RESONANCE CHARGE EXCHANGE IN ATOMIC HYDROGEN

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The charge exchange cross sections for protons with energies $E > 0.01$ eV moving in atomic hydrogen were calculated using a previously derived integral expression for the probability.[11] For $0.01 \text{ eV} < E < 2.5$ keV and $E > 1$ MeV they can be expressed by simple analytic formulas. The contribution of excited states is taken into account. The largest divergences from the results of other less exact calculations are observed at velocities v of the order of $e^2/\hbar$.

THE resonance charge exchange

$$H^+ + H \rightarrow H + H^+ \qquad (1)$$

has been studied many times both for high[1-7,11] and low[7-11] velocities. Although knowledge of the cross section of this process for all energies E from thermal to 1 MeV is needed in various applications, there is a lack of satisfactory data for moderate ($v \approx e^2/\hbar$) and very low ($E < 1$ eV) velocities. The present paper fills this gap.

Also, Bassel and Gerjuoy[6] showed that none of the previous calculations give correct charge-exchange cross sections for the process (1) at energies from 25 to 400 keV because of an incorrectly selected perturbation. The approximation of Brinkman and Kramers (BK)[2] gives values which are too high, while the approximation of Bates, Dalgarno, Jackson, and Shiff[3-5] give values which are too low. In the $v \rightarrow \infty$ limit the charge-exchange cross section is given by the BK formula.[2] It has been established[7] that the BK result is also valid for charge exchange in general and it has been shown that the difference between the exact probability and the BK probability decreases in proportion to v^{-1} when taken relative to each of these probabilities.

The present paper extends the calculations of Bassel and Gerjuoy[6] to relativistic energies. The contribution from charge exchange to excited states is taken into account.

In an earlier paper[11] the present author used a parametric method to obtain an integral expression for the probability of resonance charge exchange and this expression is used here as a starting point. The results of the present calculations, together with other theoretical values of the cross section σ_1 for charge exchange to the ground state[2,3] and experimental results,[12-15] are shown in Figs. 1 and 2. Figure 2 does not include the curve of Bassel and Gerjuoy[6] for the energies 25—400 keV because this curve exceeds our results by only 10% at the lower end of this energy range and coincides with our curve above 60 keV.

Curve M2 in Fig. 2 gives the total cross section σ for the process of Eq. (1). It was calculated using the formula

$$\sigma = \sigma_1 + (\sigma_1/\sigma_1^{(BK)})\,(\sigma_2^{(BK)} + \sigma_3^{(BK)} + 1.50\sigma_4^{(BK)}), \qquad (2)$$

which can be easily obtained using the results of Oppenheimer, Bates, and Dalgarno.[1,5] Here σ_n^{BK} is the cross section for charge exchange with the transition of an electron to a state with principal quantum number n, as calculated in the Brinkman-Kramers approximation.[2]

For $E > 1$ MeV we have

$$\sigma = 1.2\sigma_1, \quad \sigma_1 = \sigma_1^{(BK)} = 11.25E^{-1}\,(1 + 10E)^{-5} \qquad (3)$$

where the cross sections are in units of 10^{-17} cm^2, and E is in MeV. For $E < 2500$ eV the following approximate formula is accurate to within 10%:

$$\sigma(E) = 7.7\,(\lg E - 7.9)^2 \qquad (4)^*$$

where the cross section is in units of 10^{-17} cm^2 and E is in eV. The parametric method used to obtain the above formula is valid in general for resonance charge exchange at $E > 0.01$ eV. Thus Eq. (4) can certainly be used for $0.01 \text{ eV} < E$ 2500 eV.

In the case of any pair of identical atoms the resonance charge exchange cross section for small v (see, for example, [8]) is given by

$$\sigma(E) = 13.5U^{-1}\,7.7\,[\lg(E/A) - 7.9]^2, \qquad (5)$$

*$\lg = \log_{10}$.

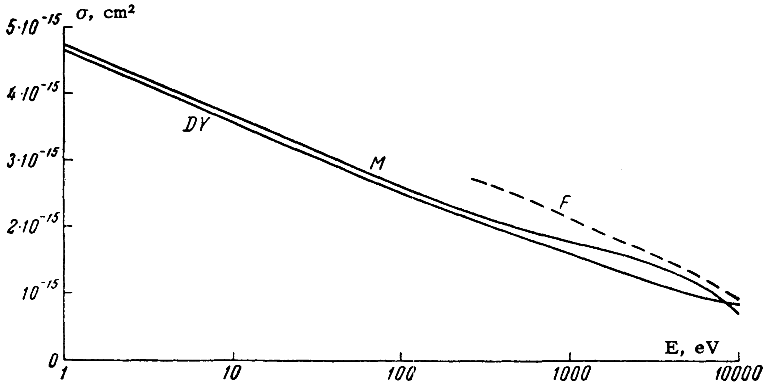

FIG. 1. Cross sections for charge exchange by protons in atomic hydrogen at low v. The continuous curves represent theory, and the dashed one is experimental; M are the results of the present work, DY are the results of Dalgarno and Yadav,[10] F is the curve of Fite, Brackmann and Snow.[12]

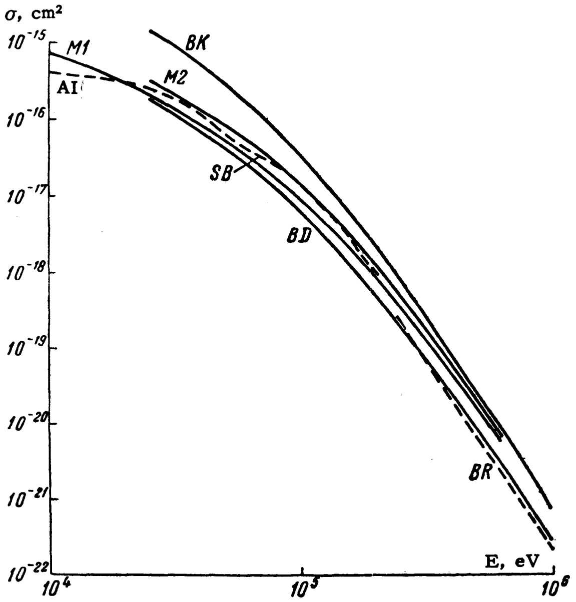

FIG. 2. Cross sections for charge exchange by protons in atomic hydrogen at high v. The continuous curves represent theory, and the dashed ones are experimental; M1 and M2 are the results of the present work for the cross section for charge exchange to the ground state (σ_1) and for the total cross section (σ) respectively; BD are the results of Bates, Dalgarno, Jackson and Schiff[3,4] for charge exchange to the ground state; BK is the Brinkman-Kramers curve[2] for charge exchange to the ground state; AI represents the data of Afrosimov, Il'in, and Fedorenko;[13] SB are the results of Stier and Barnett;[14] BR are the results of Barnett and Reynolds.[15]

where U is the ionization potential in eV and A is the atomic weight of the element.

There are no universal formulas for high and moderate velocities (see Sec. 3 in [11]).

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204