LIFETIME OF THE 2^1S STATE OF He

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A traveling Auger detector is used to measure the attenuation of a cooled thermal beam of He 2^1S atoms in a vacuum of 1×10^{-8} Torr. Its velocity is determined by a time-of-flight technique. The lifetime obtained is $(38\pm8)\times10^{-3}$ sec.

The lifetime of the 2^1S state of the helium atom is of fundamental interest because its most probable mode of decay is by spontaneous double-photon emission.[1] The existence of spontaneous double-photon emission processes was first experimentally verified by Lipeles, Novick, and Tolk,[2] who detected two-photon coincidences from a He^+ $2S_{1/2}$ beam. Thus far there has been no measurement of a double-quantum spontaneous-transition probability. The He 2^1S lifetime has been calculated by Dalgarno,[3,4] the latest value being 19.5 msec, while a previous attempt to measure it yielded a lower limit of 9 msec.[5] In this Letter, a preliminary measurement of the He 2^1S lifetime is described.

The method employed in the present experiment is illustrated in Fig. 1. Helium atoms effusing from the atomic-beam source through a stream of electrons are formed into a well collimated beam which contains atoms in the 2^1S and 2^3S metastable states, n^1P-1^1S resonance photons, and ground-state atoms. A traveling Auger-detector beam target (EMI 9603B electron multiplier) is used to measure the attenuation of the dc He 2^1S beam over a path of 1 m. The He 2^1S component is determined by quenching it with 2-μ (2^1P-2^1S) radiation from two 45-W spectral helium lamps.[6,7] The presence of the 2^3S atoms in the beam provides a useful control with which to assess nonradiative beam attenuation processes, the lifetime[3] of the 2^3S state being $\sim10^8$ sec. The system is of all metal construction in which the base pressure over the beam path is 7×10^{-9} Torr. With the beam turned on there is a partial pressure of helium in the range $(0.7\text{ to }2)\times10^{-8}$ Torr. To increase the transit time through the system, provision was built into the atomic-beam source to cool it through heat exchange with a liquid helium jacket.

The lifetime, τ, is determined from the relation

$$\tau=\bar{t}_{ox}/\ln(N_o/N_x),$$

where N_o/N_x is the ratio of the He 2^1S flux at the points o and x of the beam path and $\bar{t}_{ox}$ is the average flight time of the He 2^1S beam over the

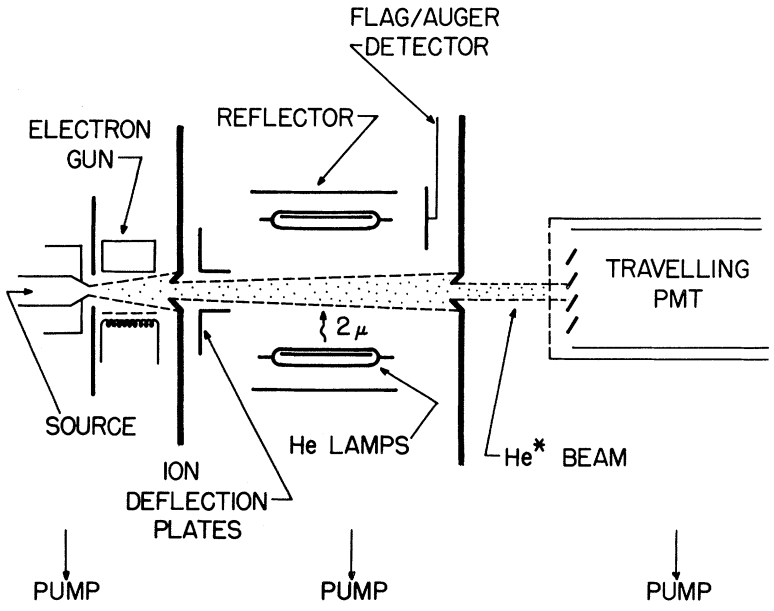

FIG. 1. Schematic diagram of experiment.

path ox. The ratio N_o/N_x is obtained by operating the electron gun in a continuous mode and measuring the flux of the resulting dc He 2^1S beam as a function of detector position. The flight time of the beam is determined by pulsing the exciting electron beam and recording the resulting He 2^1S time-of-flight (TOF) distribution with a 256-channel pulse-height analyzer and associated time–to–pulse-height conversion electronics. The TOF spectrum of the singlet metastables alone is obtained by first recording in memory the spectrum due to both the singlets and the triplets and then subtracting that due to the triplets, the singlets having been quenched through the use of the helium lamps mentioned above. To ensure >99.9% depletion of the 2^1S level with a room-temperature beam the two lamps were run at 40 W, but for cold beams less than 5 W was required.

Before measuring the radiative decay, other possible sources of beam loss were investigated, i.e., possible geometrical and collisional effects. The second circular collimating aperture (Fig. 1) was chosen such that the projected diameter of the beam at the farthest position of the detector was about 0.5 in. compared with the 1-in. diam of the first dynode of the detector. In other words, the detector is expected to intercept the whole beam over its entire path. When a scan is made, however, an 11% attenuation of the beam is observed. The magnitude of this effect depends on the angular width of the beam and is probably due to variations in detection sensitivity over the detector face. For a given collimator No. 2 (Fig. 1), however, the instrumental attenuation is the same for both He 2^1S and 2^3S atoms, for resonance photons, and for Ne and Ar metastables over a wide range of base pressures (×7) and beam densities (×3).

By normalizing the 2^1S flux, i.e., observing the ratio of the 2^1S flux to the 2^3S plus photon flux at each end of the detector travel, the instrumental factor is eliminated. The invariance of the distance dependence of the detector signal to changes in base pressure and beam density demonstrates the negligible contribution of atom-atom collisions to beam loss. On this basis any further attenuation of the 2^1S beam is attributed to radiative decay.

With the source at 300°K it was not possible to discern a radiative attenuation in excess of the errors in measurement of the He 2^1S flux (≲2%). Together with a TOF determination of the average flight time (0.60 ± 0.03 msec), this result implies a lower limit of 30 msec for the He 2^1S lifetime. Cooling the source gas to around 17°K, however, resulted in a substantial radiative attenuation of the He 2^1S beam. The normalized flux of the cold 2^1S beam was diminished by about 13% over the beam path. On the other hand the cold 2^3S beam exhibited the same variation with distance as at room temperature, further confirming the absence of collisional and radiative attenuation. The He 2^1S radiative attenuation was independent of the beam density and base pressure. The average flight time of the cold He 2^1S beam, determined by averaging over TOF distributions like the one in Fig. 2, was typically 5.3 ± 0.2 msec for the coldest beams.

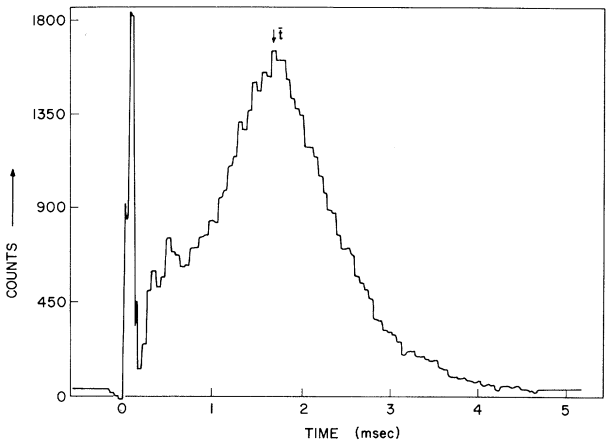

FIG. 2. Time-of-flight distribution of a cold He 2^1S beam. The sharp initial peak is due to resonance photons. $\bar{t}$ is the average time for the beam to travel from the electron gun to the point o of the beam path.

The radiative lifetime was obtained from the cold He 2^1S attenuation and its flight time. It was found to be independent of pressure when the beam density and base pressure were varied by a factor of 3. The mean value of He 2^1S lifetime was found to be

$$\tau = 38 \pm 8 \text{ msec},$$

where the main source of error is in the reproducibility of the attenuation measurements for a particular average flight time. These measurements indicate a substantial disagreement with the theoretical lifetime (19.5 msec) and will be reported in further detail later.

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[1]G. Breit and E. Teller, Astrophys. J. 91, 215 (1940).
[2]M. Lipeles, R. Novick, and N. Tolk, Phys. Rev. Letters 14, 1060 (1965).
[3]A. Dalgarno, Monthly Notices Roy. Astron. Soc. 131, 311 (1966).
[4]G.W.F. Drake, G.A. Victor, and A. Dalgarno, Phys. Rev. 180, 25, (1969).
[5]M. Steinberg, thesis, University of California, UCRL Report No. 18387, 1968 (unpublished).
[6]W.L. Williams and E.S. Fry, Phys. Rev. Letters 20, 1335 (1968).
[7]A. Lurio, private communication.

MEASUREMENT OF THE LIFETIME OF THE $A^1\Pi$ STATE OF CO BY LEVEL-CROSSING SPECTROSCOPY*

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The lifetime of the $v=2$ level of the $A^1\Pi$ state of CO has been measured by molecular level-crossing spectroscopy. Unlike previous experiments with molecules in which the Hanle effect has been analyzed for individual rotational states, the present results are obtained from analysis of the composite level-crossing signal from all of the rotational states which are excited by the entire $A \rightarrow X(2,0)$ resonance band. Our experimental result is $\tau(v=2)=9.0\pm1.0$ nsec in good agreement with Hesser's value of 10.5 ± 1.0 nsec obtained from phase-shift experiments.

Measurements of the oscillator strengths of the CO molecule have received much attention in the last few years not only because of increasing interest in the fundamental properties of molecules, but also because such measurements have astrophysical applications.[1,2] Integrated oscillator strengths of the $A^1\Pi \leftarrow X^1\Sigma$ system have been reported by Hesser[3] and by Lassettre and Silverman.[4] Individual f values between bands have also been tabulated by Hesser, by Rich,[5] and by Meyer, Skerbele, and Lassettre.[6] Hesser has measured the lifetime of the $A^1\Pi$ state by the phase-shift technique and used this lifetime in conjunction with relative intensities of the various bands excited by electron impact in order to obtain his results. The values reported by Rich have been obtained from an absorption experiment in shock-heated CO. Lassettre and his co-workers have extracted optical f values from the generalized oscillator strengths for inelastic collisions of electrons with CO. The oscillator strengths reported for the (2, 0) band reveal the typical disparity of the results; the three experiments yield 0.022, 0.033, and 0.051, respectively.

In an effort to establish the oscillator strengths of the fourth positive system more firmly, we have measured the lifetime of the $v=2$ level of the $A^1\Pi$ state from a level-crossing experiment in which we have exploited a technique that has not been used previously. Other level-crossing experiments on diatomic molecules have employed the Hanle effect to obtain g factors through the observation of spectrally resolved lines from single rotational states which have been excited either by a molecular source[7] or by an accidental overlap of an atomic line.[8] The present experiment is illustrative of a method which we believe will prove useful in certain situations for which atomic overlaps cannot be found and for which resolution of rotational lines is not possible. The entire (2, 0) resonance band (1478 Å) has been employed for excitation of the upper electronic state, and the observed level-crossing signal is the summation of signals which originate from all of the excited rotational states. The data are analyzed by fitting them to a model which accounts for the individual contributions to the total Hanle effect.

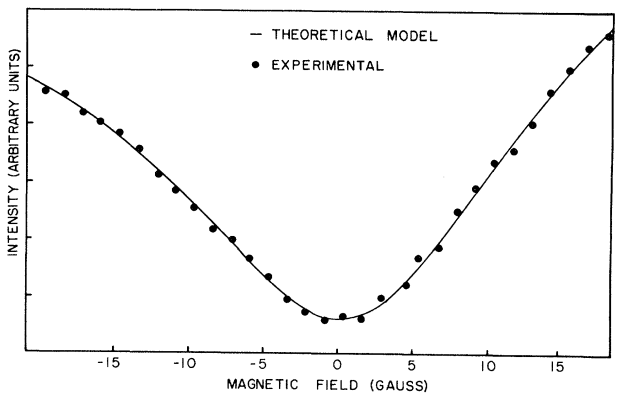

FIG. 1. Hanle-effect signal for the $v=2$ level of the $A^1\Pi$ state of CO. Experimental data from the signal averager have been plotted at intervals of eight channels.