Beam-Gas Lifetime Measurements in Ne I-II †

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The ionic beam-gas-target method was used to obtain intensity decay curves for some transitions of Ne I and Ne II. The mean radiative lifetimes of the upper levels were extracted by a computerized least-squares curve-fitting procedure. The lifetime of the $3p'\,^2D^\circ$ level of Ne II was found in this way to be 5.2 ± 0.5 nsec. Somewhat less-reliable lifetimes were obtained for some $2p$ (Paschen notation) levels of Ne I. Those lifetimes τ in nsec are as follows: $\tau(2p_1) = 15.5 \pm 0.3$, $\tau(2p_4) = 24.8 \pm 0.7$, $\tau(2p_6) = 25.5 \pm 0.8$, and $\tau(2p_9) = 23.4 \pm 0.3$. Errors quoted for the Ne I lifetimes are standard deviations of several measurements. The error for the Ne II measurement represents a combination of statistical and possible systematic errors. Since the Ne I work may be affected by unresolved cascading, we do not claim an accuracy better than (15–20)% for those measurements. This paper completes the study of the Ne^+ beam begun by Head and Head.

INTRODUCTION

In this paper we report the mean radiative lifetime for the $3p'\,^2D^\circ$ level of Ne II. This level was omitted in an earlier study[1] because of poor signal-to-noise ratios. Recent improvements in apparatus and techniques[2] have enabled us to work with transitions hitherto inaccessible. Also included are some improved lifetime measurements for Ne I.[3]

A Ne^+ beam (22–26 keV) was passed through a differentially pumped target cell of gaseous He at constant low pressure [$(10-35)\times 10^{-3}$ Torr]. Measurements of the decay of the transition intensity downstream from the collision chamber were made using a Jarrell-Ash Model No. 82-000 grating monochromator. The radiation was detected by an EMI 6256QS photomultiplier. Signals were recorded using standard pulse-counting instrumentation. Decay curves were obtained by translating the monochromator downstream from the collision cell. Because of small beam-current fluctuations, the output signal from a second photomultiplier-monochromator combination, which viewed the beam at a fixed point, was used to normalize the output of the first detection system.

The photomultipliers in this experiment were cooled using solid CO_2. The variable-position detector was also fitted with a magnetic lens in order to decrease the effective cathode area. The dark count of each photomultiplier was thereby reduced to approximately 0.5 counts per second.

The pressure differential between the collision chamber and the observation chamber was maintained at better than 300 to 1, except in the immediate region of the exit aperture. Streaming effects near the exit aperture have been studied previously and are believed to have been minimal.[1,2]

Ne II–$3p'\,^2D^\circ$ LIFETIME

Decay curves for the $3p'\,^2D^\circ$-$3s'\,^2D$(λ= 323.1 nm) transition of Ne II were fitted by computer to the sum of two exponentials and a constant,

$$I = Ae^{-x/v\tau_1} + Be^{-x/v\tau_2} + C ,$$

where I is the transition intensity, x is the distance downstream from the collision cell, v is the speed of the ions, τ_1 and τ_2 are lifetimes, and A, B, and C are constants. Extensive analysis of the decay curves demonstrated that this choice yielded the only practical and reasonable fits.

The various components of the decay curves were easily resolved except for a small component with an apparent lifetime much shorter than that of the principal decay component. It was adequately removed, however, by successively deleting points from the beginning of each curve. This deletion process was continued until the computed lifetime of the principal decay component stabilized at a definite value.

Near the collision cell each experimental point contained about 10^5 counts, while at the downstream end each point had about 10^4 counts. The dark count per point was approximately 10^3 counts.

Using the procedures outlined above and described in detail in Refs. 1 and 2, we obtained a lifetime of 5.2 ± 0.5 nsec for the $3p'\,^2D^\circ$ level of Ne II. This value agrees quite well with phase-shift measurements of 5.5 ± 0.6 nsec by Hesser[4] and with beam-foil measurements of 5.6 ± 0.3 nsec by Brand *et al.*[5] It agrees less well with a value of 7.5 ± 0.8 nsec by Denis *et al.*[6] and with a value of 4.7 nsec obtained by Hodges *et al.*[7,8] Our result is in very good agreement with the value of 5.3 nsec computed from the theoretical transition probabilities compiled by Wiese *et al.*[9]

TABLE I. Ne I lifetimes.[a]

Investigator	Lifetimes (nsec)[b] $2p_1$ (585.2 nm)	$2p_4$ (594.5 nm)	$2p_6$ (614.3 nm)	$2p_9$ (640.2 nm)	Method[c]
Present authors[d]	15.5 ± 0.3(15%)	24.8 ± 0.5(15%)	25.5 ± 0.8(15%)	23.4 ± 0.3(20%)[e]	Beam gas
Andersen[f]	14.8 ± 1.0	21.5 ± 2.0	22.0 ± 2.0	20.0 ± 1.5	Beam foil
Arrathoon and Sealer[g]				15.9 ± 0.7	Pulsed laser
Assousa, Brown, and Ford[h]	14.9 ± 2.6	21.4 ± 3.8 21.1 ± 3.9 22.6 ± 4.0		29.3 ± 5.2	Beam foil
Bennett and Kindlmann[i]	14.4 ± 0.3	19.1 ± 0.3	19.7 ± 0.2	19.4 ± 0.6	Pulsed electron
Carrington[j]		19.2 ± 1.0	18.2 ± 0.7	18.7 ± 0.7	Hanle
Denis, Desesquelles, and Dufay[k]	14.45	26.0	28.9	30.5	Beam gas
Klose[l]	14.7 ± 0.6	22.0 ± 1.0 23.0 ± 2.0	22.0 ± 1.0	22.5 ± 0.9	Pulsed electron
Kohl, Curtis Schectman, and Chojnacki[m]				21.7 ± 0.9	Pulsed electron
Schectman, Curtis and Chojnacki[n]				21.4 ± 0.9	Pulsed electron
Lui, Bashkin, Bickel, and Hadeishi[o]				22.7 ± 1.1 22.0 ± 1.0	Beam foil[p] Beam foil
Nodwell, van Andel, and Robinson[q]	15.2 ± 0.2				Pulsed electron sampling oscill.
Oshirovich and Verolainen[r]	14 ± 1	24 ± 1.5	21 ± 1.4	24 ± 1.5	Pulsed electron
NBS Tables[s]	13.9(10%)	19.5(<25%)	21.9(>10%)	23.1(10%)	

[a] This compilation is not represented as being complete, but presents a sample of some relatively recent work using different techniques for comparison purposes.

[b] Multiple entries in the same column for the same authors represent lifetimes for the same level using different transitions unless otherwise indicated.

[c] The major experimental methods included are as follows: (i) fast-ion-beam–gas-target excitation, (ii) beam-foil excitation, (iii) pulsed-laser excitation, (iv) pulsed-electron-beam excitation with delayed-coincidence detection or with sampling-oscilloscope detection, and (v) Hanle effect.

[d] Uncertainties given are standard deviations of several measurements. See text for a discussion of possible systematic errors. Estimates of absolute error are given in parentheses.

[e] The transition (640.22 nm) used for this measurement may be affected by blending with a weak 640.11-nm line from another level, thus making this measurement less reliable than the others.

[f] Reference 10.

[g] Reference 11.

[h] Reference 12.

[i] Reference 13.

[j] Reference 14.

[k] Reference 15.

[l] Reference 16.

[m] Reference 17.

[n] Reference 18.

[o] Reference 19.

[p] Beam-foil excitation with magnetic-resonance technique.

[q] Reference 20.

[r] Reference 21.

[s] Lifetimes computed from transition probabilities tabulated in Ref. 9. Error estimates, in parentheses, are taken from this publication also.

Our measurements for Ne II were reproducible to within 6%. We estimate the over-all accuracy at better than 10%.

Ne I LIFETIMES

Several spectral lines of Ne I were observed in our spectral scans. Count rates for these lines were approximately two orders of magnitude smaller than those for the principal Ne II lines observed. By using very long counting times (several minutes per point), we have obtained several decay curves with adequate statistics for the strongest Ne I lines and extracted lifetimes for the upper levels of the associated transitions. These measurements are summarized in Table I along with some recent measurements by other investigators using different techniques.[10-21]

Of the work summarized in Table I, that of Bennett and Kindlmann[13] seems to be the most universally accepted.[22,23] Their experiment was carried out using an elaborate method involving pulsed-electron-beam excitation with delayed-coincidence detection. By using electron energies just above excitation threshold, they reported that they were able to eliminate cascade effects.

It is difficult to attribute the spread in the experimental lifetimes for Ne I summarized in Table I solely to cascade effects. A very recent study by Schectman, Curtis, and Chojnacki[18] on the $2p_9$ level, which included an apparently reliable cascade correction, gives a somewhat longer lifetime than that obtained by Bennett and Kindlmann (21.7 ± 0.9 and 19.5 ± 0.6 nsec, respectively). A study by Lui, Bashkin, Bickel, and Hadeishi[19] which is reported to be unaffected by cascade yields a similar result (22.7 ± 1.1 nsec). The magnitude of cascade effects in the other work is not precisely known.

The difficulty in making an accurate analysis of cascade effects can be illustrated by using the $2p_4$ level of Ne I. This level is populated via cascade from both the $3s_2$ and $2s_2$ levels, among others. The $3s_2$ level has a lifetime somewhere between 22 and 60 nsec.[24,25] The $2s_2$ level has a lifetime of around 10 nsec.[26]

Despite our relatively good statistics, we were unable to resolve more than 2 exponentials in our decay curves. In all cases the lifetime of the second component was considerably longer than the first; see Fig. 1.

Our measured lifetime for the $2p_4$ level from these fits was 24.8 ± 0.7 nsec.

The uncertainties quoted for our measurements in Table I are the standard deviations of several measurements. The standard deviations obtained are in agreement with the errors computed from the weighted least-squares fits to the decay curves. No reasonable manipulation of the data in the curve-fitting procedure or variation of the experimental conditions during data taking caused the computed lifetimes to vary much from the values herein reported. We are therefore confident that the absolute error in our Ne I measurements does not exceed 20% for the $2p_9$ level and 15% for the other levels.

CONCLUSIONS

We conclude from our investigation and the examination of previous papers that much work still needs to be done on the various Ne I transitions. What appears to be needed is an experiment which would eliminate cascade effects and at the same time remove any questions regarding the sharpness of the excitation cut off (such as the shutting off of an electron beam). The ideal experiment

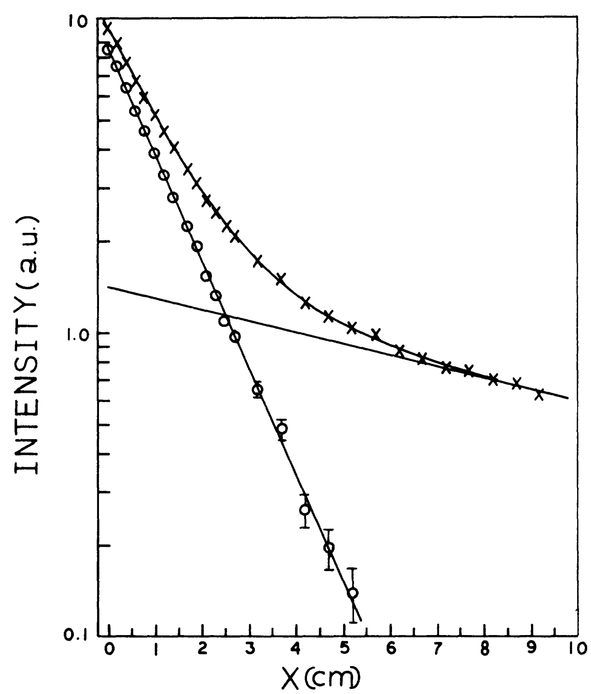

FIG. 1. Typical decay curve for the 594.5-nm transition of Ne I. Intensity in arbitrary units is plotted as a function of the distance x downstream from the differentially pumped target cell filled with He. The experimental curve (×) is decomposed into the sum of two exponentials (straight lines). The most quickly decaying component corresponds to the natural decay of the $2p_4$ level of Ne I and gives a lifetime of 25.7 ± 0.5 nsec. The slowly decaying component has a computed apparent lifetime of 270 ± 40 nsec. The first point ($x = 0$) corresponds to (26,561 counts/73,855 counts), i.e., intensity counts over beam-current counts. The dark-current counts were 145 and 22 for the intensity and the beam current, respectively. The energy was 26 keV.

would seem to involve some combination of optical-pumping and fast-ion-beam techniques or some combination of selective electron-beam excitation and fast-ion-beam techniques.

The excellent agreement between our experimental measurement for the Ne II $3p'\,^2D°-3s'\,^2D$ transition and the theoretical result based on the Coulomb approximation[9] establishes the latter value to be much better than originally estimated. In the light of the agreement of the different experimental measurements mentioned earlier, one may safely assume that the transition probabilities listed for this set of transitions on p. 133 of Ref.9 are good to at least 10% instead of the 50% originally quoted.

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