PHYSICAL REVIEW
LETTERS

VOLUME 20 | 26 FEBRUARY 1968 | NUMBER 9

POLARIZATION OF LYMAN-ALPHA RADIATION EMITTED BY H(2S) ATOMS IN WEAK ELECTRIC FIELDS*

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(Received 11 January 1968)

In 1961 Lichten[1] pointed out an error that had been made in data reduction in an experiment of Stebbings, Fite, Hummer, and Brackmann[2] to measure the cross section for electron-impact excitation of ground-state atomic hydrogen to the metastable 2S level. The point in question concerned the polarization and angular distribution of the Lyman-alpha radiation produced when the metastable atoms were quenched in a weak dc electric field. While Stebbings et al. had used a polarization fraction of unity in reducing their data, Lichten argued that a polarization fraction of zero should have been used. This correction to the original data of Stebbings et al. was made in an erratum[3] to their original paper.

In preparation for repeating and extending the experiments of Ref. 2, an experimental check of the quench-radiation polarization was carried out in anticipation that Lichten's zero-polarization prediction would be quickly verified. In the experiment a modulated beam of ground-state hydrogen atoms was crossed by a dc electron beam and metastable H(2S) atoms were produced by electron-impact excitation. The H(2S) atoms proceeded downstream with the ground-state atom beam and passed between two parallel plates providing a weak electric quench field. The Lyman-alpha radiation produced by the electric quenching of the metastable atoms was detected at 90° with respect to the quench field direction, and its polarization was examined using a LiF Brewster's-angle-reflector polarization detector,[4] followed by an oxygen-filtered iodine-vapor-filled photon counter. The quenching field ranged from 3 to 15 V/cm.

Surprisingly, it was found that the polarization was not zero, that the intensity (I_π) of the component with the electric field vector parallel to the direction of the quench field was weaker than the intensity (I_σ) of the opposite polarization, and that the polarization fraction, $P=(I_\pi-I_\sigma)/(I_\pi+I_\sigma)$ was -0.30 ± 0.02, after corrections for the finite aperture and multiple reflections of the Brewster's-angle polarizer,[4] for residual H_2 in the beam, and for collision quenching in the residual gas in the vacuum. Checks for experimental errors included changing the direction of the electric field (the plane of polarization tracked), changing the quench field strength (the polarization fraction of the quench radiation remained constant), using other quench field electrodes and configurations (no change of results), varying the exciting electron energy from 10.7 to 200 eV (no change of results) and using a magnetic quench field rather than an electric field. With the magnetic quench field the polarization was zero, exactly as expected on the basis of Zeeman mixing of the $2^2S_{\frac{1}{2}}(m_J=-\frac{1}{2})$ and the $2^2P_{\frac{1}{2}}(m_j=+\frac{1}{2})$ states with radiation from the $^2P_{1/2}$ state. There seemed to be no question that the apparatus was working correctly and that electric fields operating on the H(2S) atoms do produce partially polarized quench radiation.

The dilemma presented by these results is now understood thanks to Fano,[5] who pointed out that Lichten was in error in assuming that because the $2^2P_{3/2}$ state is about ten times as far removed in energy from the 2S metastable state as is the $2^2P_{1/2}$ state, its effects could be neglected in the weak-field, Stark-mixing problem. Although the $2^2P_{3/2}$ admixture is only about 10% of that of the $2^2P_{1/2}$ state, both states should be retained in a time-independent perturbation expansion. The dipole matrix element for radiation to the ground state then consists of two terms, one involving the $^2P_{1/2}$ state and the other the $^2P_{3/2}$ state. Upon squaring to find the radiation intensity, a cross product between these terms results which would be of the order of 20% of that from the $^2P_{1/2}$ state alone.[6]

We have worked through the details of this elementary calculation, neglecting hyperfine effects, and find that a polarization of −32.9% is predicted. Whether the slight discrepancy between the preliminary experimental value of −30% and the theoretical value −32.9% has any significance is not known at present.

This newer value of the polarization affects the cross sections for excitation to the 2S state obtained from the data of Ref. 2, by increasing the values approximately 10% above those given in Ref. 3. Based on those data, the maximum in the cross section at approximately 12 eV would be about $0.18\pi a_0^2$, which is only about 20% less than the recent calculated value of Burke, Taylor, and Ormonde[6] using close coupling with correlation terms.

We are deeply indebted to Professor U. Fano for pointing out the correct theoretical arguments, thereby making unnecessary a major effort to prove even more conclusively on experimental grounds that the apparatus was functioning properly, and to Professor E. Gerjuoy for his interest in and discussion of this and other experiments involving hydrogen atoms.

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*Research supported by the National Science Foundation.

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[6] Note: Interference terms arising from cross products in squares of sums in cases similar to this have been noted by others. See, for example, G. Breit, Rev. Mod. Phys. 5, 91 (1933), and F. D. Colegrove, P. A. Franken, R. R. Lewis, and R. H. Sands, Phys. Rev. Letters 3, 420 (1959).

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OBSERVATION OF THE EFFECT OF FREQUENCY CORRELATIONS ON A CASCADE TRANSITION

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(Received 2 January 1968)

The purpose of this Letter is to report the observation of an effect caused by the frequency correlation of photons emitted in a cascade transition.[1] The experiment consists of measuring the frequency profile of the 0.6096-μm radiation (neon $2p_4 \to 1s_4$) spontaneously emitted along the axis of a 1.15-μm (neon $2s_2 \to 2p_4$) He-Ne laser. Since the laser radiation can stimulate emission only in those atoms with a narrow range of axial velocity, there is an excess number of atoms with certain axial velocities in the $2p_4$ state. This velocity selection causes bumps to appear on the Doppler-broadened 0.6096-μm line at frequencies given by $\omega_L' = \omega_{bc} + (\omega_{bc}/\omega_{ab})(\Omega - \omega_{ab})$ and $\omega_L' = \omega_{bc} - (\omega_{bc}/\omega_{ab})(\Omega - \omega_{ab})$. ω_L' is the frequency of the 0.6096-μm radiation in the laboratory; a, b, and c are the $2s_2$, $2p_4$, and $1s_4$ states, respectively; $\hbar\omega_{ab}$ is the $2s_2$–$2p_4$ energy difference; $\hbar\omega_{bc}$ is the $2p_4$–$1s_4$ energy difference; and the laser is tuned to frequency Ω. The widths of the bumps are[1] $\gamma_1 = (\omega_{bc}/\omega_{ab})(\gamma_a + \gamma_b) + \gamma_b + \gamma_c$ and $\gamma_2 = (\omega_{bc}/\omega_{ab})(\gamma_a + \gamma_b) - \gamma_b + \gamma_c$, where the higher frequency bump is the broader when $\Omega > \omega_{ab}$, and the lower frequency bump is the broader when $\Omega < \omega_{ab}$. Since the areas of the bumps are equal, there is also a difference in the heights. The difference in the widths and heights is caused by the correlation between the frequencies of the $2s_2 \to 2p_4$ radiation and