Excitation of Metastable Levels in Helium near Threshold

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The excitation of the metastable levels in helium ($2\,^3S$ and $2\,^1S$) was studied as a function of electron energy near threshold. The excitation due to essentially monoenergetic electrons was obtained by using the retarding potential method. The metastables were detected by their emission of electrons from a gold-plated cylinder. It was found that the excitation function for the $2\,^3S$ level is linear from the onset of excitation to approximately 0.4 ev above onset except for a small amount of tailing near threshold. The excitation function peaks at 0.6 ev above the excitation threshold. The value of the cross section of the $2\,^3S$ level is in reasonable agreement with the value given by Maier-Leibnitz.

INTRODUCTION

THE excitation of the metastable levels in the rare gases by electron impact has been the subject of some experimental[1–3] and theoretical[4] studies which show a wide disagreement, especially near the threshold of excitation. Maier-Leibnitz[1] used retarding curves on electrons in an electron swarm experiment to determine the inelastic collision cross section in helium. Dorrestein,[2] on the other hand, used an electron beam to produce the metastable helium atoms and detected them by their secondary electrons, as described below. Woudenberg and Milatz[3] measured the metastables by the absorption of the 10 830 angstrom line. For the metastable levels in helium, these experiments showed a sharp increase of the excitation cross section near threshold and a peak in the cross section quite close to the threshold. However, all these experiments suffered from a poor resolution in the energy of the primary electrons; the width of the distribution of electron energies was of the order of 0.5 to 1 electron volt. It therefore seemed advisable to perform an experiment in which the electron energy distribution is narrower. In the present experiment the retarding potential difference method[5] was used to obtain cross sections for excitation resulting from electrons in a band of energies about 0.1 electron volt wide.

It is well known that metastable atoms impinging on a metal liberate secondary electrons provided that the energy of the metastable level is larger than the work function of the metal.[6,7] In helium where the first metastable levels are 19.82 and 20.61 electron volts above the ground state, this condition is certainly fulfilled since the work function of the metal, in this case gold, is of the order of four electron volts. This property of the metastable atoms is used to detect them.

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EXPERIMENT

Description of Tube

A diagram of the tube used in this experiment is shown in Fig. 1. It consists of an electron gun, a collision chamber (C), and the electron collector (E). Electrons are emitted by a tungsten wire (F), about 0.1 millimeter in diameter and 3 millimeters long, and pass through the electron gun to be described later. The electrons, accelerated to the proper energy, pass through the collision chamber and are collected by the electron collector. The collision chamber is surrounded by two concentric cylindrical grids, G_1 and G_2, made of mesh which is 90% transparent. The diameter of these grids is 6.3 and 8.4 millimeters, respectively. A concentric solid cylinder M, 10 millimeters in diameter, is mounted from long glass insulators so that small currents to this cylinder can be measured.

All parts of the tube are gold-plated to reduce contact potentials. The whole tube is baked at 450 degrees centigrade and the ultimate vacuum is of the order of 10^{-10} to 10^{-9} millimeter of mercury. Operating pressures range from 10^{-4} to 10^{-2} millimeter of mercury. Reagent grade helium gas is used.

Electron Gun

The electron gun uses the retarding potential difference method[5] to obtain the excitation function due to

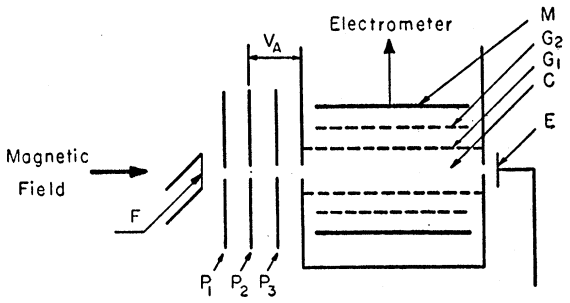

FIG. 1. Diagram of excitation tube. F is the filament, P_1, P_2, and P_3 are the three electrodes constituting the electron gun, C is the collision chamber, G_1 and G_2 are two concentric cylindrical grids, M is the gold-plated cylinder where electrons released by metastable atoms are measured, and E is the collector for electrons in the electron beam.

essentially monoenergetic electrons. The electrons coming from the filament travel through three electrodes. The first electrode (P_1) is at a positive potential (about three volts) with respect to the filament and serves to draw the electrons from the filament. The second electrode (P_2) is at a slightly negative potential V_R with respect to the filament. In order to prevent defocusing of the electron beam by this retarding potential, an axial magnetic field of about 100 gauss is applied. The electron distribution in the forward direction is chopped off by the retarding potential V_R; Only the high-energy electrons in the distribution can penetrate through the potential barrier presented by the second plate. The third plate (P_3) is again at the same potential as P_1. The collision chamber is at the potential V_A with respect to the retarding electrode P_2. If we change the retarding potential V_R by a small amount δV_R, say 0.1 volt, then the distribution of electrons will be cut off sharply at a slightly different energy. The difference between retarding by V_R and $V_R+\delta V_R$ is due solely to electrons in the energy band δV_R. Thus in order to obtain the excitation function due to electrons in a small energy range δV_R, one takes two readings for every value of electron accelerating voltage V_A. The difference between the two readings gives the excitation due to electrons in the band δV_R. By measuring the "difference current," one can obtain the excitation due to electrons in a small energy band without actually creating a beam of monoenergetic electrons. Since P_1 and P_3 are at the same potential, no change in focusing action of the lens will occur when the potential on P_2 is changed slightly.

Another advantage of the retarding potential method should be noted. Since electrons start with zero energy at the retarding electrode P_2, the accelerating voltage V_A (see Fig. 1) will be very close to the true energy of the electrons. The contact potential between filament and the electrodes is thus eliminated.

Operation

Metastable atoms created by electron impact in the center of the collision chamber C, move out of the collision chamber with thermal velocities since the mean free path of the metastable atoms is larger than the dimensions of the tube. A portion of these metastable atoms reaches the outer cylinder M where they liberate secondary electrons. The secondary electrons in turn are accelerated to the grid G_2 by a potential of about 15 volts. A vibrating reed electrometer is connected through a resistor (10^{10} ohms) to cylinder M. Thus, by measuring the departure of secondary electrons from M one obtains a measure of the number of metastable atoms created by the electron beam and arriving at M provided that the secondary emission coefficient for liberation of electrons by metastable atoms is known.

RESULTS

The difference current departing from the cylinder M as a function of electron accelerating voltage is plotted in Fig. 2. The accelerating voltage, V_A, should be corrected by approximately 0.06 ev to give the electron energy. The optical values for the excitation of the $2\,^3S$, $2\,^1S$, and $2\,^3P$ states are indicated by the arrows. The excitation function exhibits, within experimental error, a linear rise near threshold. The tailing for the first 0.1 volt near threshold is attributed to the finite distribution in energy of the electron slice. The excitation function peaks at 0.6 ev above threshold and then falls off. The onset of the $2\,^1S$ excitation occurs 0.8 volt above the onset of the $2\,^3S$ excitation and this is evidenced by an increase in the excitation function.

From this point on, the sum of the excitation functions for the $2\,^3S$ and $2\,^1S$ levels is measured. Triplet and singlet metastable states cannot be separated in this experiment. The second peak at 21.1 volts indicates, however, that the $2\,^1S$ level also has a peak in its cross section quite close to threshold. This is contradictory to the theory by Massey and Moiseiwitsch[4] which predicts a peak in the cross section for excitation of the $2\,^1S$ level at 12 ev above threshold.

Magnitude of Cross Section for the $2\,^3S$ Level

The magnitude of the cross section for the excitation of the $2\,^3S$ level can be computed provided that the electron yield due to the thermal metastables on the

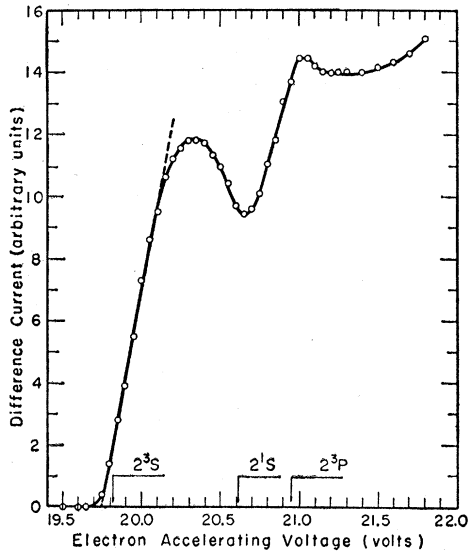

FIG. 2. Difference current as a function of electron accelerating voltage. The difference current is proportional to the excitation cross section. The dashed line is an extension of the straight line fit to the experimental points in the region from 19.8 to 20.1 ev. The arrows locate the spectroscopic values of excitation levels for the indicated states. The electron accelerating voltage is the potential difference V_A (see Fig. 1). The difference between the dashed line intercept and the location of the $2\,^3S$ state (0.06 ev) indicates the approximate correction necessary to convert the electron accelerating voltage V_A into electron energy.

metal cylinder M is known. Also, an assumption about the angular distribution of the scattered metastable atoms has to be made. The electron yield of the cylinder M depends on the conditions of the surface of the cylinder. No special provisions were made in the present tube to outgas cylinder M other than baking it at 450°C for 12 hours. Stebbings and Massey[8] measured the electron yield due to helium metastables impinging on such a surface. In their experiment the surface was gold-plated, as is the case in our experiment. The value of Stebbings and Massey for the electron yield, γ, is 0.29 ± 0.03 electron per metastable.

Using this value, one can compute the cross section for the excitation of the $2\,^3S$ level from the relation

$$i_m = i_- Q_m N \gamma G l,$$

where i_m is the electron current departing from the cylinder M due to the arrival of metastable atoms, i_- is the electron current through the collision chamber, Q_m is the cross section for excitation of the helium metastable atoms, G is a geometric factor giving the ratio of the area subtended by the collector M to the total solid angle, and l is the length of the electron path. The factor G is computed under the assumption that the angular distribution of the metastable atoms is isotropic. N is the gas density.

With the assumptions enumerated above, the cross section at the peak of the $2\,^3S$ excitation becomes 4×10^{-18} cm$^2\pm30\%$. This value is in good agreement with the value reported by Maier-Leibnitz who obtained a value of 5×10^{-18} cm^2 for the peak of the $2\,^3S$ cross section.

DISCUSSION

Figure 3 shows a comparison between the present data (curve A), Dorrestein's data (curve B), and the theoretical curve by Massey and Moiseiwitsch for the $2\,^3S$ level alone, (curve C). All curves are normalized such that the peak of the $2\,^3S$ level lies at unity. The present experiment compares well with Dorrestein's data.[2] The superior electron energy distribution in the present experiment reduces the tailing near the onset of excitation from about 0.3 electron volt in Dorrestein's experiment to 0.1 electron volt in the present experiment. Also, Dorrestein's curve is shifted on the voltage

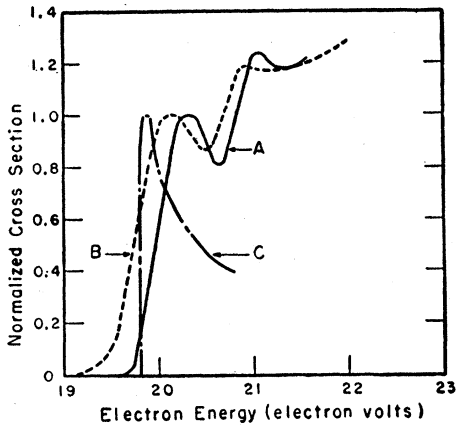

FIG. 3. Comparison of the lowest excitation functions for helium. A is the present experiment; B is Dorrestein's experiment; C is the theoretical excitation for the $2\,^3S$ level (Massey and Moiseiwitsch[4]). The curves are normalized in such a way that the peak of the $2\,^3S$ level lies at unity.

scale. This is probably the result of contact potentials in Dorrestein's experiment. The theoretical curve C exhibits a sharper rise than the experimental curve.

The curve obtained, by a rather indirect method, by Maier-Leibnitz lies between curves A and C. It peaks about 0.3 electron volt above threshold. No comparison can be made with the data of Woudenberg and Milatz because their energy resolution was not good enough to establish the excitation function near the threshold.

The linear behavior of the experimental excitation curve is surprising in view of Wigner's theory[9] which predicts a square root dependence above threshold. It may be that the square root law is applicable only at energies less than 0.1 electron volt above threshold. In that case, the true curve would be masked by the finite distribution in electron energy from 0 to 0.1 electron volt above threshold. These questions are discussed more fully by Baranger and Gerjuoy in an accompanying paper.[10]

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