

NEGATIVE PHOTO-EFFECT IN HELIUM

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EXCITATION STATES OF HELIUM

The states of helium excited by electron impacts are shown in figure 1. In the left column appear the singlet states of the normal atom in which the spins of the two electrons are anti-symmetric. The term *parhelium* was originally applied to this form of excited helium emitting singlet lines. If, in the process of excitation, the spin of the emission electron is reversed, a series of triplet states results. The name given to atoms having these configurations is *orthohelium*.

The parhelium state $1s\ 2s\ ^1S_0$ is metastable. The corresponding state of the orthohelium configuration, $1s\ 2s\ ^3S_1$, is also metastable. The latter forms the "ground" state of the triplet system. Atoms in either of these states cannot return to the normal ground level by simple emission of radiation. Although both can lose their energies by collision processes, there is one respect in which they differ. An atom in the parhelium metastable state can be transformed to a normal helium atom by absorption of radiation which lifts it to a higher excitation level, from which it can return to the ground state by the emission of spectral lines. Orthohelium atoms can return to normalcy only by some collision process.

The line most strongly emitted by parhelium is the line at 2.0582 microns. The corresponding emission by orthohelium consists of three lines at 1.08304, 1.083025, and 1.082908

microns, the last three lines being unresolved by most spectrographs. Conversely, all of these lines are strongly absorbed by atoms in the corresponding metastable states. One method used in this laboratory to determine the relative abundance of atoms in the two states in a discharge is to measure the absorption of these lines emitted by a bright helium gas source and sent through the excited gas.

INFRARED LINE RADIATIONS

Many measurements of the relative intensities of the two "resonance" type of lines arising from transitions from the next higher level to the metastable levels in helium have been carried out in this laboratory. In Geissler glow discharges the ratio of the emitted intensities at 1.0830μ and at 2.0582μ varies strongly with pressure. It is a nearly linear relationship, varying from a value of 4:1 at .5 mm Hg pressure to about 50:1 at 10 mm Hg pressure. The ratios are slightly higher at higher currents in the range from 10 to 80 milliamperes. In the case of arc discharges, the ratios vary from about 12:1 at 8 mm Hg pressure to more than 100:1 at higher gas pressures.

These results indicate that parhelium metastables are rapidly destroyed through absorption of radiation as well as by collisions, these effects becoming more efficient as the gas pressure and current densities are increased. Orthohelium metas-

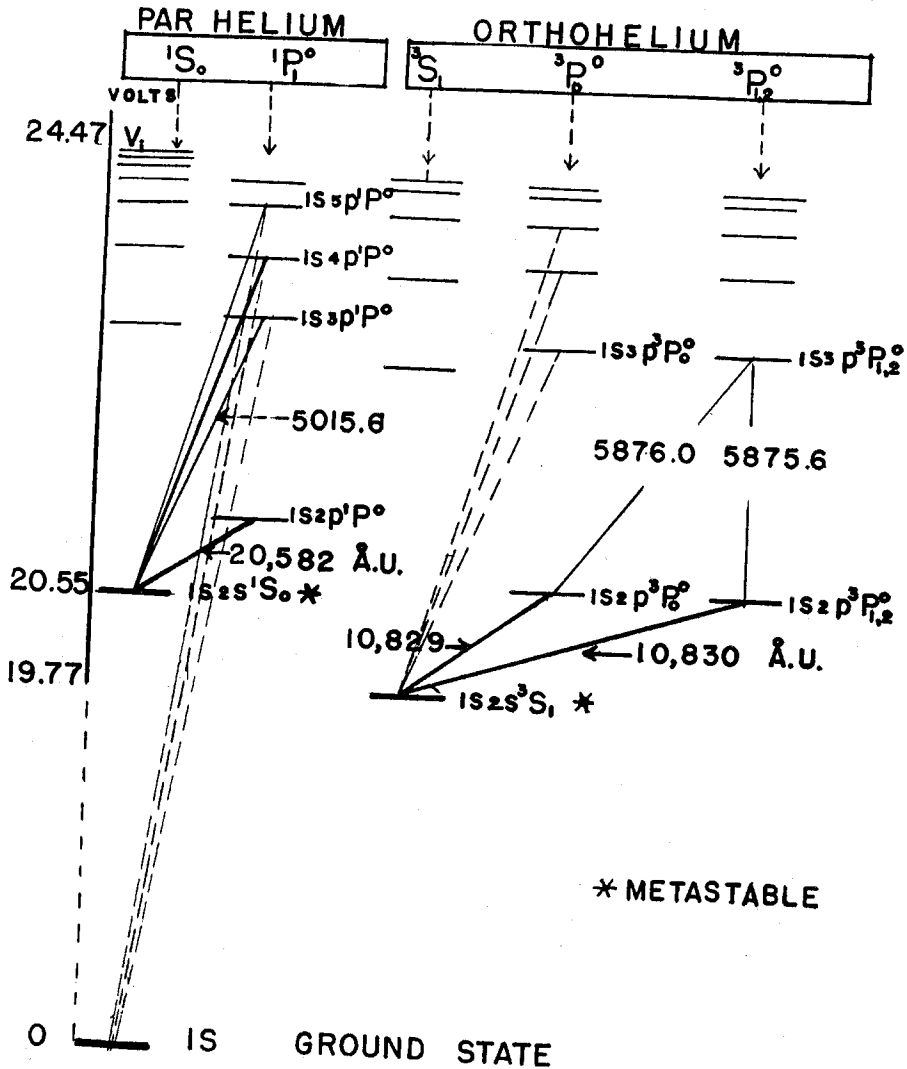


FIG. 1.—Energy level diagram of He atom.

tables are destroyed by collision processes only and by diffusion to the walls or electrodes of the discharge chamber.

CHANGE OF CURRENT PRODUCED BY LIGHT IN GLOW DISCHARGES

When light emitted by a strong glow discharge in helium is allowed

to shine upon a second discharge, the current in the second tube decreases and the potential increases. However, these changes are small, particularly for discharges in narrow capillary tubes. Results obtained for radiation from one Geissler discharge allowed to fall on a second tube placed parallel to it about 3

inches away is shown in fig. 2. If the light is focussed on various parts of the second tube it is found that 90% of the effect occurs when the

negative glow region near the cathode is irradiated. No effect is found in the positive column of the glow where metastable atoms make a neg-

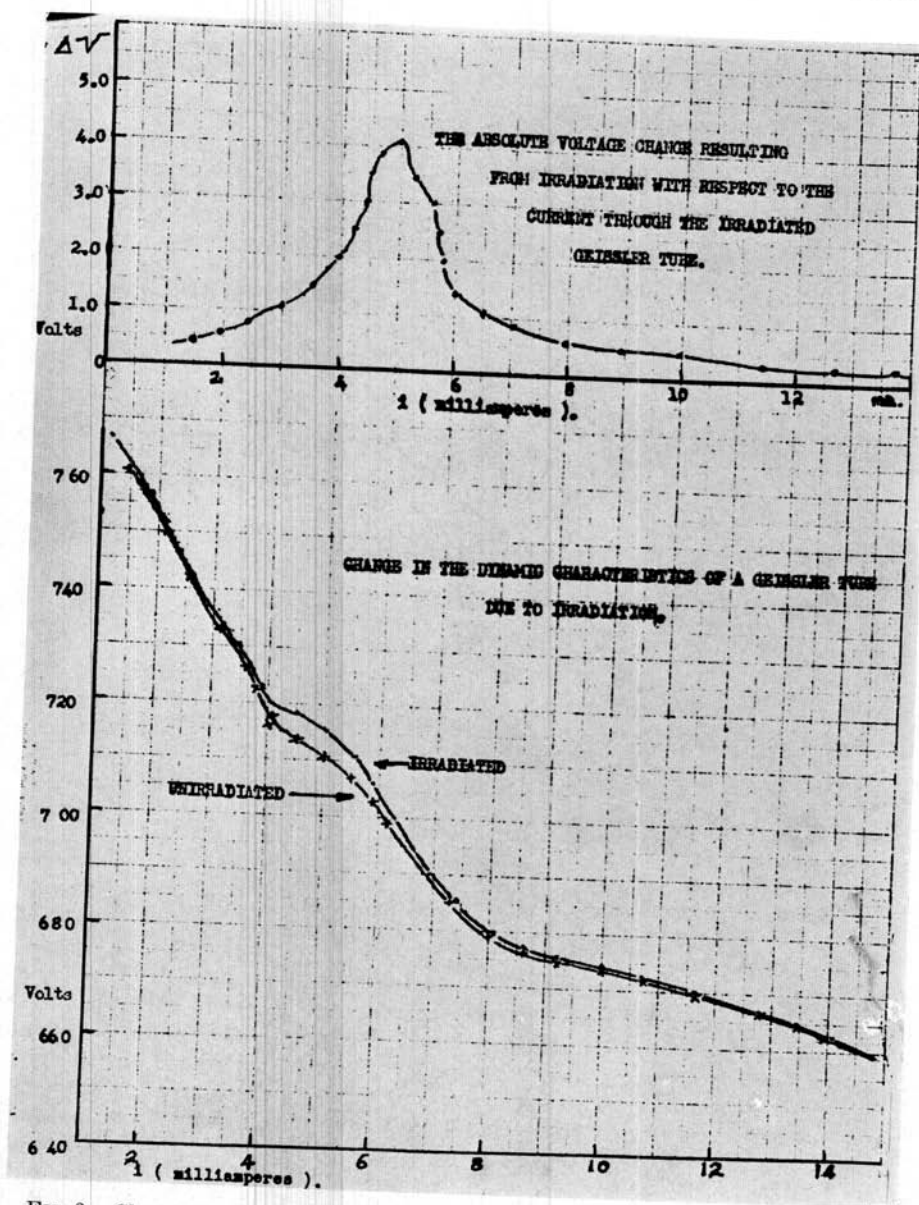


FIG. 2.—Change in characteristic of Geissler discharge due to 2.0582μ radiation.

ligible contribution to the maintenance of the discharge.

Careful studies were made on the effect produced by both the 1.0830μ line and the 2.0582μ line on the discharge. Using both a spectrometer and filters it was found that no measurable change is caused by the 1.0830μ line. The conclusion has since been confirmed that only the 2.0582μ line affects the discharge. This result is understandable as only parhelium metastable atoms can be destroyed by light. Even though both types of metastable atoms may promote ionization processes in the gas, only the parhelium metastable state can be permanently affected by the absorption of line radiation.

ROLE OF METASTABLE ATOMS IN THE DISCHARGE

Several years ago it was established in this laboratory that metastable atoms play a significant role in Townsend currents in an argon-filled cesium phototube. The current between parallel plates of a phototube in which a current of emitted electrons, i_0 , is caused by light falling on the cathode is given by

$$(1) \quad i = \frac{i_0 \epsilon \alpha [x - \delta]}{1 - \gamma \left(\frac{\alpha [x - \delta]}{\epsilon} - 1 \right)}$$

In this equation i_0 is the electron current which would flow due to light if there were no gas in the tube; x is the separation of the parallel plates in cms; α is the number of ion-electron pairs produced by collision of electrons with gas atoms; $\delta = V_i / E$, where V_i is the

ionization potential of the gas and $E = V / x$ is the field intensity, and $\gamma =$ the average number of secondary electrons emitted from the cathode per positive ion reaching it. The coefficients α and γ determine the amplification constant $K = i / i_0$ for a gas-filled phototube.

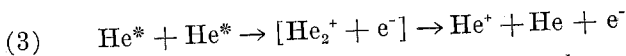
It was found that the secondary Townsend coefficient γ appearing in this expression must include the effect of metastable atoms which diffuse to the cathode and release electrons, as well as the effect of ions. In other words

$$(2) \quad \gamma = \gamma_m + \gamma_p$$

Here γ_p represents the release of electrons due solely to the ion, while γ_m is the effect of metastable atoms in releasing electrons. It turns out that γ_m and γ_p are of the same order of magnitude at $p = 1$ mm Hg pressure. For Cs-Ag-O cathodes $\gamma_m \cong \gamma_p \cong .2$. Although metastable atoms and ions are formed in about equal numbers, only a part of the metastable argon atoms diffuse to the cathode. All of the ions formed in the discharge are drawn to the cathode by the field.

In these experiments at pressures $p \leq .8$ mm Hg, the main effect of metastable atoms is at the cathode in releasing electrons to the discharge. Current densities were of the order of 10^{-8} or 10^{-7} amp/cm².

At higher pressures and at larger current densities metastable atoms contribute to the discharge in other ways. They may effectively ionize impurity vapors or foreign gas atoms, or they may, by collision with each other, produce electron-ion pairs. Thus, if He* represents a metastable He atom,



This stepwise ionization process can be significant in a pure gas at elevated pressures and high excitation densities. The frequency of collision of metastable atoms with each other varies as n^2 , where n is the number of metastable atoms per cm^3 in the discharge space.

One of the objectives of the present research is to attempt to determine in a particular discharge how much metastable atoms contribute to the discharge by release of secondaries (γ -mechanism), and how much they contribute by other processes which occur in the gas phase (volume effect). Because from the results obtained with a glow tube it was found that destruction of parhelium metastable atoms produces a measurable effect only in the near-cathode region of the discharge, it was decided to build tubes in which only the negative glow occurs. Such tubes are referred to generally as negative glow lamps, and include such forms as the hollow cathode glow and gas-filled phototubes. The negative photo effect is found to be largest at rather low pressures, since presumably collisions and radiations within the discharge itself greatly reduce the population of parhelium metastable atoms.

EFFECT OF 2.0582 MICRON LINE ON PHOTO CURRENTS

A number of helium-filled phototubes were prepared having regular activated cathodes and high purity gas. Cathodes of both cesium-silver-oxide and cesium-antimony types were used. Gas pressures for the former ranged from .5 to 3.0 mm Hg, and for the latter from 1 to 3 mm Hg.

These tubes were made for this work by R. W. Engstrom of the RCA Tube Laboratory, Lancaster, Pa.

These tubes are not operated in the normal manner as photo-detectors. Instead, a series resistance of from 4 to 100 megohms is connected in series with the tube and a d-c voltage source higher than the breakdown potential of the gas. At the higher pressures this potential is about 120 volts at 3 mm Hg pressure, but it is of the order of 400 volts at the lowest pressures used. The tube requires no external light for its operation. Upon breakdown the IR drop in the resistor limits the current to values in the range of from 10^{-10} amperes to 10 or 20 microamperes as may be desired by change of the input voltage. The activated electrodes are not damaged by prolonged operation at the higher currents.

This type of "dark" discharge is referred to as a "self-maintained" Townsend discharge. The reason for this name is that no space charge and hence no cathode fall space is created. The electrodes may be parallel plates or a wire and semi-cylinder arrangement. The present tubes are of the latter type, and either electrode may be made the cathode. When the activated surface is the cathode, the potential across the discharge is lower than for the reverse polarity. This potential is constant over a range of current values from 10^{-9} to 10^{-6} amperes. Beyond about 1 microampere the potential drops linearly with increase in current through the tube.

The circuit used for operating the helium phototubes is shown in figure

3. Both a 350-volt rectifier supply and a bank of 45-volt dry batteries have been used as a source of potential. An electrostatic voltmeter reading up to 300 volts is used to determine the voltage across the discharge tube. Currents are read by a galvanometer or microammeter.

When line radiation at 2.0582 microns from a high-intensity 60-watt helium arc operating at about 18 mm Hg is allowed to fall on the excited gas in the phototube, the current decreases and the tube potential increases. A Bausch and Lomb glass filter, which passes only wave lengths beyond 1.3 μ , was used between the light source and the tube. Changes in the volt-ampere characteristic due to radiation of a tube containing helium at a pressure of .55 mm Hg

are shown in figure 4. The dotted lines show the shift of the characteristic with a constant light flux shining on the tube.

The current change produced by the light with the source about 3 inches from the phototube is remarkably constant over the range from 1 to 12 microamperes. It is about .5 μ amp. and is progressively smaller for tube currents below one microampere. Apparently there are only so many quanta available for absorption in the 2.0582 μ line radiation from the source, and the constant current change represents a saturation effect. This phenomenon occurred in all of the measurements. The corresponding voltage change is about .6 volt for the data shown in figure 4.

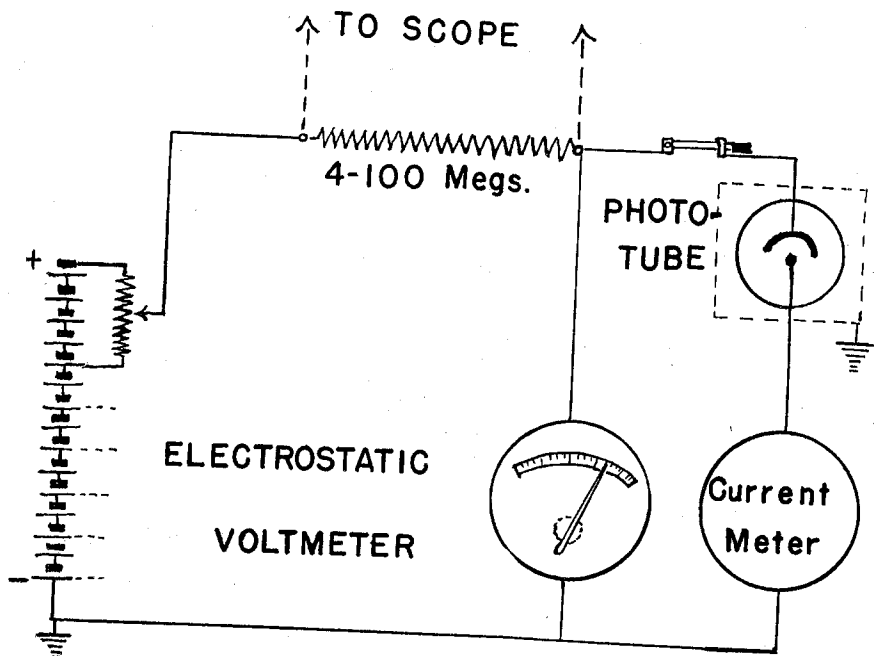


FIG. 3.—Circuit for detecting negative photo-effect.

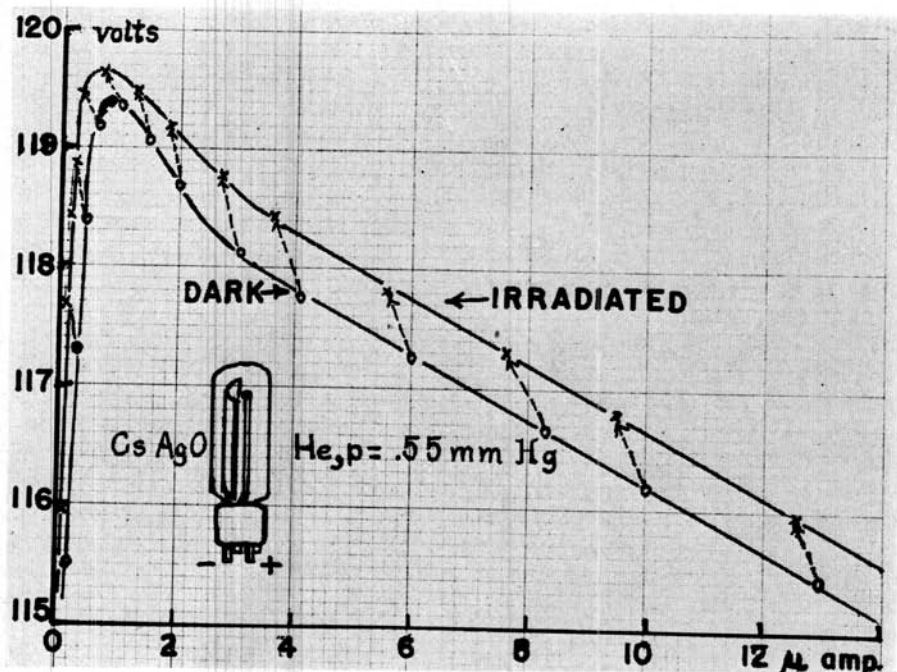


FIG. 4.—Negative photo-effect in He phototubes.

The current changes caused by a given light flux are larger when the tube is connected with the activated cathode positive. Since the γ -mechanism for metastable atoms causing release of electrons must be very small in this case, since the wire electrode used as cathode is not activated, and since also it has a very small area for intercepting the diffusing metastable atoms, their role in the discharge must be a volume effect. Measurements are being carried out to determine the lifetime of metastable atoms in these discharges. To date the mean lifetimes appear to be a few milliseconds.

Another method of investigation being used is to employ modulated or pulsing radiation. The time response of the phototube current to this light is determined by applying

the potential across the series resistor of figure 3 to an oscilloscope. The signal detected may then be analyzed to determine the presence of more than one kind of current change as a function of time.

Figure 5 shows four oscilloscope photographs made using the helium arc operated from the output of a 60-cycle 650-volt transformer. There are 120 half sine wave loops per second. The effect of these light pulses is shown in figure 5a where unfiltered light of the arc falls on the helium phototube with cesium surface used as cathode. In this the tube responds as a normal phototube, with positive current loops turned upward.

Figure 5b shows the results obtained when the phototube is connected with the wire used as cathode.

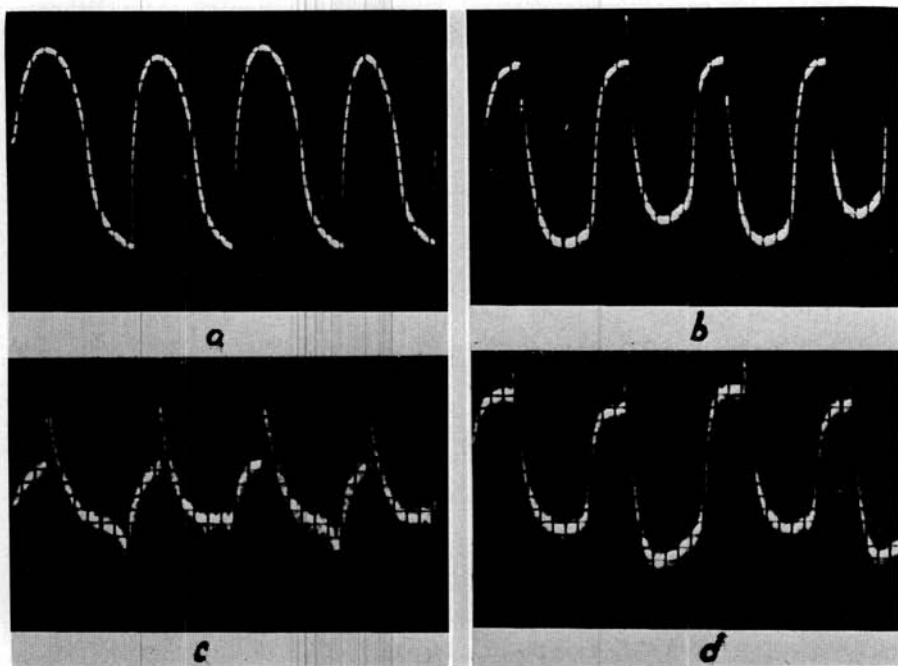


FIG. 5.—Negative photo-effect using pulsed radiation. (a) Positive wave pulses from A-C helium arc; $p = 3$ mm Hg. (b) Negative current pulses, Cs-Ag-O surface positive. (c) Negative current pulses, Cs-Ag-O surface negative. (d) Negative pulses, Cs-Ag-O negative; $p = 55$ mm Hg.

The shape of the current pulses are similar to those shown in figure 5a. In this case, however, the loops appear reversed and represent the effect of absorption of 2.0582μ line radiation. The pulses represent *decrease* of current in the tube with increasing light intensity.

Figure 5c shows the negative current pulses produced when the cesium activated electrode is the cathode, the image of the arc light being carefully focussed on the gas in the region of the collecting wire electrode. In this region metastable atoms are most dense. Absorption of light and decrease of current sets in as the light intensity increases. However, there is a pronounced lag in

response of the cell, and at about three-fourths of a half period later, an additional negative tip in the current loop is observed. This is believed to be a rather sudden change, occurring when there is a "hole" in the supply of metastable atoms which normally reach the cathode, causing a further sudden decrease in current. The relative change is small and presumably the volume effect of metastable atoms is greater than the γ -action, causing release of secondary electrons from the cathode surface.

The tube used in the above experiments had a pressure of 3 mm Hg of helium gas. Figure 5d shows the results with light focused near the

positive wire electrode in a tube in which the pressure is .55 mm Hg. No distinct pip appears in the pulse, but initial decrease of current is much more rapid. In alternate pulses a distortion is present, indicating a release of secondary cathode electrons but contributing to the current decrease much earlier in the period than in the first. This interpretation is reasonable since the rate of diffusion of metastable atoms is much more rapid at .55 mm Hg than at 3 mm Hg.

CONCLUSIONS

The existence of a negative photoeffect in pure helium has been confirmed. In phototubes containing helium in the pressure range from

.25 mm to 3.0 mm Hg a readily measured decrease in current is obtained when the gas is irradiated with the arc line of helium in the infrared at 2.0582 μ . It is shown that a similar effect is not produced by the 1.0830 μ line of helium, although the latter is much more intense in the arc source. The results show that in phototubes having a wire cathode and at currents greater than 2 microamperes per cm^2 the action of the metastable atoms is predominantly that of volume ionization. It is also believed that secondary emission of electrons, induced by metastable atoms arriving at an activated Cs cathode, contributes less to the discharge mechanism than ionization produced by metastable atoms in the gas itself.

REFERENCES

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