Influence of Irradiation on the Characteristic of a Glow Discharge in Pure Rare Gases

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Irradiation of the positive column of a glow discharge in pure rare gases by the radiation from a second discharge tube filled with the same gas influences the $V-I$ characteristic of the irradiated glow discharge, shifting it to a higher voltage for the same current. The effect arises from the reduction of the concentration of metastable atoms by absorption. In the case of helium the effect could be studied separately for the two mainly absorbed lines 10 830A and 20 581A. Practically the whole effect is caused by the latter. This result can be understood by considering the possible transitions involved.

INTRODUCTION

IT is well known that in a gaseous discharge metastable atoms play an important role as a source of secondary ionization. Thus, decreasing the lifetime and concentration of metastable atoms should have an effect on the characteristic quantities of the discharge. Such a decrease in lifetime and concentration may be effected by irradiation with light from an auxiliary discharge tube filled with the same gas. The explanation for this process may be given as follows.

Without irradiation the concentration of metastable atoms can be reduced by collisions which transfer the atoms to the ground state or which raise them to some nonmetastable state from which they may undergo transitions to the ground state either directly or by steps. With irradiation an additional process is involved, namely the absorption of radiation of the proper wavelength which raises the metastable atoms to nonmetastable states.

That the irradiation decreases the lifetime and concentration of metastable atoms, was first shown experimentally by Meissner and Graffunder[1] for neon and argon. More recently, much improved measurements have been carried out by Phelps and Molnar[2] who also have contributed new theoretical ideas. Further, Penning[3] found in experiments on starting potentials of neon and argon that the starting potentials are changed by addition of impurities to the main gas, the cause for which was attributed to a change in the role played by the metastable atoms. It was found that addition of a gas whose ionization potential is less than the excitation potential of the metastable atoms of the main gas causes a decrease in the starting potential. For example, a small amount of mercury added to argon resulted in the lowering of the starting potential of the mixture below that of pure argon. The following explanation was offered by Penning. Since the ionization potential of mercury (10.38 volt) is lower than the excitation potential of metastable argon atoms (11.49 volt), the mercury atoms may be ionized by collisions of the second kind, leaving the argon atoms in the ground state. In this manner metastable argon atoms cause the formation of secondary ions and herewith a decrease in the starting potential of the mixture. If the decrease of the starting potential is attributed to the action of the metastable atoms, then diminishing the number of metastable atoms present should again raise the starting potential. The reduction of metastable argon atoms may be achieved by either addition of a third gas or irradiation with argon light. Indeed, Penning found that irradiating the argon-mercury mixture with argon light raised the starting potential.

Similar experiments in mixtures of mercury and rare gases were carried out by Kenty,[4] who found that for a given value of current the tube voltage was raised appreciably by irradiating the discharge with light from another source of mercury vapor.

Penning[5] in two patent papers describes a similar effect on the $V-I$ characteristic curve for pure rare gases. The effect was found experimentally by Meissner and Pierson[6] for pure neon and rather pure helium.

In the present investigation the latter experiments were repeated for neon and pure helium and new experiments were conducted in pure argon, krypton, and xenon.

TECHNICAL DETAILS

A conventional vacuum system was employed to permit pressure control and purification of the rare gases. The design of the system varied slightly from gas to gas. In the case of helium, circulation through a charcoal trap at liquid nitrogen temperature was used. The other gases were cleaned by circulation through a large discharge tube, in which intense sputtering of the magnesium electrodes was maintained. After the tubes were sealed off from the vacuum system, the sputtered deposit from the molybdenum electrodes of the tubes themselves served as a getter. The dimensions and construction of the discharge tubes can be seen from Fig. 1.

The measurements of the $V-I$ characteristics of the discharge tubes were made by means of the electrical circuit shown in Fig. 2. The electric source was a dc

[1] K. W. Meissner and W. Graffunder, Ann. Physik **84**, 1009 (1927).
[2] A. V. Phelps and J. P. Molnar, Phys. Rev. **89**, 1202 (1953).
[3] F. M. Penning, Phil. Mag. **11**, 961 (1931).
[4] Carl Kenty, Phys. Rev. **80**, 95 (1950).
[5] F. M. Penning, U. S. Patent No. 1,958,066 May 8, 1934; U. S. Patent No. 2,080,926 May 18, 1937.
[6] K. W. Meissner and R. M. Pierson, Proc. Indiana Acad. Sci. **59**, 269 (1950).

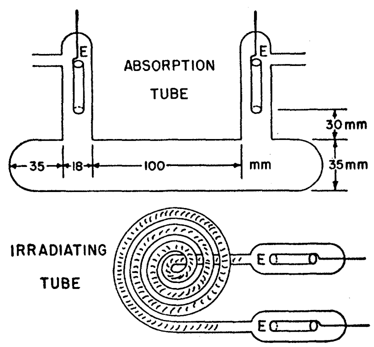

FIG. 1. Dimensions and construction of absorption tube and spiral shaped irradiating tube. E are hollow cylindrical molybdenum electrodes. The axes of the endparts of the irradiating tube containing the electrodes are in reality perpendicular to the plane of the spiral as indicated in Fig. 2.

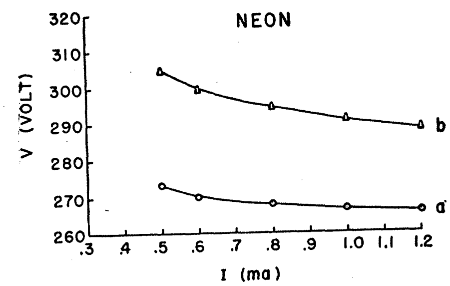

FIG. 4. Characteristics of neon (pressure 2.8-mm Hg). (a) without irradiation, (b) with irradiation.

choke input power supply employing full wave rectification with input controlled by a variac rated at 110 volt and 5 ampere. A 7500 volt transformer, a 4400 volt high current transformer, and a 0–15 000 volt dc Radar Power Unit served as sources for operating the irradiating tubes.

After cleaning the gases, the spiral shaped irradiating tubes were sealed off from the vacuum system. Before sealing off the absorption tubes, preliminary measurements were made to determine the pressure at which

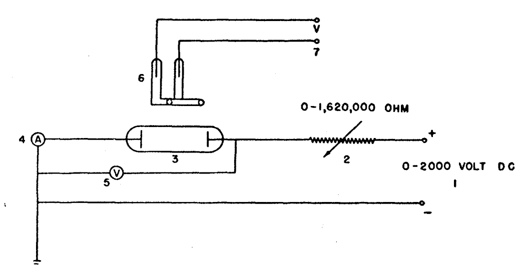

FIG. 2. Electrical Circuit. (1) dc power supply, (2) variable resistance, (3) absorption tube, (4) ammeter, (5) voltmeter, (6) irradiating tube, (7) power supply for 6.

the greatest irradiation effect is observed. The final measurements were made with the absorption tubes sealed off at optimum pressure. The irradiating tube was placed about 4 cm away from the absorption tube, and a grounded wire screen was interposed between irradiating tube and absorption tube. The position of the irradiating tube relative to the absorption tube was such that mainly the positive column was irradiated.

In all experiments the points on the $V-I$ characteristic curves were obtained by adjusting the tube current to a desired value by emf control, reading the tube voltage, turning on the irradiating tube, adjusting the tube current back to the original value, and reading the new tube voltage. This procedure was repeated throughout the range of the measurements.

Two experiments were made to show that the changes in the $V-I$ characteristics were due only to incident irradiation. In the first experiment, instead of turning

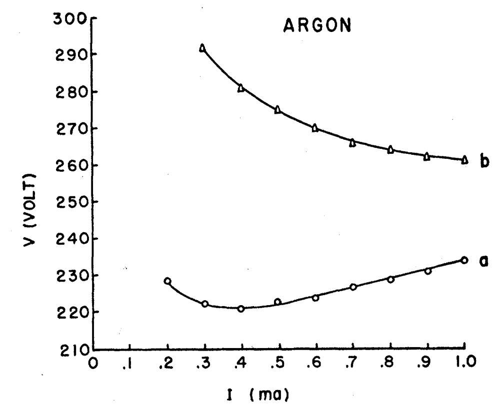

FIG. 5. Characteristics of argon (pressure 1.5-mm Hg). (a) without irradiation, (b) with irradiation.

off the irradiating tube to measure the $V-I$ curve without irradiation, the irradiating tube was left in operation, but a sheet of black paper was interposed between the two tubes. The results were the same as those obtained in the usual manner. In the second experiment the irradiating tube was placed about one meter from the absorption tube and the irradiation tube was focused on the positive column of the absorption

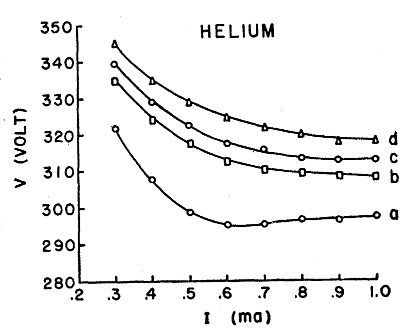

FIG. 3. Characteristics of helium (pressure 5.3-mm Hg) with different irradiating intensities. (a) without irradiation, (b) irradiation with source No. 1, (c) irradiation with source No. 2, (d) irradiation with sources No. 1 and No. 2.

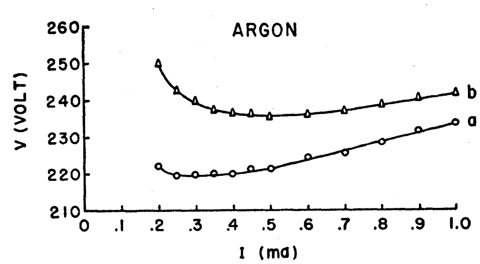

FIG. 6. Characteristics of argon (pressure 1.5-mm Hg), (a) without irradiation, (b) with irradiation produced by imaging the removed irradiating tube on the positive column of the absorption tube.

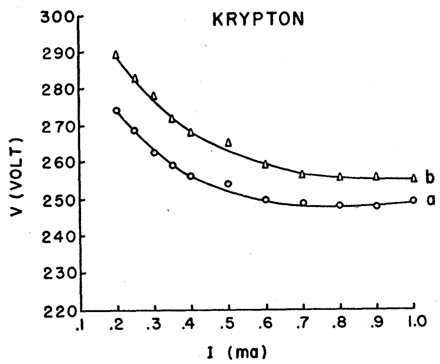

FIG. 7. Characteristics of krypton (pressure 1.1-mm Hg). (a) without irradiation, (b) with irradiation.

tube by a large concave mirror. The shift in the $V-I$ curve was about one-third of that observed for direct irradiation (compare Figs. 5 and 6), the difference being accounted for by the reduction of intensity with the mirror arrangement (diminished aperture and reflection losses).

EXPERIMENTAL RESULTS

Typical results of the experiments with helium are given in Fig. 3 for three different irradiation intensities. The greater the intensity, the greater is the shift of the $V-I$ characteristic to higher voltages for the same current value. The irradiation sources 1 and 2 were operated under different conditions such that source 2 was more intense than source 1.

Typical results for neon are shown in Fig. 4, for argon in Figs. 5 and 6, for krypton in Fig. 7, and for xenon in Fig. 8.

The outstanding irradiation effect found for argon at optimum pressure is of particular interest; however, thus far it has not been possible to find a satisfactory explanation for it. Most likely this outstanding effect is connected with the relative long mean life of argon metastables. Measurements of the lifetimes of metastable atoms under experimental conditions comparable to those of the present investigations have shown that for helium, neon, and argon the maximum values are 8×10^{-4} sec, 6×10^{-4} sec, and 35×10^{-4} sec, respectively.[1]

In the experiments already discussed the whole

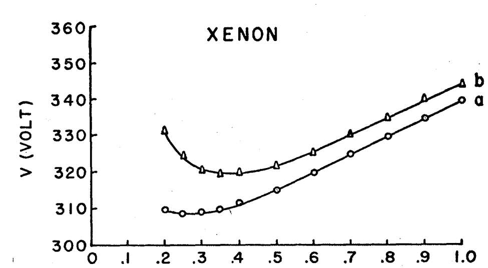

FIG. 8. Characteristics of xenon (pressure 3.5-mm Hg). (a) without irradiation, (b) with irradiation.

spectrum of emitted light from the irradiating tube was directed on the absorption tube. It would be of interest to separate the effects of the different strongly absorbed wavelengths. By use of filters it was possible for the case of helium to study separately the effects of the two strongly absorbed lines 10 830A and 20 581A. One of the filters employed was a glass cell containing a 1 mm thickness of water which absorbed the 20 581A line and transmitted the 10 830A line. The transmission of the water filter was checked by photography. The other filter employed was a 90 micron thick Biotite Mica[7] sheet which had 60 percent transmittance for 20 582A and 1 percent transmittance for 10 830A. The transmittance of the Biotite Mica was checked by means of a recording Perkin-Elmer infrared spectrometer.

Figure 9 shows the results of the filtering experiments. When the absorption tube was irradiated through the water filter, no detectable effect was produced, whereas irradiation through the Biotite Mica filter gave an effect corresponding to the high trans-

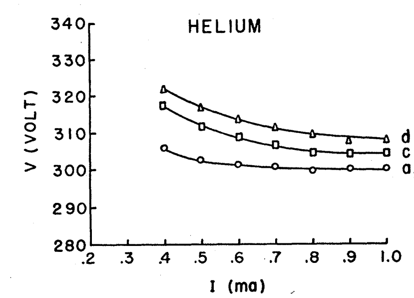

FIG. 9. Effect of filtered irradiation on the characteristics of helium (pressure 5.3-mm Hg). (a) without irradiation, (b) water filter transmitting 10 830A line, absorbing 20 582A line, (c) Biotite Mica filter transmitting 20 581A line, absorbing 10 830A line, (d) without filter.

mittance for the 20 581A line. These experiments show that practically the entire irradiation effect is due to absorption of the 20 581 line.

This result can be explained as follows. The two strongly absorbed lines 20 581A and 10 830A start from the metastable states 2^1S_0 and 2^3S_1, respectively. Absorption of the 20 581A line raises the atoms from the 2^1S_0 state to the 2^1P_1 state from which most of them go to the ground state, emitting the strong 584A line. It is interesting to note that Paschen[8] had remarked in an early paper that no resonance radiation of the 20 581A line could be observed. Thus, absorption of the 20 581A line is quite effective in reducing the concentration of the 2^1S_0 metastables. However, absorption of the 10 830A line raises the metastable atoms from the 2^3S_1 state to the 2^3P state, from which the only permitted transition leads back to the metastable 2^3S_1 state. Hence, absorption of the 10 830A line has no detectable effect on the concentration of the 2^3S_1 metastables.

[7] A. Ignatieff, Ann. Physik **43**, 1123 (1914).
[8] F. Paschen, Ann. Physik **45**, 625 (1914).