Lifetime and Alignment of the 5^1D_2 State of ^{4}He by Beam-Foil Level Crossing*

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The lifetime of the 5^1D_2 state of ^{4}He was measured by the beam-foil, zero-field, level-crossing techniques. The result is compared with measurements based on conventional beam-foil and level-crossing methods. A multiparameter least-squares reduction of the data was used to determine the alignment in addition to the lifetime, thus eliminating the need for separate measurements to determine the alignment.

The beam-foil method has the useful property that the atoms (ions) are excited at a precisely known position. This fact has been exploited to measure atomic (ionic) lifetimes by observing the exponential decay of excited states.[1-5] The method suffers from a serious drawback in that the measurements are sensitive to cascading from highly excited states which feed the state under observation. In the experiment reported here we have used another useful property of the beam-foil interaction process to measure the lifetime of the 5^1D_2 state of ^{4}He. The atoms emerge from the foil in an aligned state so that application of a magnetic field perpendicular to the beam axis results in the creation of a coherent superposition of states with magnetic quantum numbers $+m_J, -m_J$. This leads to the quantum-beat phenomenon, which has been exploited in the measurement of g factors and alignment,[6] and to the Hanle effect, which has been used to measure lifetimes.[7] In the present investigation we have used the zero-field level-crossing method (Hanle effect) to measure both the lifetime and alignment of the 5^1D_2 state of ^{4}He. Previously, alignment was determined from quantum-beat experiments while lifetimes were determined from the Hanle effect. The purpose of the present measurement is to compare the lifetime as determined by the technique reported here to lifetimes based on conventional beam-foil and level-crossing methods. The lifetime of the 5^1D_2 state was previously measured by both the conventional beam-foil[8] and level-crossing methods.[9] It is of interest to compare these measurements since level crossing is inherently less sensitive to cascading.

A schematic of the experiment is shown in Fig. 1. A 3.5-μA, 40-keV, singly charged helium ion beam from the Berkeley mass separator was incident on a 6.7-μg/cm^2 carbon foil[10] and the light emitted by coherently excited 5^1D_2 ^{4}He atoms observed down stream from the foil through a linear polarizer with axis parallel to the beam axis. The observation was along the magnetic field perpendicular to the beam axis. The detector viewed a 7-mm portion of the beam. Photon counts were collected in a multichannel analyzer sweeping synchronously with the magnetic field sweep. After completion of a predetermined number of field sweeps the foil was advanced by a small increment and data collected for the same number of field sweeps, the photon counts being added to those taken at the previous foil position. This procedure was continued until each point along a 7-cm segment of the beam with extreme limits 3.5 mm and 7.35 cm from the foil was viewed for the same length of time. The foil was advanced upstream and downstream to average out beam fluctuations and drift. Generally, the ^{4}He$^+$ beam intensity drifted by $\lesssim 10\%$ in the time it took to cover the 7-cm beam path. By changing the direction of travel of the foil several times these beam excursions were largely averaged out. However, the excitation efficiency of the foil decreases as the foil ages and this introduced a slight slope to the signal. The slope was corrected for in the analysis.

The intensity of the 5^1D_2-2^1P_1 (4388 Å) transition when the observation is made through a lin-

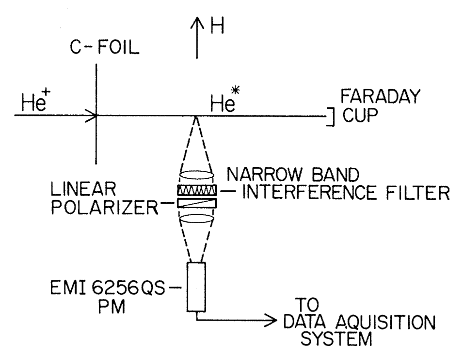

FIG. 1. Schematic of the beam-foil level-crossing experiment.

ear polarizer whose axis is parallel to the beam axis is given by

$$I(\omega,t)=Ae^{-\gamma t}[1+(B/A)\cos 2\omega t], \qquad (1)$$

where γ is the reciprocal lifetime in radians per second, B/A is the alignment, and $\omega = g_J\mu_0 H/\hbar$. H is the magnetic field intensity and t is the time following excitation at which the observation is made. This relation holds for an infinitesimal detector slit width. When a finite segment of the beam is viewed, the signal observed is

$$S(\omega)=\int_{l_{min}/v}^{l_{max}/v} I(\omega, l/v)\,d(l/v), \qquad (2)$$

where $l_{max}-l_{min}$ is the segment of beam intercepted by the solid angle of the detector, v is the beam velocity, and $t=l/v$ is the time following excitation. In our experiment, $l_{max}-l_{min}=7$ mm, but by changing the foil-detector separation and summing up contributions from many overlapping 7-mm segments the integration path was effectively increased to 7 cm corresponding to 59 nsec of observation time or about one lifetime.

The result is shown in Fig. 2 along with a fit of the data with Eq. (2). The data were fitted by means of a multiparameter least-squares computer program in which the lifetime, the incoherent background (A), and the amplitude of modulation (B) were free parameters. The end points of integration were fixed by geometrical considerations and the velocity of the atoms. A source of uncertainty in the type of experiment reported here is the velocity of the atoms since the foil thickness is known to at best 5% and furthermore there is an uncertainty in the calculated energy

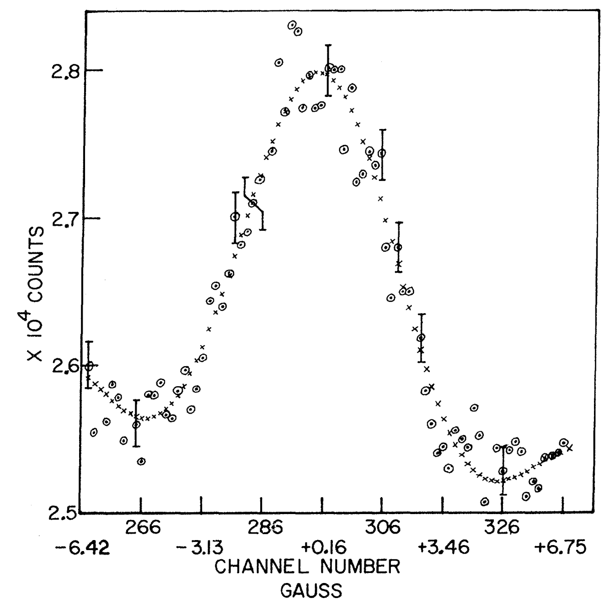

FIG. 2. Zero-field level-crossing signal for the 5^1D_2 state of He. Circles, experimental points; crosses, calculated points from a least-squares fit. The slope of the curve is due to foil aging and was corrected for in the curve fitting.

loss. We used initially the theoretical velocity $v=1.30\times10^8$ cm/sec, calculated from the energy loss, and then adjusted the velocity to obtain the best fit. The best fit was obtained for a velocity 1% lower than that calculated. The lifetime is summarized in Table I along with previous measurements and is seen to be in better agreement with conventional level crossing than with the conventional beam-foil determination. In addition to the lifetime we also determined the alignment of the 5^1D_2 state resulting from the beam-

TABLE I. Comparison of the lifetime of the 5^1D_2 state of He as determined by conventional beam foil (BF), level crossing (LC), and level crossing combined with beam foil (BF-LC).

Lifetime (nsec) of 5^1D_2 state of He							
BF[a]	LC[b]	BF-LC[c]	d	e	f	g	Theory[h]
66 ±4	49 ±5	52 ±6	43 ±15	79 ±6	63 ±9	46 ±3	71.9

[a]Ref. 8.
[b]Ref. 9.
[c]Present measurement.
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[h]Ref. 11.

foil interaction at 40 kV. The alignment was found to be 12%.

In conclusion, the beam-foil level-crossing method combines the best features of the beam-foil and level-crossing techniques. On the one hand, beam foil offers a universal means of producing coherently excited states, bypassing the technical difficulties of electron excitation in magnetic fields; on the other hand, level crossing is inherently more accurate for lifetime determinations. Furthermore, the alignment induced in the beam-foil interaction process can be determined simultaneously with the lifetimes. It is of interest that the measured lifetimes tend to be lower than the theoretical value which is based on calculated oscillator strengths[11] and this may indicate that systematic effects are still of importance. The method is being extended, in the case of the triplet states, to high-field level crossing.[12] In the case of high-field level crossing, cascading can be significant only if in addition to alignment transfer from the upper state to the state under observation level crossings occur in the upper state at the same magnetic field value as for the state under observation. Since the latter is highly unlikely, high-field level crossing should be largely free from the influence of cascades.

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Observations with Oriented Nuclei of One-Electron Atoms of F^{19}†

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Substantial nuclear orientation of excited F^{19} has been preserved in flight through vacuum at velocities where only a few electrons remain bound. Identification of the fraction of atoms with one electron has been made by applying a weak field and observing the effect of the atomic precession in flight on the γ-ray angular correlation.

The strong hyperfine interactions observed in highly ionized atoms have been previously used to measure g factors of short-lived nuclear states.[1-3] In particular, few-electron systems have shown promise for such measurements because of the possibility of static interactions and calculable hyperfine fields. The present work elucidates the interactions taking place in vacuum and reports measurements of the fraction of atoms traversing the flight region in a particular atomic state.

A beam of F^{19} ions from the Stony Brook FN tandem impinges on a Au scattering foil as shown in Fig. 1. The projectile is Coulomb excited to the $I=\frac{5}{2}$, $\tau_{1/2}=89$ nsec level at 197 keV, and the F^{19} nuclei scattered through an average angle of 40° pass down a flight path to a Cu catcher foil. Because the scattering process detected in this experiment does not have symmetry around the beam direction, the excited nuclear state is oriented perpendicular to the scattering plane. If this orientation is preserved in flight to the catcher foil, an anisotropic γ-ray angular distribution is observed.

The beam energy is chosen so that the scattered F^{19} are stripped to few-electron atoms in