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Collisional-Quenching Processes in H(2s)

R. A. Baragiola* and E. R. Salvatelli†
Centro Atómico Bariloche, Comisión Nacional de Energía Atómica, Instituto de Física "Dr. José A. Balseiro," Universidad Nacional de Cuyo, San Carlos de Bariloche, Río Negro, Argentina
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We have resolved quantitatively different collisional-quenching processes of H(2s) by means of a calculation using measured charge equilibrium fractions and cross sections. The results show that at 5 keV and for neon as a target, quenching to the ground state H(1s) is the dominant process.

Recent measurements by Kroktov and Medeiros (KM),[1] Byron *et al.*,[2] and Dose *et al.*[3] have brought up an interesting question as to which is the most efficient mechanism for the destruction of metastable hydrogen atoms colliding with gases at low keV energies.

While KM and Byron *et al.* state that the predominant process is collisional deexcitation via

$$H(2s)+X\to H(2p)+\cdots\to H(1s)+\cdots .$$

Dose *et al.* conclude that quenching should be attributed mainly to

$$H(2s)+X\to H^-(1s)^2+X^+.$$

Accurate theoretical calculations by Bates and Walker[4] on the cross section for electron loss from H(2s) show that the ratio of this cross section to that for total quenching as measured by Dose *et al.* is nearly 1 at energies above 30 keV, decaying rapidly at lower energies, so that this ratio is 0.5 around 10 keV and 0.2 at about 3 keV.

In order to determine the relative importance of the above-mentioned processes, we carried out a calculation using charge equilibrium fractions and cross sections in a four-component system. Let us denote by the indices $g, m, 1$, and $\bar{1}$ the states H(1s), H(2s), H^+, and $H^-(1s)^2$, respectively. Let Φ_i be the equilibrium fractions and $Q_i=\sum_{i\neq j}\sigma_{ij}$, where σ_{ij} is the cross section for the transition between the initial state i and the final state j. In equilibrium we get

$$\Phi_0=\Phi_m+\Phi_g\,,$$

$$\Phi_m(Q_m+\sigma_{gm})=\Phi_1\sigma_{1m}+\Phi_0\,\sigma_{gm}+\Phi_{\bar{1}}\,\sigma_{\bar{1}m},$$

$$\Phi_0\,Q_g=\Phi_m(\sigma_{mg}+Q_g)+\Phi_{\bar{1}}\,\sigma_{\bar{1}g}+\Phi_1\sigma_{1g}\,,$$

$$\Phi_1\,Q_1=\Phi_m(\sigma_{m1}-\sigma_{g1})+\Phi_{\bar{1}}\,\sigma_{\bar{1}1}+\Phi_0\,\sigma_{g1}\,,$$

$$\Phi_{\bar{1}}\,Q_{\bar{1}}=\Phi_m(\sigma_{m\bar{1}}-\sigma_{g\bar{1}})+\Phi_1\sigma_{1\bar{1}}+\Phi_0\,\sigma_{g\bar{1}}\,,$$

where any three of the last four equations are linearly independent.

In view of the availability of cross-section data, the calculation was done for Ne as a target gas and at an energy of 5 keV. Because of discrepancies between different published values of the equilibrium fractions, it was felt necessary to remeasure them with higher accuracy. Using the experimental setup described elsewhere,[5] we obtained the results presented in Table I. The cross sections used in the calculation were taken from the literature and their values are listed in Table II.

By using these data in the previous equations and taking due account of propagation of errors we arrive at

$$\Phi_m=0.0209\pm0.0097,\quad \sigma_{mg}=(69\pm45)10^{-17}\ \mathrm{cm}^2,$$

$$\sigma_{m\bar{1}}<1.1\times10^{-17}\ \mathrm{cm}^2,\quad \sigma_{m1}=(21\pm19)10^{-17}\ \mathrm{cm}^2,$$

$$\sigma_{mg}-\sigma_{m1}=(48\pm45)10^{-17}\ \mathrm{cm}^2\,.$$

Here, we have applied the constraint that $\sigma_{m\bar{1}}$ be positive. The uncertainty associated with σ_{mg} is due primarily to the uncertainty in the determination of $Q_m+\sigma_{gm}$ by Byron, Kroktov, and Medeiros, whereas the main uncertainty in σ_{m1} and $\sigma_{m\bar{1}}$ comes from uncertainties in quantities other than $Q_m+\sigma_{gm}$.

This calculation supports the standpoint of Kroktov and Byron in the sense that quenching of H(2s) by collisions leads primarily to ground-state atoms.

Measurements by Donnally and Sawyer[10] on Ar provide further arguments against Dose's conclusions. They show a larger probability for electron capture from H(2s) than from H(1s) at energies below 3 keV, which they attributed to pseudocrossing of potential-energy curves. With 25% of their neutral beam in the metastable level[11] the ratio $\sigma_{m\bar{1}}/\sigma_{g\bar{1}}$

TABLE I. Equilibrium fractions for H on Ne at 5 keV.

i	Φ_i	Error (%)
0	0.659	0.7
1	0.325	1.5
$\bar{1}$	0.0160	2.5

TABLE II. Cross sections for H on Ne at 5 keV (in units of 10^{-17} cm^2).

Cross section		Maximum relative error (%)	Reference
σ_{g1}	10.0	5	6
$\sigma_{g\bar{1}}$	0.90	5	6
σ_{gm}	2.64	15	7
σ_{1g}	20.9	2	6, 8
σ_{1m}	0.17	50	8
$\sigma_{1\bar{1}}$	0.044	2	6
$\sigma_{\bar{1}g}$	25.7	11	6, 7
$\sigma_{\bar{1}m}$	5.4	21	7
$\sigma_{\bar{1}1}$	3.3	8	6
$Q_m+\sigma_{gm}$	90	45	1, 9

is only about 1.8 at 3 keV, rising rapidly at lower energies. Moreover, it could be expected that at energies greater than 10 keV for which pseudocrossing is unimportant, $\sigma_{m\bar{1}}$ could be even smaller than $\sigma_{g\bar{1}}$ in spite of a lower energy defect, due to the fact that to form $H^-(1s)^2$ from H(2s) requires simultaneously a $2s \rightarrow 1s$ transition and the pickup of a 1s electron.

We conclude that deexcitation to ground state is, at least at the energy of the present discussion, the most important mechanism in the collisional destruction of metastable hydrogen.

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*Fellow of the Argentine "Consejo Nacional de Investigaciones Científicas y Técnicas."

†Captain "Fuerza Aérea Argentina."

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Evolution of Electron Angular Momentum due to Spin-Exchange Collisions Involving Nuclear Spin*

S. B. Crampton†
Williams College, Williamstown, Massachusetts 01267
(Received 4 August 1970)

The evolution of electronic angular momentum due to spin-exchange collisions between two species of ground-state alkali atoms is shown to depend substantially on nuclear spin when the effects of spin precession between collisions are included with the effects of the collisions themselves. General results are illustrated for nuclear spin $\frac{1}{2}$ and 1.

I. INTRODUCTION

In a recent paper Lambert[1] showed that the rate of change of electron polarization of one electron-spin-$\frac{1}{2}$ atomic species due to electron-spin-exchange collisions with a second electron-spin-$\frac{1}{2}$ species is independent of nuclear spin. It was argued that this result reaffirms the original assertion by Balling, Hanson, and Pipkin (BHP)[2] that the equations describing the effects of spin-exchange collisions on electron polarization derived using systems with no nuclear spin also hold for systems having nuclear spin. We wish to point out that when the effects of spin precession between collisions are also taken into account, the equations for the evolution of electron angular momentum are substantially different for nonzero nuclear spin. For nuclear spin $I=0$, the z component of electron spin commutes with the free-space Hamiltonian which describes the evolution of spin states between collisions, so that changes of electron polarization re-