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Abstract

Full Text

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Yu. S. Sayasov

On the Probability of Electron Capture by Neutral Atoms in Triple Collisions

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The capture of electrons by neutral atoms or molecules in the presence of a third (heavy) particle, which carries away the excess energy, plays an important role in many phenomena (ionization in combustion processes, gas discharge, the ionosphere). Nevertheless, at present there are no data (theoretical or experimental) on the probabilities of this process that possess even qualitative reliability. Recently, however, sufficiently accurate measurements have appeared of the cross section of the reverse process ([1])—the detachment of an electron from the negative ion of the hydrogen atom in its collisions with hydrogen molecules:

$$H^- + H_2 = H + H_2 + e,$$

measured by irradiating hydrogen with a monochromatic beam of H^- ions. In the present note a calculation is given of the coefficient of electron capture α cm^6/sec in the process

$$e + H + H_2 = H^- + H_2$$

from data on the cross sections of the process

$$H^- + H_2 = H + H_2 + e.$$

From the condition that the total numbers of collisions of the two kinds per unit time are equal at equilibrium, we have:

$$\alpha\,(e)(H)(H_2) = \alpha^*(H^-)(H_2) \qquad (1)$$

(the concentrations of H^- and H are assumed small in comparison with the concentration of H_2). From relation (1), knowing the value of the ionization coefficient α^*, one can calculate α:

$$\alpha = \alpha^* \frac{(\mathrm{H}^-)}{(\mathrm{e})(\mathrm{H})} = \alpha^* K(T), \tag{2}$$

where

$$K(T) = \frac{(2\pi)^{3/2}}{4} \frac{h^3}{(mkT)^{3/2}} e^{\Delta E/kT} = 3.25 \cdot 10^{-21} \theta^{-3/2} e^{8.7/\theta}$$

is the equilibrium constant $\mathrm{H}^- \rightleftarrows \mathrm{H} + \mathrm{e}$ ([2], p. 332); $\Delta E = 0.747$ eV is the ionization energy of H^-; m is the electron mass; $\theta = T^\circ\mathrm{K}/1000$; $h = 1.05 \cdot 10^{-27}$ erg · sec.

The quantity α^* can be determined from the data of ([1]) in the following way. From quite general considerations it follows that the ionization cross section, under the condition that the effective collision time a/v (a is the effective size, v is the relative velocity of the colliding particles) is much greater than the transition time between the electronic states of the system with energy difference ΔE, equal to $2\pi h/\Delta E$, must be described by the formula ([3])

$$\sigma = \sigma_0 e^{-c\Delta E a/2\pi\hbar v}, \qquad c \sim 1. \tag{3}$$

The data of ([1]) for the range of H^--ion energies from 6.8 to 75 eV can in fact be represented with sufficient accuracy by the empirical formula

$$\sigma = 1.67 \cdot 10^{-16} e^{-5.7 \cdot 10^6/v},$$

where $\exp(-5.7 \cdot 10^6/v)$ has a reasonable value, since for $\Delta E = 0.747$ eV, $\Delta E a/2\pi\hbar v = 2 \cdot 10^6/v$. The coefficient α^* cm^3/sec is, obviously, the result of averaging the quantity σv over the Maxwellian velocity distribution of H^- and H_2:

$$\alpha^* = \sigma_0 v_T \frac{4}{\sqrt{\pi}} \int_0^\infty e^{-\varkappa/c - c^2} c^3 \, dc, \tag{4}$$

where $v_T = (2kT/\mu)^{1/2}$; $\mu = \frac{2}{3} m_H$ is the reduced mass of H^- and H_2; $c = v/v_T$; $\varkappa = 5.7 \cdot 10^6/v_T$. For $\varkappa \gg 1$, as will be assumed below, the integral (4) is easily evaluated by the saddle-point method. The function $-(\varkappa/c + c^2)$ has a maximum at $c_m = (\varkappa/2)^{1/3}$, and the principal role is played by the region of values of c close to c_m, i.e., one may use the expansion $\varkappa/c + c^2 = 3(\varkappa/2)^{2/3} + 6(c - c_m)^2 + \ldots$. Hence we readily find*

$$\alpha^* = \sigma_0 v_T \frac{1}{\sqrt{3}} \varkappa e^{-3(\varkappa/2)^{2/3}} = 5.50 \cdot 10^{-10} e^{-9.6/\theta^{1/3}}. \tag{5}$$

The final expression for the capture coefficient α therefore has the form

$$\alpha = 1.8 \cdot 10^{-30} \theta^{3/2} e^{-9.6/\theta^{1/3} + 8.7/\theta} \text{ cm}^6/\text{sec}.$$

We give a table of values of α:

θ	1	1.5	2	2.5	3	3.5
α	$0.74 \cdot 10^{-30}$	$1.08 \cdot 10^{-31}$	$2.5 \cdot 10^{-32}$	$1.34 \cdot 10^{-32}$	$0.78 \cdot 10^{-32}$	$0.61 \cdot 10^{-32}$

The values of α given above provide an approximate idea of the orders of magnitude of the coefficient of electron capture by various atoms or molecules with the participation of a third particle in the indicated temperature range. It should be noted that the values of α found here greatly exceed those determined from the approximate formula given in ([6]), p. 39:

$$\alpha \sim \sigma_H \sigma_{H_2} a \lambda v_{\text{el}} \sim 10^{-34}\text{–}10^{-35} \text{ cm}^6/\text{sec},$$

where σ_H, σ_{H_2} are the geometrical cross sections of H and H_2; a is a quantity of order 10^{-8} cm; $\lambda \sim 10^{-2}$–10^{-3} is the probability of transfer of the electron energy to H_2 molecules; $v_{\text{el}} \sim 10^7$ cm/sec is the electron velocity at $T \sim 1000^\circ$K.

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Institute of Chemical Physics
Academy of Sciences of the USSR

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CITED LITERATURE

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* As is known, a formula analogous to (5) is obtained for the probability of thermonuclear reactions (see, for example, ([5])).

Note: Figure translations are in progress. See original paper for figures.