EXCITATION OF H 2s BY ELECTRON IMPACT

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The cross section, $Q_T(2s)$, for production of H 2s atoms by electron bombardment of ground-state atoms, has been measured by Lichten and Schultz[1] and by Stebbings, Fite, Hummer, and Brackmann.[2] The results obtained have been discussed by Lichten[3] and are discussed further in the present Letter.

In the LS experiment measurements were made for energies up to 45 ev. The shape of the curve appears to be determined accurately, but the absolute values are much less certain, the measured maximum cross section being $(0.28 \pm 0.14) \times \pi a_0^2$. The published results of LS are obtained on normalizing to the first Born approximation at energies of 30-40 ev; this gives a maximum cross section of $0.36\pi a_0^2$. In the SFHB experiment measurements were made for energies up to 700 ev. For the determination of the curve shape the SFHB measurements are less accurate than those of LS, but, in the common energy range, the agreement between the two curve shapes is satisfactory. For their absolute values SFHB claim an accuracy much better than that claimed by LS, but Lichten[3] has correctly pointed out that the published values of SFHB must be multiplied by a factor of 1.5 to correct for an erroneous assumption made in the reduction of the data. With this correction the maximum SFHB cross section, $(0.16 \pm 0.01) \times \pi a_0^2$, is consistent with the absolute LS measurement but is not consistent with the LS cross section normalized to the first Born approximation.

In order to discuss the matter further we put $Q_T(2s) = Q_C(2s) + Q(2s)$, where $Q_C(2s)$ is the cross section for the process of excitation of $3p$ and higher states, followed by cascade to $2s$, and $Q(2s)$ is for direct excitation of $2s$. Putting $Q_C(2s) = \gamma Q(3p)$, LS obtain $\gamma = 0.21$ using an extrapolation formula for the higher states. Using Born cross sections[4] we obtain $\gamma = 0.23$. We calculate $Q(3p)$ on assuming that the correction factor by which the Born $3p$ cross section must be multiplied, as a function of $(E/\Delta E)$, is the same as the factor of $2p$ as determined experimentally.[5,6] Figure 1 shows results for $Q(2s)$ obtained from the SFHB measurements. The full-line curve is obtained from the LS results normalized on making a least-squares fit to SFHB.

In Fig. 1 we give the cross section obtained by Smith[7] from a solution of the $1s$-$2s$ coupled exchange equations. Lichten[3] argues that this calculation justifies the procedure of normalizing to the first Born approximation at 30-40 ev. The assumption made is that coupling to intermediate states can be neglected. The coupling most likely to be of importance is that between the $2s$ and $2p$ states. The calculations of Burke and Seaton[8] show that this coupling is fairly strong, but a better estimate of its effect is obtained from the second Born approximation calculations of Kingston, Moiseiwitsch, and Skinner.[9] Figure 1 shows the results they obtain on including the following states in the second Born summation: $(1s, 2s)$, $(2p)$, and $(1s, 2s, 2p)$. It is seen that allowance for coupling to $2p$ brings about a drastic reduction in the cross section.

We compare the second Born $(1s, 2s)$ curve, which represents an approximation to the solution of the $1s$-$2s$ nonexchange equations, with the curve from the exact solution of the $1s$-$2s$ exchange equations. For energies of about 30 ev it is seen that the effect of exchange is to bring about a considerable reduction in the cross section.[10] It may, therefore, be expected that a calculation allowing both for exchange and for coupling to $2p$ would give a cross section smaller than the second Born $(1s, 2s, 2p)$ and, hence, in better agreement with the SFHB results. At higher energies, greater than about 150 ev, the corrections to the first Born approximation are fairly small, and for these energies the SFHB results are in satisfactory agreement with the first approximation.

We conclude that there is no evidence for any discrepancy between the SFHB results and the most recent theoretical work.

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[1]W. Lichten and S. Schultz, Phys. Rev. 116, 1132 (1959); referred to here as LS.

[2]R. F. Stebbings, W. L. Fite, D. G. Hummer, and R. T. Brackmann, Phys. Rev. 119, 1939 (1960); referred to as SFHB.

[3]W. Lichten, Phys. Rev. Letters 6, 12 (1961).

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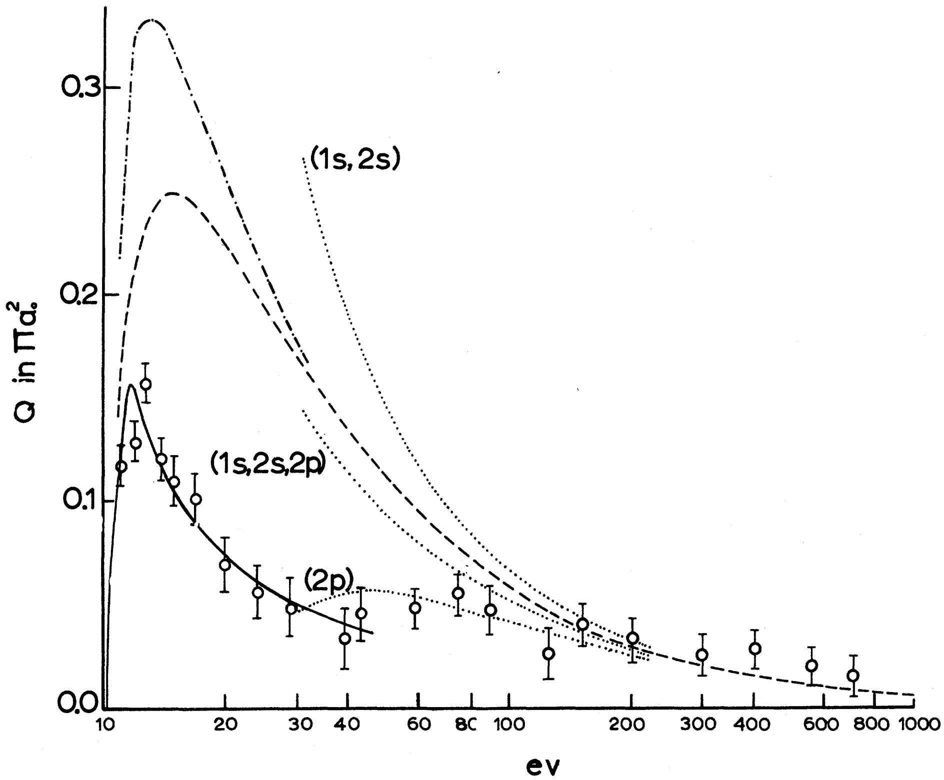

FIG. 1. The cross section for $1s$-$2s$ transitions by electron impact. The experimental points with error bars are from the measurements of SFHB and the full line curve is from the measurements of LS normalized to the SFHB results. The dashed curve is the first Born approximation, the dotted curves are the second Born approximation for various terms included in the summation, and the dot-dashed curve is from the solution of the $1s$-$2s$ exchange equations.

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[6]W. L. Fite, R. F. Stebbings, and R. T. Brackmann, Phys. Rev. 116, 356 (1959).

[7]K. Smith, Phys. Rev. 120, 845 (1960). We have added a small correction, calculated in the first Born approximation, for $l \geq 3$.

[8]V. M. Burke and M. J. Seaton, Proc. Phys. Soc. (London) 77, 199 (1961).

[9]A. E. Kingston, B. L. Moiseiwitsch, and B. G. Skinner, Proc. Roy. Soc. (London) A258, 245 (1960). In the second Born calculations, fourth-order terms in the interaction are neglected in the expressions for the cross sections.

[10]Exact solutions of the $1s$-$2s$ nonexchange equations have been obtained by K. Smith, W. F. Miller, and A. J. P. Mumford, Proc. Phys. Soc. (London) 76, 559 (1960). This gives a cross section smaller than that obtained in the second Born $(1s, 2s)$ approximation but larger than that obtained from exact solutions of the $1s$-$2s$ exchange equations.