[2]M. Baranger, Phys. Rev. 111, 481 (1958); 111, 494 (1958); 112, 855 (1958).

[3]H. Margenau and M. Lewis, Rev. Mod. Phys. 31, 569 (1959).

[4]S. Y. Ch'en and R. O. Garrett, Phys. Rev. A 4, 412 (1971).

[5]Typical frequencies introduced by argon collisions (e.g., the line shift) correspond to times of about 2×10^{-13} sec and cannot be properly calculated by either an impact or quasistatic theory. The main features of the helium experiment fall in the impact regime. The slope of the imaginary parts of the correlation function exponent between 7×10^{-13} and 10×10^{-13} sec corresponds to a shift of 4.55 cm^{-1}/relative density which is 6% greater than the value reported by Tan and Ch'en [D. K. L. Tan and S. Y. Ch'en, Phys. Rev. A 2, 1124 (1970)] for shifts produced by helium below relative density = 2.

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Lifetime Lower Limits for the $^3P_0$ and $^3P_2$ Metastable States of Neon, Argon, and Krypton†

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A time-of-flight technique has been used to investigate the lifetime τ of the long-lived $^3P_0$ and $^3P_2$ states of neon, argon, and krypton. The results are, for neon, $\tau(^3P) > 0.8$ sec; for argon, $\tau(^3P) > 1.3$ sec; and for krypton, $\tau(^3P) > 1.0$ sec. The present measurements are limited by residual-gas or beam-beam scattering and by the length of the time-of-flight region being short compared to a decay length.

The very long-lived $^3P_0$ and $^3P_2$ metastable states of neon, argon, and krypton have been studied using the same time-of-flight technique[1] and apparatus previously described in a paper reporting the mean life of the $2\,^1S_0$ metastable state of helium. Unlike that experiment, no quenching lamp is required, since it is probable that both ^3P states for the noble gases studied have lifetimes that are long when compared to the observation time, and thus act as a single state.

The properties of these long-lived states should be of particular interest to astrophysicists when orbiting telescopes become available. Only then can these uv transitions (~ 1000 Å) be studied in emission from nonplanetary sources. The lifetimes of long-lived metastable states should also be of interest to theoreticians because the decay processes of such states are sensitive to exact electronic wave functions and also to very small perturbing interactions. Indeed, a rare magnetic quadrupole transition to the ground $^1S_0$ state may be the most probable mode of decay for the metastable $^3P_2$ level.

The lowest-lying levels of krypton are shown in Fig. 1 as a typical noble gas energy-level diagram. The $^1P_1$ and $^3P_1$ states are absent from our metastable beam because they decay to the $^1S_0$ ground state by allowed electric dipole ($E1$) radiation before the atoms leave the electron gun. Lifetimes[2] for these states vary from 2 to 30 nsec.

Because of the large spin-orbit coupling for Ne, Ar, and Kr, only rigorous selection rules apply when considering possible decay modes; total angular momentum J and total parity are conserved. The only transition possible for the $^3P_2$ state is to the $^1S_0$ ground state; since parity changes and $\Delta J = 2$, the decay must occur through emission of magnetic quadrupole ($M2$) radiation. However, the $^3P_0$ state may make a transition to either the $^3P_1$ or the $^3P_2$ state, but not to the $^1S_0$ ground state since a $J=0 \rightarrow J=0$ transition is not allowed for single-photon decay. The emission of two $E1$ photons is also disallowed because parity cannot change for this particular two-photon decay. Other multiple-photon decay modes are subsequently much less probable than single-photon emission to the $^3P_1$ or the $^3P_2$ states. Transitions to the $^3P_1$ or the $^3P_2$ states must proceed by magnetic dipole ($M1$) or electric quadrupole ($E2$) radiation, respectively. An estimate indicates that the rate for $E2$ radiation is 10^4–10^5 times less probable than the rate for $M1$ radiation. Thus, cascading to the $^3P_2$ should be small; the population of the $^3P_2$ state will be determined primarily by the initial distribution and by the $M2$ decay rate.

A complete description of our apparatus, data collection scheme, data analysis, and time-of-flight theory has been described previously.[1] The experiment is based primarily on the time-of-flight technique where an atom is assumed to leave the metastable state only by radiative decay as it drifts over a 5-m path between two fixed detectors; this assumption demands a very low pressure in the drift region to minimize scattering losses.

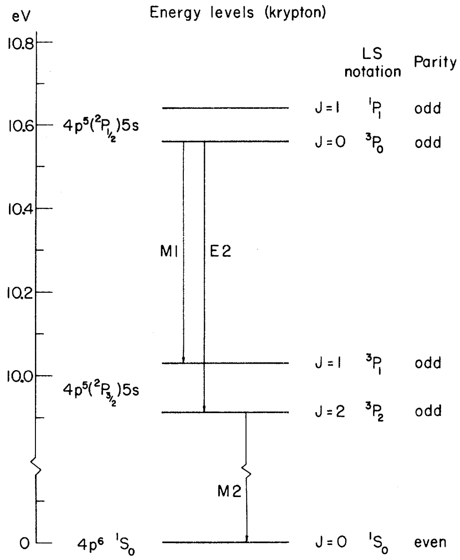

FIG. 1. Krypton energy-level diagram showing the lowest-lying levels. Both $J=1$ states decay to the $^1S_0$ ground state by electric dipole ($E1$) radiation. The $^3P_0$ state can decay to either the $^3P_1$ state by magnetic dipole ($M1$) radiation or to the $^3P_2$ state by electric quadrupole ($E2$) radiation. The $^3P_2$ state can decay only by magnetic quadrupole ($M2$) radiation to the $^1S_0$ ground state.

The following two expressions represent the number of metastable atoms counted by detectors 1 and 2:

$$n_1(v)=\int_{\text{surface}} \epsilon_1 n_0(v)\, ds_1 , \tag{1a}$$

$$n_2(v)=\int_{\text{surface}} \epsilon_2 n_0(v) e^{-t/\tau}\, ds_2 , \tag{1b}$$

where $n_0(v)$ is the initial velocity distribution and ϵ is a detector efficiency factor. The exponential factor in the expression for the number of counts at detector 2 allows for radiative decay of the metastable beam between the two detectors. Though a single lifetime τ appears in the exponential, atoms in both the $^3P_0$ and $^3P_2$ metastable states actually exist in the beam. However, since the lifetimes of both states are very long compared to the time of flight between detectors, the beam appears to decay as a single component which can be represented as a single average lifetime τ.

After assuring that n_0 is uniform across the beam, the time and velocity dependence can be extracted from the integrals in Eqs. (1). Then, taking a ratio of detector 2 counts to detector 1 counts for atoms of the same velocity, we obtain

$$R(t)\equiv n_2(v)/n_1(v)=C\,e^{-t/\tau} , \tag{2}$$

where t is the time of flight between detectors and C is a constant independent of the initial velocity distribution. The natural logarithm of Eq. (2) gives the equation of a straight line; a straight line is least squares fitted to the data and the lifetime τ determined from the slope $=-1/\tau$.

The initial step in the data analysis involves partitioning the detector 2 data to correspond to the channel width at detector 1 for metastable atoms with the same velocity. However, our previous discussion of the data analysis must be extended to include the effect of gravity on the heavier noble gases, which have much slower thermal velocities than helium. Since the drift region is oriented in a vertical configuration, atoms drifting to the second (upper) detector are retarded by gravity by different amounts depending on their initial velocity. This retardation can be accounted for by comparing atoms with arrival times t_1 and t_2, where time t_2 must correspond to an atom arriving at detector 2 whose original velocity would have allowed the atom to arrive at detector 1 in time t_1. The correct partitioning of the data, followed by calculation of the ratio R for metastable atoms of the same velocity, then leads to a plot of ln$R$ vs time of flight, as shown in Fig. 2. The least-squares straight line is fit only to data points corresponding to a number of counts greater than 10% of the peak value.

In order to achieve the best statistics possible, individual runs (2 h each) were added together, channel by channel for each noble gas, before being analyzed. The results, to be interpreted as lower limits for the composite lifetime of the metastable ^3P states, are

$$\tau(^3P)>0.8 \text{ sec for neon}$$

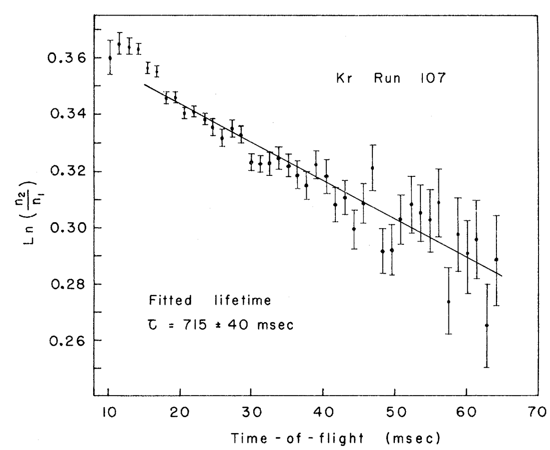

FIG. 2. Decay plot for krypton. The ratio of detector 2 to detector 1 metastable atom distributions vs. time of flight between detectors is a straight line on a logarithmic plot. The measured lifetime is obtained from the slope $=-1/\tau$ of the least-squares-fitted straight line, using data points corresponding to a number of counts greater than 10% of the peak value.

>1.3 sec for argon

>1.0 sec for krypton.

Interpreting these lifetimes as lower limits is natural, since they are probably limited by scattering from residual gas in the drift region. All runs were taken at a pressure of 2×10^{-9} Torr, which is the usual pressure in the apparatus when the drift region is liquid nitrogen trapped. Untrapped, the drift pressure is approximately 2×10^{-8} Torr and the measured lifetimes are reduced by about 50%. Another important consideration in this interpretation is the use of such a small initial interval of decay from which to extract a long lifetime.

Unlike the helium result previously reported, these heavier noble gases show no significant systematic error due to the initial velocity distribution $n_0(v)$ being nonuniform across the metastable beam (referred to earlier as "source dependency"). Sensitivity to background subtraction is minimized by excluding from the data analysis the small number of counts in the tail of the time-of-flight distribution. All other experimental parameters such as gun voltage, beam temperature, and channel width have no effect on the measured lifetime.

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[1]R. S. Van Dyck, Jr., C. E. Johnson, and H. A. Shugart, Phys. Rev. Letters 25, 1403 (1970); Phys. Rev. A 4, 1327 (1971). Preliminary results for the heavier noble gases appeared in Bull. Am. Phys. Soc. 16, 533 (1971).

[2]J. D. Dow and R. S. Knox, Phys. Rev. 152, 50 (1966).

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ERRATA

Foreign-Gas-Induced Cesium Hyperfine Relaxation, N. Beverini, P. Minguzzi, and F. Strumia [Phys. Rev. A 4, 550 (1971)]. Unfortunately, the results reported for the pair Cs-N_2 have been mistaken with those obtained in a preliminary fit. The correct values to appear in Table I are the following: Gas N_2, $\sigma_{\langle \vec{s}\cdot\vec{i}\rangle}=(60.0\pm4.4)\times10^{-23}$ cm^2, $D_0=0.087\pm0.015$ cm^2/sec.

Production of Carbon K X Rays by Heavy-Ion Bombardment, R. C. Der, R. J. Fortner, T. M. Kavanagh, and J. M. Kan [Phys, Rev. A 4, 556 (1971)]. Because of a publisher's error the following corrections are required: On p. 557, column 2, line 18 "mm" should read "mil" (0.001 in). In the neon data, Table I, for entry 1, column 3, read "0.031"; for entries 5 and 6, column 2, read "0.057" and "0.087." The three references, shown as unpublished, were as follows: Ref. 9, Phys. Rev. Letters 25, 1473 (1970); Ref. 18, Rev. Sci. Instr. 41, 1797 (1970); Ref. 19, Nucl. Instr. Methods 91, 555 (1971).

In addition to the above, the x-ray *yield* values given in the paper for Xe^+-C are a factor of 10 too large in both Table I and Fig. 1. The other numbers shown for Xe^+-C are correct.

Nonthermal Saha Equation and the Physics of a Cool Dense Helium Plasma, M. S. Manalis [Phys. Rev. A 4, 364 (1971)]. The correction of the two following errors does not change the quantitative comparison between theory and experiment reported in the paper. First, small errors exist in the values for the electron binding energy X_n of the $nd\,^3D$ series given in Table II, p. 369. The first two columns of Table II should read as follows:

n	X_n (eV)
3	1.51
4	0.85
5	0.54
6	0.38
7	0.28
8	0.21
9	0.17
10	0.14
11	0.11
12	0.095

Second, the radiative cascading term which appeared in the differential equation on p. 371 and in Eq. (17) was included by mistake and should be omitted. As these equations are now written, the electron loss rate is identically zero. This is of course incorrect. The omission of the cascading term will not change the quantitative discussion following Eq. (17) since it was assumed to be small and was neglected in the calculation of Γ. The corrected equations now read as follows: