compare the results with published data. The only comparison could be made with results obtained in the work of Fogel' and Krupnik. In that work measurement was made of the cross section

* The necessity of compensating for this arises from the fact that actually measurement is made of the ratio of currents I^-/I^+ in the Faraday trap of the electrostatic analyzer, while according to Eq. (2) it is necessary to measure the ratio I^-/I^+ where I^+ is the current of protons at the entrance to the collision chamber.

[4] A. C. Whittier, Canad. J. Phys. 32, 275 (1954).

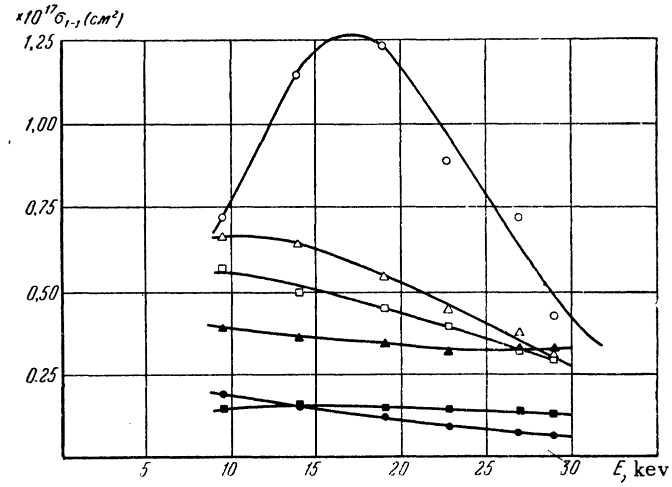

FIG. 2 ○ — H_2, △ — N_2, □ — O_2, ● — Ne, ▲ — A, ■ — He

$\sigma_{1/1}$ for protons in hydrogen for the energy 21 kev and this was given as 1.5×10^{-17} cm^2. According to the results of this present work σ_{1-1} for the mentioned energy is 1.1×10^{-17} cm^2. The difference is within the limits of experimental error.

It is of interest to compare the effective cross sections for the capture by protons of one and two electrons by collision with gas molecules. Such comparison can be made for protons in hydrogen and helium, since only for these two cases reliable measurements were made of the effective cross sections of one electron capture.

For comparison curves of the effective cross section dependence of one electron capture by protons in hydrogen are shown in Fig. 3. The data were taken from the work[5] (solid curve) and[2] (dotted curve), and curves of effective cross section for the capture of two electrons as measured in the present work. As can be seen from this Figure, the effective cross section for one electron capture in the investigated energy interval is 50 to 100 times greater than the effective cross section of two electron capture.

A similar comparison (Fig. 4) for protons in helium made on the basis of data obtained in this work and by Keene[5] shows that in this case the ratio σ_{10}/σ_{1-1} for the investigated energy interval varies from 120 to 250.

The dependence of the equilibrium value of the ratio I^-/I^+ on the energy of protons for the investigated gases is shown in Fig. 5. For nitrogen, oxygen, neon and argon in the interval from 9.5 to 29 kev, there is observed a decrease of $(I^-/I^+)_p$ with increase of energy; for helium this ratio remains approximately the same; in the case of hydrogen for which this ratio is much higher than for the rest of the gases, there is a maximum of 17% (for energies of the order of 8.5 kev). The dependence of $(I^-/I^+)_p$ on energy for protons in hydrogen was investigated by Whittier[4]. His results

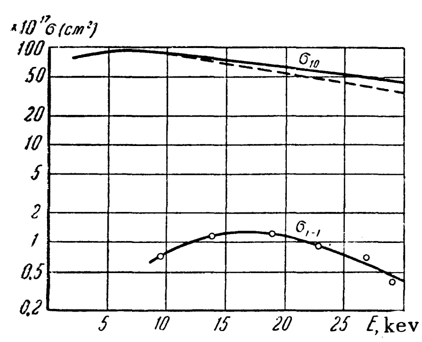

FIG. 3

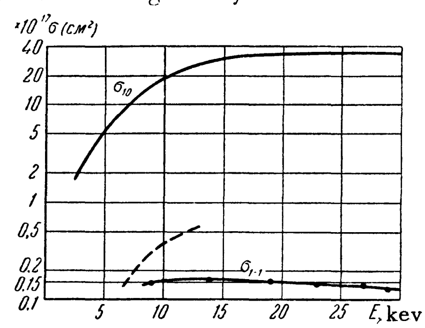

FIG. 4

[5] J. P. Keene, Phil. Mag. **40**, 369 (1949).

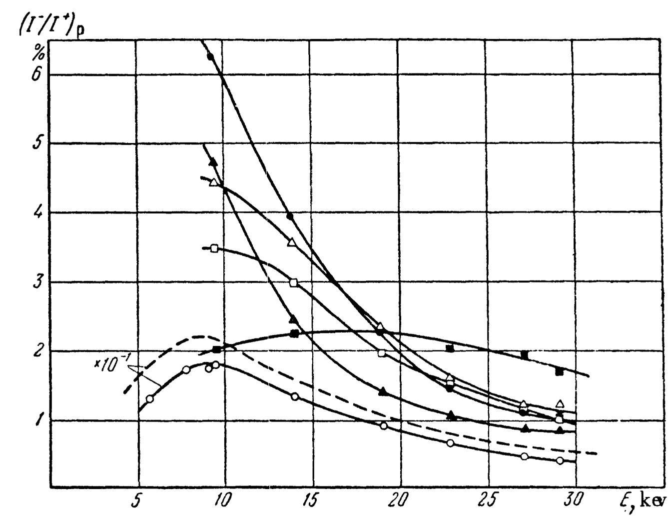

FIG. 5 ○ — H_2, △ — N_2, □ — O_2, ● — Ne, ▲ — A, ■ — He

are shown in Fig. 5 by the dotted line. As seen from this Figure, our values of $(I^-/I^+)_p$ are systematically smaller than those of Whittier, while the differences are beyond the limits of measurement errors.

It should be noted that the collision chamber used in the work of Whittier differed very little in length from our chamber but had an output channel 1 mm in diameter and 75 mm long while the dimensions of the output channel in our camera were 5 and 50 mm respectively. On the assumption that the scattering of protons and negative hydrogen ions in the gas of the collision chamber are not equal, we can conclude that there must exist a systematic error in the determination of $(I^-/I^+)_p$ connected with this unequal scattering. It is easy to understand that this error must be greater in the work of Whittier than in ours since in his chamber the scattered particles are restricted to a much smaller angle than in ours. In order to determine the influence of unequal scattering of protons and negative hydrogen ions on the quantity $(I^-/I^+)_p$ we have placed in the output channel of the collision chamber a 2 mm diameter diaphragm and under these conditions determined the ratio $(I^-/I^+)_p$ for

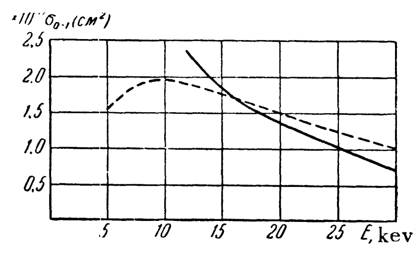

FIG. 6

protons in hydrogen. The results were the same as those obtained without the diaphragm in the output channel. This experiment shows quite conclusively that scattering of the beam particles in the gas of the collision chamber has no effect on the value of $(I^-/I^+)_p$ and therefore cannot be considered as the cause of discrepancy between results of Whittier and the data obtained in this work. The possibility is not excluded that these differences are connected with unequal neutralization of protons and negative hydrogen ions on the walls of the output canal in the collision chamber used by Whittier.

DISCUSSION OF RESULTS

An examination of the shape of the curves of effective cross section dependence on energy in Fig. 2 shows that the energy range studied by us is located in the region of maximum cross section or near it. As is known, the theoretical computation of effective cross sections of inelastic processes is possible for either slow collisions, when $v_u \ll v_0$ (v_u is the relative velocity of the colliding particles, v_0 is the velocity of the electrons in the atom) or for fast collisions, when $v_u \gg v_0$. For collisions accompanied by exchange of electrons, such computations were made only for the simplest ion-molecule pairs (protons and singly charged ions of helium in hydrogen and helium) and for single electron exchanges. For the simplest atomic collision $H_1^+ + He \rightarrow H_1^- + He^{++}$, accompanied by an exchange of two electrons, computation of effective cross section σ_{1-1} for slow collisions was made by Rosentsveig and Gerasimenko[6]. The results obtained by them on the dependence of cross section σ_{1-1} on energy are shown by the dotted lines in Fig. 4. At 9.5 kev, the smallest energy in the energy range investigated by us, the computed theoretical value of σ_{1-1} is approximately three times greater than the experimental value. Such a disagreement is quite understood since at the energy of 9.5 kev the condition of slow collisions is not fulfilled. It would be of considerable interest, to refine, on one hand, the theoretical computation of the effective cross section of σ_{1-1} for collisions of protons with helium atoms and on the other to make experimental investigations in the proton energy range of 100 to 1000 ev where the criterion of slowness of collisions is well fulfilled.

The position of the maximum on the curve of dependence of cross section of nonelastic processes on energy is determined by Massey's[7] criterion:

$$a\,|\Delta\varepsilon\,|\,/\,hv_u \approx 1, \qquad (8)$$

where a is the range of the force of mutual action between the colliding particles, $\Delta\epsilon$ the resonance defect, i.e., the change in the internal energy of the particles as the result of their interaction, h = Planck's constant.

The resonance defect for the collision of a proton with two atoms of helium which is accompanied by the exchange of two electrons, is equal to the difference between the energy released at the formation of the negative hydrogen ion and the energy spent in the double ionization of the helium atom. In the case under consideration, $|\Delta\epsilon| = 64.4$ ev. If we consider that the maximum cross section σ_{1-1} for the process $H_1^+ + He \rightarrow H_1^- + He^{++}$ is observed at an energy of 14.0 kev, we have according to Eq. (8), $a \approx 1$ A. Computation shows that the parameter a for collisions between the same particles, but with single electron exchanges, is of the order of 8A. This result appears reasonable since for the exchange of two electrons the particles must be in closer proximity than for the exchange of single electrons. Similar conditions prevail for collisions of a proton with a hydrogen molecule. For the exchange of two electrons between these particles $\Delta\epsilon$=35.5 ev (see Ref. 1), the maximum cross section is observed at 17.5 kev, which yields, according to Eq. (7), $a = 2A$. For the single electron exchange the parameter $a \sim 26\,A$.

It woukd be interesting, for the understanding of the processes of negative ion foramtion, to study atomic collisions with the capture of one electron by the neutral particle. There are no data on direct experimental measurements of effective cross sections σ_{0-1} for such a process, but it is possible to evaluate this cross section for hydrogen atoms in hydrogen, from the known values of other effective cross sections for collisions of protons, hydrogen atoms and negative hydrogen atoms with molecules of hydrogen.

Assuming that the effective cross section σ_{-11} for the loss of two electrons by a negative hydrogen ion through a single collision with a molecule of hydrogen for the energy range investigated by us is equal to zero, the following expression for the cross section σ_{0-1} can be obtained by making use of Eq. (4):

$$\sigma_{0-1} = \frac{[(I^- + I^+)/I^0]_p}{1+(I^-/I^+)_p}\{[(\sigma_{-10} - \sigma_{10}) + \sigma_{10}]\,(I^-/I^+)_p - \sigma_{1-1}\}. \qquad (9)$$

For the computation of σ_{0-1} we have used values of $[(I^- + I^+)/I^0]_p$, obtained in Ref. 8, values of $(I^-/I^+)_p$ and σ_{1-1} as measured in the present work, cross section σ_{10} as measured in Ref. 2. The values of σ_{10} and $(\sigma_{-10} - \sigma_{10})$, were determined by Whittier[4]. We consider the values of the difference $(\sigma_{-10} - \sigma_{10})$, as measured by Whittier more reliable since this value was determined from the tangent of the slope of a semilogarithmic dependence, (see Fig. 8 in Ref. 4) the extrapolation of which to zero pressure gives values of $(I^-/I^+)_p$ not much different from ours. On the other hand the value of σ_{10} obtained by Whittier by subtracting the value $(\sigma_{-10} - \sigma_{10})$ from σ_{-10} is roughly twice smaller than the most reliable values obtained by other authors[2,5,9], which points to a systematic error in the determination of cross section σ_{-10}. For this reason we preferred, in computing cross sections σ_{0-1}, to use Eq. (9), and the values of $(\sigma_{-10} - \sigma_{10})$ from Ref. 4.

Computations of cross section σ_{01} were also made by Whittier, who considered cross sections σ_{-11} and σ_{1-1} equal to zero. In Fig. 6 are given curves of cross section σ_{0-1} dependence on energy, computed by us (solid curve) and by Whittier (dotted curve). It is interesting to note that the magnitude of the effective cross section σ_{0-1} is only 1½ to 2 times greater than the cross section σ_{1-1}

---

[6] L. N. Rosenzweig and V. I. Gerasimenko, Works (Trudy) of the Phys.-Mat. Dept., Univ. of Kharkov, 6, 87 (1955).

[7] H. S. W. Massey and E. H. Burhop, *Electronic and ionic impact phenomena*, Oxford, 1952.

[8] H. Bartels, Ann. Physik **13**, 373 (1932).

but is 40 to 50 times smaller than cross section σ_{10}.

There exists another possible method of computing σ_{0-1} using equation (7) which, taking $\sigma_{-11} = 0$, can be written in the form

$$\sigma_{0-1} = \{2\delta (kT/L)^2 - \sigma_{1-1}[\sigma_{1-1} - (\sigma_{-10} - \sigma_{10})]\}/\sigma_{10}. \quad (10)$$

Substituting here the value $\delta = 1.03 \times 10^3$, obtained from the curve in Fig. 1, and also the values of σ_{1-1}, σ_{10}, $(\sigma_{-10} - \sigma_{10})$ and kT/L we obtain for the energy 29 kev cross section $\sigma_{0-1} = 1.3 \times 10^{-17}$ cm^2. By computing σ_{0-1} according to Eq. (9) we obtain for this energy the value 0.8×10^{-17} cm^2. Considering the large errors in the measurements of the quantities entering into equations (9) and (10) the agreement between the values of σ_{0-1} computed by two different methods must be considered satisfactory.

In conclusion we consider it a pleasant duty to thank Prof. A. K. Val'ter for his constant interest and attention to this work and also V. Z. Surkov for his practical help in the construction and arrangement of the equipment.

Translated by J. L. Herson
88

SOVIET PHYSICS JETP VOLUME 3, NUMBER 2 SEPTEMBER, 1956

Nucleomesodynamics in Strong Coupling. II. The Ground and Isobar States, Nucleon Charge and Spin

V. N. BAIER AND S. I. PEKAR
Institute of Physics, Academy of Sciences, Ukrainian SSR
(Submitted to JETP editor July, 28, 1954)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 317-329 (February, 1956)

A nucleon is considered that interacts strongly with a pseudoscalar meson field. The interaction is assumed to be of the symmetric pseudovector type. The eigenvalues of the energy, charge and spin of the nucleon are determined, and also the explicit form of the wave function of the system. The ground and isobar states of the system are obtained.

1. WAVE EQUATION OF THE MESON FIELD IN THE ABSENCE OF THE NUCLEON

IN a previous paper[1] (which appears in this issue of the journal and which shall be referred to later as I), an approximate method is given for the consideration of a nucleon which interacts strongly with the meson field. The Hamiltonian of the system was simplified with the aid of a series of approximations and the spin-charge part of the wave function was determined. As a result the problem of the determination of the stationary quantum states of the system reduces to finding the eigenfunction and eigenvalues of the operator

$$\hat{H} = -G + {}^1/_2 \sum_{\alpha \vec{\varkappa}} \omega_{\vec{\varkappa}} \left[(q_{\alpha\vec{\varkappa}} - q^{v}_{\alpha\vec{\varkappa}})^2 - \partial^2 / \partial q^2_{\alpha\vec{\varkappa}} \right]. \quad (1)$$

[1] S. I. Pekar, J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 304 (1956); Soviet Phys. JETP 3, No. 3 (October, 1956).

ERRATA
(both of our own and of JETP)

Vol.	Page	Column	Line	Reads	Should read
2	434	2	22	27.3 μ	23.7 μ
2	557	Fig. 10			On the right hand side, abscissa values should read 0, 200 400, 600, 800, 1000.
2	591	2	7	$A = \frac{e^2 H_0^{\ 2} \delta_{00}}{mc^2}$	$A = \frac{e^2 H_{00}^{\ \ 2} \delta_{00}^{\ \ 2}}{mc^2}$
2	754	1	3 ff.	———————	[14] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **82**, 380 (1951). [15] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **83**, 234 (1951).
2	771	1	10	Intermediate State	Intermediate State of Tin
	771	1	19	sphere of lead	sphere of tin
3	145	1	1	$R = 10\ ec$	$R = 1/ec$