PHYSICAL REVIEW LETTERS

VOLUME 21 | 9 SEPTEMBER 1968 | NUMBER 11

EXPERIMENTAL TRANSITION PROBABILITIES FOR TRIPLET-SINGLET TRANSITIONS IN HELIUMLIKE HEAVY IONS*

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(Received 22 July 1968)

The transition probability of the 1^1S_0-2^3P_1 transition has been measured in the helium-like ions O^{6+} and N^{5+}. The results are $(5.2 \pm 1) \times 10^8$ sec^{-1} and $(1.7 \pm 0.3) \times 10^8$ sec^{-1}, respectively. They agree well with very recent calculations.

The 1^1S_0-2^3P_1 transition in helium is long lived compared with the ordinary allowed transitions because it arises through the breakdown of *LS* coupling induced by the spin-orbit interaction. In two-electron systems with higher nuclear charge these intercombination transitions become detectable due to the stronger spin-orbit interaction. We appear to have made the first measurements of such intercombination transition probabilities, using O^{6+} and N^{5+} ion beams from the Oak Ridge tandem accelerator. A comparison between theoretical and experimental transition probabilities is best obtained for low-Z, heliumlike ions because recent detailed calculations[1] are available for the helium isoelectronic sequence through $Z = 10$ and because the Z dependence is very strong ($\sim Z^{10}$ for low Z vs Z^4 for $Z \gg 1$). The lines (but not the transition probabilities) have been observed in the laboratory[2] and in the solar corona.[3] Understanding of the solar corona and of corona-model plasmas depends in part on these transition probabilities as does a method for absolute calibration of photon detectors in the soft x-ray region.[4]

Beams of ions from 6 to 42 MeV were passed through a 30-μg/cm^2 C foil, producing various charge and excitation states of the emerging ions. The radiative decay in flight of the beams was tracked with Geiger counters containing He and butane, and fitted with thin Zapon windows. They viewed successive 1-cm-long sections of beam at 90° to the beam direction. Figure 1 shows sample semilogarithmic plots of radiation intensity versus counter position along the beam. Straight lines would be found for a single decaying state. The curvature at downstream points stems from backgrounds which appeared approximately constant but which may contain states whose lifetimes are about one order of magnitude or more larger than that of the primary decay. The fits

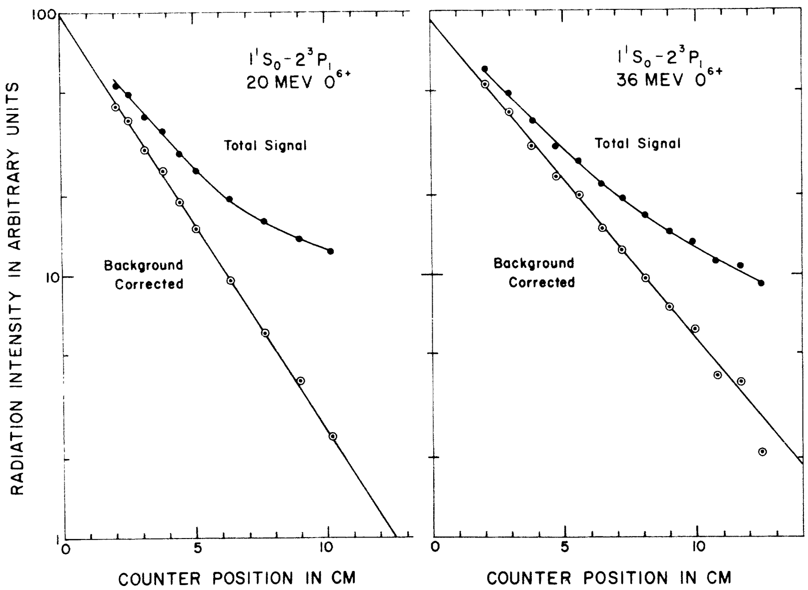

FIG. 1. Semilogarithmic plots of radiation intensity versus counter position for O^{6+} beams. The linear fits to the background-corrected data are also shown. Their slopes scale as v^{-1}.

by straight lines after a suitable constant background subtraction are also plotted. The uncertainties in our background corrections account for nearly all of our assigned experimental errors. These and other plots accumulated over the entire energy range scale correctly with beam velocity and yield a transition probability of $(6\pm1)\times10^8$ sec^{-1}. After subtracting off the known 2^3S_1-2^3P_1 transition probability[5] of $(0.8\pm0.02)\times10^8$ sec^{-1}, our O^{6+} (λ21.8) result for 1^1S_0-2^3P_1 is $(5.2\pm1)\times10^8$ sec^{-1} as compared with $(5.1\pm1)\times10^8$ sec^{-1} obtained theoretically by Elton, using measured term values.[1] A similar experiment with N^{5+} (λ29.1) yielded $(1.7\pm0.3)\times10^8$ sec^{-1} vs $(1.3\pm0.3)\times10^8$ sec^{-1} obtained theoretically.[1] Close agreement (particularly for N^{5+}) is also obtained with overlapping variational calculations of Dalgarno, Drake, and Victor[1] whose results are 5.8×10^8 sec^{-1} for O^{6+} and 1.5×10^8 sec^{-1} for N^{5+}.

Additional support for our identifications is found in the fact that the decays are observed at 6 MeV where there are few completely stripped and one-electron ions present and at 42 MeV where there are few ions with more than two electrons. The window transmission effectively cuts off radiation of wavelength over 100 Å, except for a narrow band from 1100 to 1145 Å in which the window transmits but the photoionization limit of butane has not been reached. Attenuation measurements obtained by interposing a second window were consistent with wavelengths of about 20 Å. The decay curves were not altered by electric fields of 25 kV/cm applied to the beam thus removing the one-electron 2S state from consideration. The two-photon decays of the one- and two-electron systems had lives too long to observe. Cascade effects were unlikely to appreciably affect our results since the transition probabilities for the allowed transitions are generally $\gtrsim10^{11}$ sec^{-1}; several nanoseconds elapse between the time of excitation and observation.

Our present inability to measure signal and background separately is the principal source of uncertainty. Our previous work on Lamb shifts in one-electron heavy ions[6] did not have this limitation since we could selectively Stark quench the Lyman-α radiation on which the measurement depends. Similar experiments on Lamb shifts in heavy ions for $Z\gtrsim6$ must either suppress any two-electron beam constituent, see to it that no excitation of ^3P states (as at a slit edge) occurs, or provide good wavelength resolution with small intensity loss in the soft x-ray region. Otherwise the two decays will add. Another conclusion is that the theoretical lifetimes and in particular the strong Z dependence of the 1^1S_0-2^3P_1 transitions are verified, as are the presently accepted term values to the extent the error limits permit.

Finally, it should be noted that the $j=1$ levels of the 2^3P states are depleted preferentially because of the selection rules for Δj. The fine-structure composition of a beam component in the 2^3P states thus changes as the beam travels.

*Research sponsored in part by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

[1]R. C. Elton, Astrophys. J. 148, 573 (1967); A. Dalgarno, G. W. F. Drake, and G. A. Victor, in Proceedings of the First International Conference on Atomic Physics, New York, 1968 (to be published), and private communication. The theoretical values used for comparison are those of the former reference. Our experimental accuracy was insufficient to test clearly which of the two sets of values is superior.

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[3]R. L. Balke, T. A. Chubb, H. Friedman, and A. E. Unziker, Astrophys. J. 142, 1 (1965).

[4]See Ref. 1 for a short discussion and citation of other references.

[5]A. Weiss, in W. L. Wiese, M. W. Smith, and B. M. Glennon, Atomic Transition Probabilities, U. S. National Bureau of Standards National Standard Reference Data Series—4 (U. S. Government Printing Office, Washington, D. C., 1966).

[6]The method involves measuring the lifetime of the Lyman-α line obtained by Stark quenching the 2S ions in a fast beam of one-electron ions. See C. Y. Fan, M. G. Munoz, and I. A. Sellin, Phys. Rev. 161, 6 (1967).

H(2p) EXCITATION RESONANCES IN (e-H) SYSTEM NEAR THRESHOLD*

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High-resolution electron-impact measurements reveal that just above the threshold for excitation of the $2p$ level of atomic hydrogen there is a complicated resonance structure, part of which had not previously been predicted or observed.

In this note we discuss our recent measurements of the resonance structure found in the total cross section for the production of Lyman-α from the reaction

$$e + \mathrm{H}(1s) = e + \mathrm{H}(2p) \;\; \lfloor\!\!\longrightarrow \mathrm{H}(1s) + \text{Lyman-}\alpha.$$

The observed structure is associated with the temporary formation of one or more H^- compound states in the $(2s)^2$, $(2p)^2$, or $(2s, 2p)$ doubly excited configurations. These "potential" resonances are of the same configurations as the resonances previously studied in the elastic channel below the first inelastic threshold.[1]

It has previously been observed, both theoretically[2-4] and experimentally,[5] that the excitation cross section does not follow what is normally considered Wigner's law. The most recent calcualtions have demonstrated that near threshold there is at least one resonance. However, a major point of this report will be to show that the resonance structure in the threshold region is more complicated than has been suggested thus far by theory. In the paper which follows, a partial explanation of this observation is given by Marriott and Rotenberg.[6] In a subsequent experimental paper, the details of our experimental technique, our total cross-section measurements, and our measurements of the resonances below and above the $n=3$ level will be discussed.

A modulated rectangular beam of H atoms (more than 85% pure) is crossed with a rectangular beam of electrons with an energy distribution (the width of the Gaussian energy distribution at half-maximum) of 0.07 eV. Electrons from a 127° electron-energy selector enter a magnetic- and electric-field free region, cross the modulated H-atom beam from below, and then pass into a collector in which a crossed electric field can be applied to collect all the electrons in the beam. When this field is removed the electrons pass through the collector region into a second, rotatable, electrostatic energy analyzer which measures the energy and angular distribution of the electrons. Photons from the interaction of the electron and hydrogen atoms are detected at an angle of 54.5° with respect to the direction of the electrons. At this angle the observed signal