Collisions of Electrons with Hydrogen Atoms. IV. Excitation of Lyman-Alpha Radiation near Threshold*

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By use of improved experimental techniques, the cross section for excitation of Lyman-alpha radiation in collisions between electrons and hydrogen atoms has been remeasured. It has been determined that in the threshold region, the results reported previously were somewhat low. The remeasured energy dependence of the cross section near threshold has been found to be as the square root of the excess energy.

I. INTRODUCTION

An earlier paper[1] reported the results of an experiment to measure the cross section for excitation of Lyman-alpha radiation on electron impact. In that experiment a highly dissociated hydrogen beam from a furnace source was crossed by an electron beam, and an oxygen-filtered Lyman-alpha photon counter viewed the region of interaction of the two beams. The atomic beam was modulated at 100 cps by a mechanical chopper and the electron beam was run dc so that the signal arising from the interaction of the two beams could be distinguished above the high dc level of countable photons produced from collisions of the electron beam with the residual gas in the vacuum chamber and with electrodes of the electron gun.

In the course of this earlier experiment, measurements were made of the angular distribution of the emitted photons. Although these measurements appeared satisfactory at electron energies above 25 ev, below this energy an anomaly was encountered. The radiation was apparently not emitted symmetrically about the plane perpendicular to the electron beam direction as expected for electric dipole radiation, but was enhanced in the forward direction.

The conjecture was made that this apparent anomalous angular distribution might be caused by a noncoincidence of Lyman-alpha radiation and the Lyman-alpha window in the oxygen absorption spectrum. In particular, if Lyman-alpha radiation lay slightly on the long wavelength side of this window, the angular distribution anomaly could be explained on the basis of momentum transfer from the incident electron to the excited atom. For the counter looking back into the electron beam, a Doppler shift of the radiation toward shorter wavelengths would permit more of the radiation to pass through the oxygen filter and reach the counter, and conversely.

This conjecture led to another experiment to determine the position of Lyman-alpha radiation with respect to the oxygen window.[2] The atom beam was crossed by an electron beam, and the output of an oxygen-filtered photon counter was measured as a function of azimuthal angle in the plane perpendicular to the electron beam. In this way the thermal velocities of the initial atom beam provided a known Doppler shift. The result of this experiment was that the Lyman-alpha radiation lay in a very nearly flat part of the oxygen window. Thus, the conjecture regarding the angular distribution problem was untenable.

The possibility that the anomalous angular distribution below 25 ev was symptomatic of some systematic failure in the experiment for these energies was the primary reason for an experimental re-examination of the excitation process.

It was expected that a remeasurement of the cross section for Lyman-alpha excitation would give improved results because of several improvements made in the apparatus since the earlier experiments. Among these were (1) the addition of a large final vacuum chamber of greatly improved pumping speed and better vacuum, (2) the replacement of the stainless-steel electron guns by gold-plated guns, where less difficulty with surface effects is encountered, and (3) the incorporation of circuitry to pulse-shape the photon counter output in order to improve the ac signal-to-noise ratio at the low count rates characteristic of electron energies near threshold.

II. EXCITATION OF PHOTONS OBSERVED AT 90°

The experimental approach using modulated photon counting techniques has already been described; for observation of photons emitted perpendicular to the direction of the electron beam, the experiment was performed as previously reported.[1] For such measurements, the measured cross section Q_{90} is not proportional to the total cross section, but is given by

$$Q_{90}=[3/(3-P)]Q_{\mathrm{tot}}, \qquad (1)$$

where P is the energy-dependent polarization fraction. In the present experiments, as earlier, relative cross section curves were normalized to the Born approximation values at high energies (>250 ev). Both the earlier experiments and theory[3] indicate that at such

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[1] W. L. Fite and R. T. Brackmann, Phys. Rev. **112**, 1151 (1958).
[2] Hummer, Fite, and Brackmann, Bull. Am. Phys. Soc. 4, 67 (1959).
[3] S. Khashaba and H. S. W. Massey, Proc. Phys. Soc. (London) **A71**, 574 (1958).

energies the polarization is sufficiently small so that the measured cross section may be taken equal to the total cross section, within experimental error. At the lower energies, the polarization becomes positive so that the measured cross section is higher than the total cross section.

Figure 1 compares the previous and present experimental results for Q_{90} and also shows the theoretical predictions for this cross section calculated from the theoretical results of Khashaba and Massey,[3] using their total cross sections and the polarization percentages. While the agreement between the two experimental curves is satisfactory above 25 ev, below this energy severe disagreement is found.

Figure 2 shows a log-log plot of Q_{90} as a function of

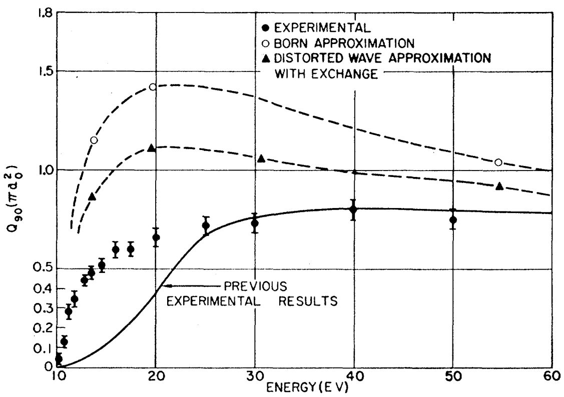

FIG. 1. Cross section for excitation of Lyman-alpha radiation near threshold.

E, the excess energy, i.e., the kinetic energy of the electron after it has excited the atom. Stopping-potential measurements on the electron-gun current were used to measure contact potential differences in the guns and the energy spread of the electrons. These measurements were used (1) to determine the threshold for the excitation (10.15±0.15 ev) and (2) to make corrections on the foot of the excitation curve for the energy spread. The points for the first 4 ev above threshold lie very satisfactorily on a line of slope $\frac{1}{2}$. This is expected for the total cross section from the physical requirement that the electron after excitation

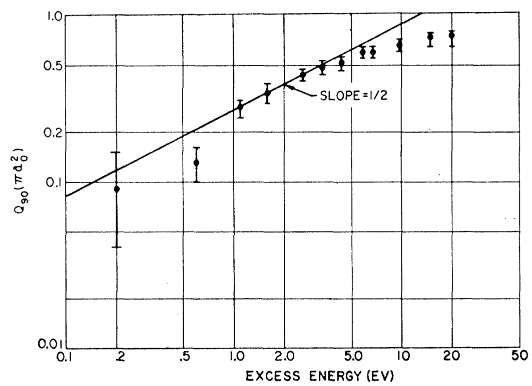

FIG. 2. Semilog plot showing the square root relationship between the $1S-2P$ cross section and the excess electron energy.

must be an S-wave electron and from the prediction[4] that the threshold shape for outgoing S-wave electrons must be as $E^{\frac{1}{2}}$. The earlier result, that the cross-section dependence near threshold appeared to be $E^{1.3}$, was evidently erroneous.

It may be noted that the theoretical results near threshold are relevant to total cross sections and not to the Q_{90}'s. The agreement of the newly measured values for Q_{90}, with predictions for the energy dependence of the total cross section, appears to imply that the polarization fraction must be a slowly varying function of the energy for the first few volts above threshold or else must be small.

The reason for the failure of the earlier measurements to give correct results below 25 ev is not clear, although it is thought to be caused by the use of stainless-steel electron guns and by energy depression due to surface-charging effects. The use of heated gold-plated guns, instead of heated stainless-steel guns, is the only known alteration in the experiment that would eliminate a systematic error of the type encountered at the lower electron energies.

In the interests of making early correction to the published values of the $1S-2P$ cross section below 25 ev, these results are presented prior to the completion of the remeasurement of photon angular distribution and polarization fractions using improved techniques.

[4] E. P. Wigner, Phys. Rev. **73**, 1002 (1948).