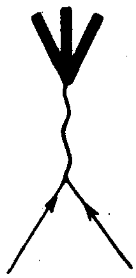

Fig. 3

a magnetic field at the point of encounter even at a zero scattering angle. An important competitor of the two-photon production is the hadron "bremsstrahlung" process (Fig. 2), which likewise does not decrease with increasing energy. This process can be calculated fully if the cross sections for single-photon annihilations into hadrons is known (Fig. 3). It is important here that the amplitudes of the processes in Figs. 1, 2a, and 2b do not interfere pairwise.

The existence of these methods of hardon production must be taken into account in the interpretation of colliding-beam experiments.

Thus, accelerators with colliding electron and (or) positron beams can be used as sources of colliding photon beams, i.e., for the study of the "condensation" of photons into hadrons at high energies. The characteristic cross sections of such processes are 10^{-33} - 10^{-34} cm^{-2}.

[1] F.I. Gilman, Preprint, SLAC-PUB-674, 1969.
[2] P.C. DeCelles and I.F. Goehl, Phys. Rev. 184, 1617 (1969).

ANOMALOUS VIBRATIONAL EXCITATION OF THE CO^+ ION PRODUCED UPON COLLISION OF NOBLE-GAS IONS WITH CO MOLECULES

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Recent papers [1 - 3] have reported deviations from the Franck-Condon law upon population of the vibrational levels of excited electronic states of diatomic molecular ions produced in slow collisions of ions with molecules in the electronic ground state. In [1, 2] there was observed an increase of the population of vibrational levels with vibrational quantum numbers v' = 1, 3, and 3 of the state $B^2\Sigma_g^+$ of the molecular ion N_2^+ excited by collision of different ions of velocity $v < 1 \times 10^8$ cm^2/sec with N_2 molecules.

A deviation from the Franck-Condon principle was observed in [3] upon population of the vibrational levels v' = 0, 1, 2, 3, 4, and 5 of the excited electronic state $A^2\Pi$ of the CO^+ ion produced in collisions between Ar^+ ions of energy 1 keV with CO molecules.

It was of interest to study the effect of anomalous population of the vibrational levels of the $A^2\Pi$ state of the CO^+ ion produced by collisions of various ions having velocities $v < 1 \times 10^8$ cm/sec with the CO molecule. In the present investigation, the molecular ion CO^+ in the state $A^2\Pi$ was produced in collisions between He^+, Ne^+, and Ar^+ ions of energy 0.16 - 30 keV with CO molecules. The experimental setup used for the measurements is described in [1]. The effective cross sections σ for the productions of the $CO^+(A^2\Pi)$ ions in different vibrational states were determined in relative units by measuring the intensities of the bands of the system of comet tails, emitted in $A^2\Pi$ -- $X^2\Sigma$ transitions ($X^2\Sigma$ is the ground state of the CO^+ ion). The functions $\sigma(v)$ were determined for the bands of the comet-tail systems with vibrational transitions (0, 1), (1, 0), (2, 0), (2, 1), (1, 1), (3, 0), and (4, 2). Figure 1 shows the functions $\sigma(v)$ for the (2, 0) band, excited by collisions with He^+, Ne^+, and Ar^+ ions. The functions for the other bands of the $A^2\Pi$ -- $X^2\Sigma$ system were similar. The measured effective excitation cross sections of $A^2\Pi$ -- $X^2\Sigma$

system and the probabilities of the transitions between the states $A^2\Pi$ and $X^2\Sigma$ of the CO^+ ion, taken from [4], were used to calculate the relative populations of the vibrational levels v' = 0, 1, 2, 3, 4 of the state $A^2\Pi$ of the CO^+ ion.

The dependences of the populations of these vibrational levels on the velocities of the ions He^+, Ne^+, and Ar^+ are shown in Fig. 2. The dashed lines parallel to the abscissa axis are drawn at a height corresponding to the population of the given vibrational level of the CO^+ ($A^2\Pi$) ion in accord with the Franck-Condon principle. We determined these populations experimentally from the measured relative intensities of the bands of the $A^2\Pi$ -- $X^2\Sigma$ system, excited by 600-eV electrons. The experimental and calculated [5] values of these populations turned out to be close.

Turning to Fig. 1, we can state that the rapid decreases of σ with increasing incident-particle velocity, stops starting with (1 - 4) × 10^7 cm/sec, and the effective cross section of the processes decreases very slowly with further decrease of the velocity; in the case of the He^+ ions there is

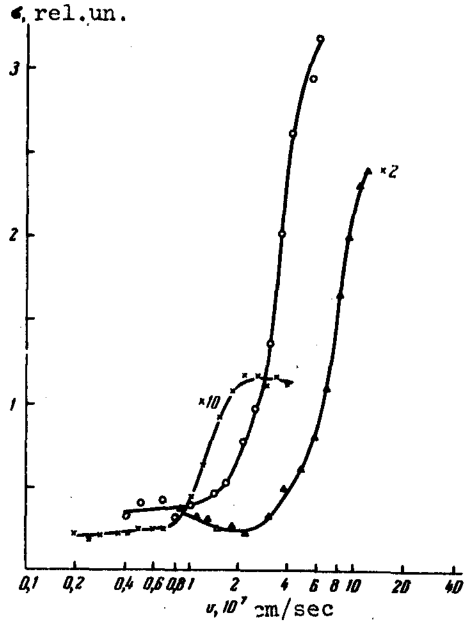

Fig. 1. Excitation function of the (2, 0) band of CO^+ ions ($A^2\Pi$ -- $X^2\Sigma$): Δ = He^+, o - Ne^+, × - Ar^+.

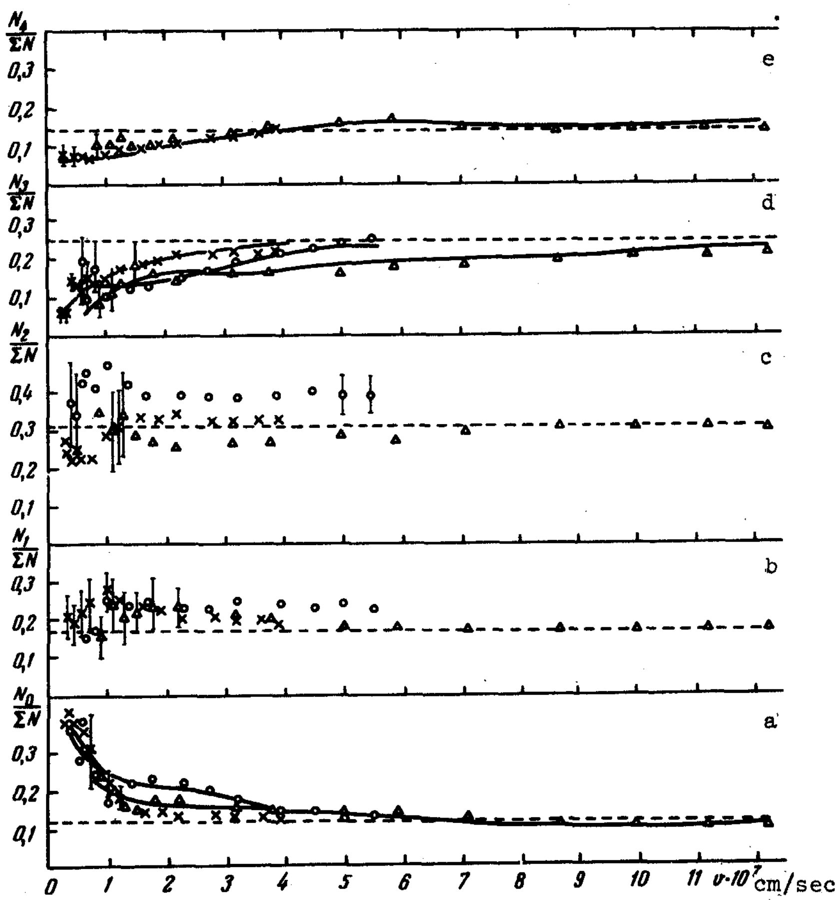

Fig. 2. Relative population of vibrational levels of the $A^2\Pi$ state of the CO^+ ion vs. velocity of incoming particles: Δ - He^+, o - Ne^+, × - Ar^+.

even a tendency of σ to increase.

The region of velocities in which the slow change of σ with velocity is observed is the adiabatic region. This conclusion is based on the fact that this region is appreciably shifted towards decreasing velocities relative to the maximum of the $\sigma(v)$ curve[1)].

We can thus state that in the velocity region $v < (1 - 4) \times 10^7$ cm/sec the shape of the $\sigma(v)$ curve differs from that expected on the basis of Massey's adiabatic hypothesis.

An examination of Fig. 2 shows that the points showing the dependence of the relative population of the vibrational level of the $CO^+(A^2\Pi)$ ion on the velocity of the incident particles at velocities $v > (2 - 4) \times 10^7$ cm/sec lie on the dashed straight line. This means that the population of the vibrational levels of the $A^2\Pi$ state of CO^+ produced by collision between an incident particle and a CO molecule proceeds in accord with the Franck-Condon principle. However, at velocities $v < (2 - 4) \times 10^7$ cm/sec the populations of the vibrational levels of the $CO^+(A^2\Pi)$ ion deviate from the values corresponding to the Franck-Condon principle. For the level $v' = 0$, the population increases, and decreases for the levels $v' = 3$ and 4 in comparison with the populations in accordance with the Franck-Condon principle. The deviation increases with decreasing velocity of the incoming particle. In the case of the levels $v' = 1$ and 2, the deviation does not exceed the measurement error.

A comparison of the curves shown in Figs. 1 and 2 leads to the conclusion that the velocity regions in which the $\sigma(v)$ curves exhibit an anomalous behavior and deviations from the Franck-Condon law take place in the population of the vibrational levels of the CO^+ ion approximately coincide. This allows us to suggest that both effects result from one cause. At the present time, the anomalous form of the $\sigma(v)$ curves in the adiabatic region of velocities is explained on the basis of the hypothesis that the potential-energy surfaces of the initial and final states of the system of colliding particles come close together or intersect. The same circumstance may be one of the causes of the anomalous population, compared with that resulting from the Franck-Condon principle, of the vibrational levels of the $CO^+(A^2\Pi)$ ion produced upon decay of the quasimolecule produced when the incident ion collides with a CO molecule.

[1] G.N. Polyakova, Ya.M. Fogel', V.F. Erko, A.V. Zats, and A.G. Tolstolutskii, Zh. Eksp. Teor. Fiz. 54, 374 (1968) [Sov. Phys.-JETP 27, 201 (1968)].
[2] J.H. Moore, Jr. and P. Doering, Phys. Rev. 177, 218 (1969).
[3] M. Lipeles, J. Chem. Phys. 51, 1252 (1969).
[4] R.W. Nichols, Can. J. Phys. 40, 1772 (1962).
[5] M.E. Wacks, J. Chem. Phys. 41, 930 (1964).

[1)] The values of v_{max} (v_{max} - velocity of the incoming particles, at which the effective cross section of the process has a maximum), calculated on the basis of the well-known Massey-Hasted criterion, turn out to be 1.3×10^8, 7.8×10^7, and 2.1×10^7 cm/sec respectively for the ions He^+, Ne^+, and Ar^+.