Ionization of Argon Atoms by Helium or Neon Metastable Atoms

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IN connection with some studies of electron-ion recombination[1] we have used helium and neon samples containing 0.115 percent argon. Helium (or neon) metastable atoms ionize the argon according to the equation,

$$He^*+A \rightarrow He+A^+ + e^-.$$

The excess energy appears as kinetic energy of the electron. This type of reaction was studied extensively by the Eindhoven group under Penning, and estimates were obtained for the ionizing cross section in Ne–A mixtures.[2] The present experiment, in which microwave techniques are used to measure the electron density following a discharge, affords a more direct means of measuring this cross section.

During the afterglow, helium (or neon) metastable atoms produced in the discharge will be lost by diffusion to the walls, by de-exciting collisions with normal helium (or neon) atoms, and by collisions with argon atoms which result in ionization of the argon. The rate of change of metastable concentration is therefore given by

$$dM/dt = D_m \nabla^2 M - \nu_d M - \nu_i M, \quad (1)$$

where M is the metastable atom concentration, D_m is the metastable diffusion coefficient; ν_d and ν_i are the de-excitation and ionization frequencies, respectively. The solution of Eq. (1) is

$$M = M_0 \exp(-t/T_m),$$

where

$$1/T_m = (D_m/\Lambda^2) + \nu_d + \nu_i. \quad (2)$$

Λ is the characteristic diffusion length of the container. Measurements of D_m and ν_d for pure helium and neon are described in a recent paper.[3]

The electrons and argon ions produced by the metastables will be lost by diffusion to the walls. The rate of change of electron density is

$$dn/dt = D_a{}^A \nabla^2 n + \nu_i M, \quad (3)$$

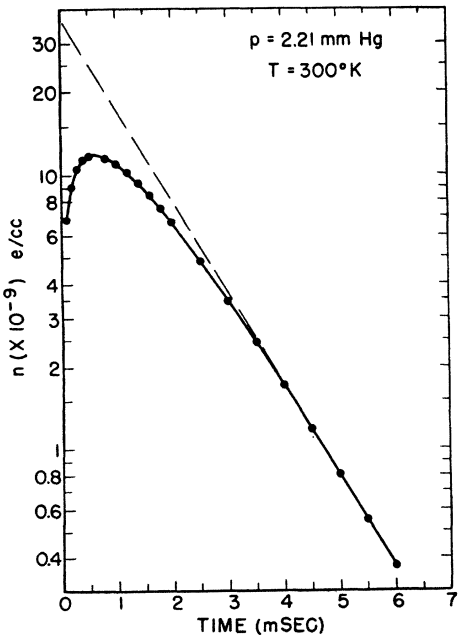

FIG. 1. Production of argon ions by helium metastable atoms.

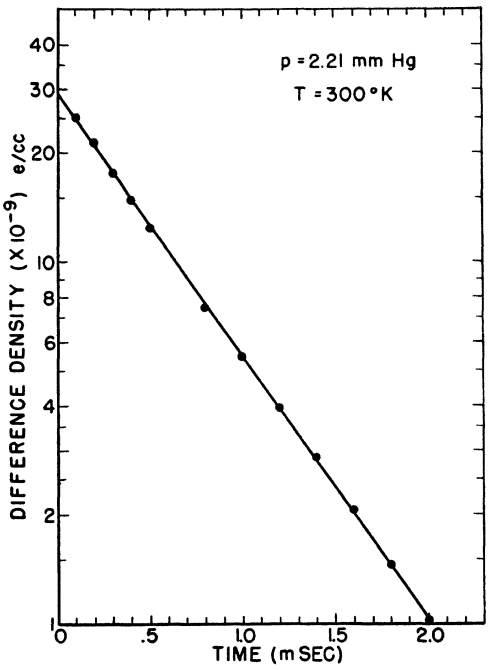

FIG. 2. Decay of metastable helium atoms in a helium-argon mixture.

where n is the electron density and $D_a{}^A$ is the ambipolar diffusion coefficient of electrons and argon ions in helium or neon. The solution of Eq. (3) is

$$n = A \exp(-t/T_D) - B \exp(-t/T_m), \quad (4)$$

where

$$1/T_D = D_a{}^A/\Lambda^2. \quad (5)$$

Typical experimental data are shown in Fig. 1. The terminal slope of the curve corresponds to the first term of Eq. (4).[4] The difference between the actual curve and the dashed extrapolated curve yields the second term of Eq. (4), shown plotted in Fig. 2. The slope of the curve is T_m. From T_m and the previously measured values of D_m and ν_d we may calculate ν_i, the frequency of ionization of argon atoms by metastable helium atoms. We define the cross section, σ_i, for this reaction by

$$\nu_i = n_A \bar{v} \sigma_i, \quad (6)$$

where n_A is the argon atom concentration and $\bar{v}$ is the rms velocity of relative motion between helium (or neon) metastable atoms and argon atoms. From data of the type shown in Figs. 1 and 2, taken over the pressure range 1.6–3.2 mm Hg, we find $\sigma_i = 9.3 \pm 0.8 \times 10^{-17}$ cm² for the helium-argon reaction.

By a similar procedure, the cross section in neon-argon mixtures between 1.4 and 4.7 mm Hg is calculated to be

$$\sigma_i = 2.9 \pm 0.25 \times 10^{-16} \text{ cm}^2.$$

In this case we may compare our results with earlier estimates by Kruithof and Druyvesteyn.[2] From their data they obtain a value for the ratio of σ_i to the de-excitation cross section of neon metastables by normal neon atoms, σ_d, of $\sigma_i/\sigma_d = 4.1 \times 10^4$. Using the aforementioned value of σ_i and our previously published value[3] of $\sigma_d = 1.2 \times 10^{-19}$ cm², we obtain $\sigma_i/\sigma_d = 2.5 \times 10^3$. Thus our value of the ratio of the two cross sections is an order of magnitude smaller than estimates obtained from breakdown data.

The estimate of Kruithof and Druyvesteyn of σ_i/σ_d required lengthy calculations and involved several simplifying assumptions. In the present experiment, σ_i/σ_d is obtained from values of σ_i and σ_d which are calculated from experimental data quite simply. In addition our gas samples are at least as pure[5] as those

referred to in reference 2; therefore, it is felt that the present values of σ_i and σ_d and, hence, of σ_i/σ_d are more nearly correct.

The author wishes to thank T. Holstein for his continued interest and helpful discussions of this problem.

[1] M. A. Biondi and T. Holstein, Phys. Rev. **82**, 962 (1951).
[2] Kruithof and Druyvesteyn, Physica **4**, 462 (1937).
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[4] Using Eq. (5) we find the ambipolar diffusion coefficient of argon ions in helium to be $D_a{}^A p = 905$ (cm²/sec)-(mm Hg). These measurements are discussed in detail in Part II of reference 1.
[5] The gases used were Airco reagent grade helium, neon, and argon (impurity $\sim 1:10^4 - 10^5$). The vacuum system used pumped to 10^{-9} mm Hg and exhibited a rate of rise of gas pressure of $\sim 10^{-10}$ mm/min. See D. Alpert, Rev. Sci. Instr., to be published.

The Energy of the Metastable State of Ba^{135}

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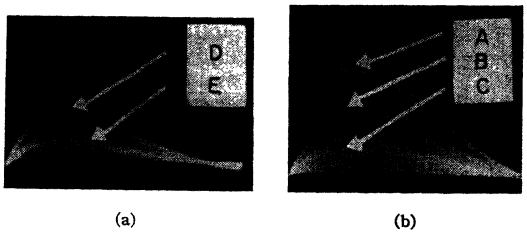
UP to the present time the only information existing in the literature on the radiations from the metastable state of Ba^{135} arises as a result of absorption measurements.[1-3] The energy of the gamma-ray has been reported to be 0.3 Mev and that of the internal conversion electron 0.28 Mev. Ba^{135} lies in that region of the chart of nuclides, running roughly from Ag^{111} to Ba^{137}, in which a large number of isomeric states are found, owing to the fact that the $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ shells are being filled competitively. Since there appear to be certain regularities in the energy of filling the $h_{11/2}$ shell,[4] it was considered important to obtain an accurate value for the energy of the metastable state of Ba^{135}. The energy of the gamma-ray from Ba^{135} was measured with the help of a scintillation counter and that of the internal conversion electrons in a magnetic lens spectrometer.

The Ba^{135} was made by the bombardment of barium with 11.5-Mev deuterons in the Indiana University cyclotron. After chemical separation for barium the only periods found were the 85-min period of Ba^{139} and the 28.7-hr period of Ba^{135}. The 38.6-hr period of Ba^{133} was not seen.

The gamma-rays were investigated with the help of a scintillation spectrometer consisting of a NaI(Tl) crystal and an RCA 5819 photomultiplier tube. The pulses from the photomultiplier were fed through a cathode follower and then to a linear amplifier. The amplified pulses triggered the sweep of a Tektronix Model 514D oscilloscope. Time exposures[5] of the pulses displayed on the oscilloscope were taken with a camera using Eastman Panchromatic Super XX film. The exposure times varied from 10 seconds to several minutes depending on the intensity of the source.

The instrument was calibrated using the gamma-ray from Cs^{137} at 0.660 Mev and the linearity of the instrument was checked by measuring the 1.12-Mev gamma-ray of Zn^{65}, the 1.33-Mev gamma-ray of Co^{60}, and the two gamma-rays of Os^{185} at 0.878 and 0.648 Mev. The latter two gamma-rays arise from orbital electron capture and were measured in a magnetic lens spectrometer by Bunker, Canada, and Mitchell,[6] and with a scintillation spectrometer using a differential pulse height sorter by Miller and Wilkinson.[7] The photographs in the present experiments show



(a) (b)

FIG. 1. (a) Photoline of the 267-kev gamma-ray in Ba^{135} appears at D, and the corresponding Compton distribution appears at E; (b) the photoline and the Compton distribution for the 660-kev gamma-ray in Cs^{137} appear at A and B, respectively. The line at C is due to backscattering of the 660-kev gamma-ray.

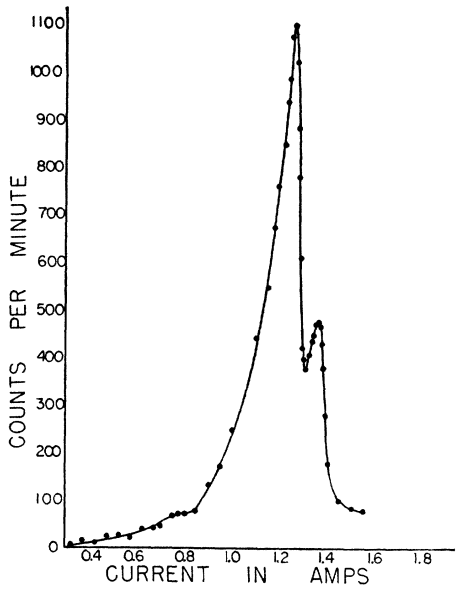


FIG. 2. Internal conversion electrons from Ba^{135}.

strong photo- and Compton peaks for a gamma-ray of 0.620 Mev and a weaker photopeak for a line at 0.870 Mev, together with a strong x-ray line at 60 kev coming about as a result of K-capture.

A photograph showing the results of the Ba^{135} investigation is given in Fig. 1(a) together with a photograph of Cs^{137} [Fig. 1(b)] for comparison. A photopeak and a Compton peak for a line at 0.270 Mev are clearly seen.

A "beta-ray" source of Ba^{135}, rather thick on account of the low intensity, was investigated in the magnetic lens spectrometer. The results are shown in Fig. 2, in which are seen a K- and an L-peak corresponding to the K- and L-conversion for a line of energy 0.267 Mev. The decay of these lines was followed in the spectrograph, and it is certain that they arise from the 28.7-hr Ba^{135}.

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On the Structure of Te II*

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OF the spectra of all atoms, those of tellurium are among the least known. On the basis of new measurements of lines from a hollow-cathode source (JSR) and an electrodeless discharge (FAP), vacuum-arc Zeeman-effect data (JCvdB), and new hyperfine structure data (KM and JSR), we have made some progress in finding and interpreting the energy levels in the first spark spectrum, as shown in Table I.