PHYSICS 350 Experiment 10

Ionization and Excitation of Mercury

References

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Introduction

It is known (cf. the Franck-Hertz experiment) that as electrons are accelerated through a mercury vapour they will lose energy to the atoms of the vapour when they have a specific amount of energy. From the atomic point of view, it may be concluded that there is a resonance in mercury at which a fixed energy can be absorbed. The emission of spectral lines of characteristic wavelengths also suggests that there are other definite energy levels in an atom. Finally, it might be hypothesized that a certain fixed energy is required to remove an electron from an atom, i.e. to ionize it. This experiment is designed to confirm these ideas.

Electrons thermionically emitted by a hot filament are accelerated between the cathode and anode of a mercury vapour rectifying diode. Reference should be made to the experiment *Electrical Conduction in a Thermionic Diode* for background information on thermionic emission. The main point here is that the current in the present experiment is dominated by space charge effects and so we expect the Langmuir-Child equation to be appropriate, i.e.

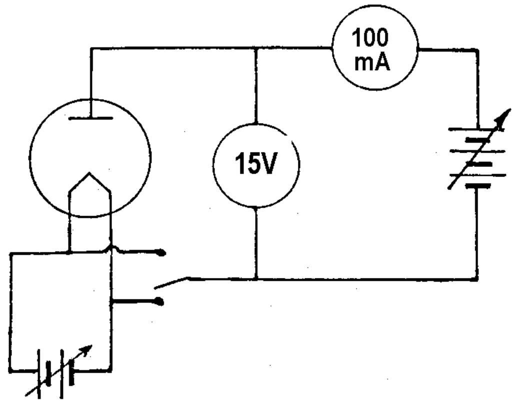
$$I \propto V^{3/2} \qquad (1)$$

where V is the potential difference between the anode and cathode, and I the current. The constant can be calculated by the use of Poisson's equation solved in the appropriate geometry (cf. Frank 1940), e.g., in cylindrical geometry with V in volts, the current per unit length is approximately $15/b$ µA where b is the radius of the outer conductor in cm. As the accelerating potential is increased it is found that the current in the tube suddenly increases when electrons colliding with a mercury atom have enough energy to ionize the atom. The ionization potential can be determined from the voltage at which the current departs from the $V^{3/2}$ law.

Ionized mercury atoms emit light as they capture electrons and return to the ground state. Atoms that are in excited states, but not ionized, also emit light in transitions to lower energy states. The potential at which a particular spectral line disappears as the voltage is decreased is called the extinction potential and gives the energy of the upper level of the transition.

The Apparatus

A convenient and low-cost device which demonstrates the properties we are interested in is the mercury filled diode. This dates from the days of vacuum tubes and was used as a rectifier of electric current. Liquid mercury is often visible in the tube, and this produces a mercury vapour when the tube is hot. When the current through the tube is sufficient, the mercury vapour in the conducting region emits a blue light.



Schematic of Apparatus

The spectral lines are observed with a grating monochromator and photomultiplier tube. The monochromator consists of a reflection diffraction grating mounted on a rotating table so that as the table is rotated the reflected spectrum is scanned across an exit slit onto a photomultiplier. Hence the intensity of each spectral line may be measured

Experiments

1. Connect the circuit shown and supply 2.5 V to the filament of the tube. This heats the cathode giving thermionic emission. Wait 5-10 minutes for equilibrium. In the first part of the experiment, the two digital multimeters (DMM) should be used to measure the current and voltage across the tube. Note that the voltmeter should not include the voltage drop across the ammeter. Measure the current in the tube as a function of the applied voltage in steps of 1.0 V initially and approximately 0.1 V near the ionization or breakdown potential for both positions of the single-pole, double-throw switch. Because of the heating effects associated with large ionization currents, it is advisable to take a complete set of data in one switch position then repeat the procedure for the other switch position. The current through the tube must not exceed 80 mA. The switch is included so that you may compensate for the potential drop across the filament.

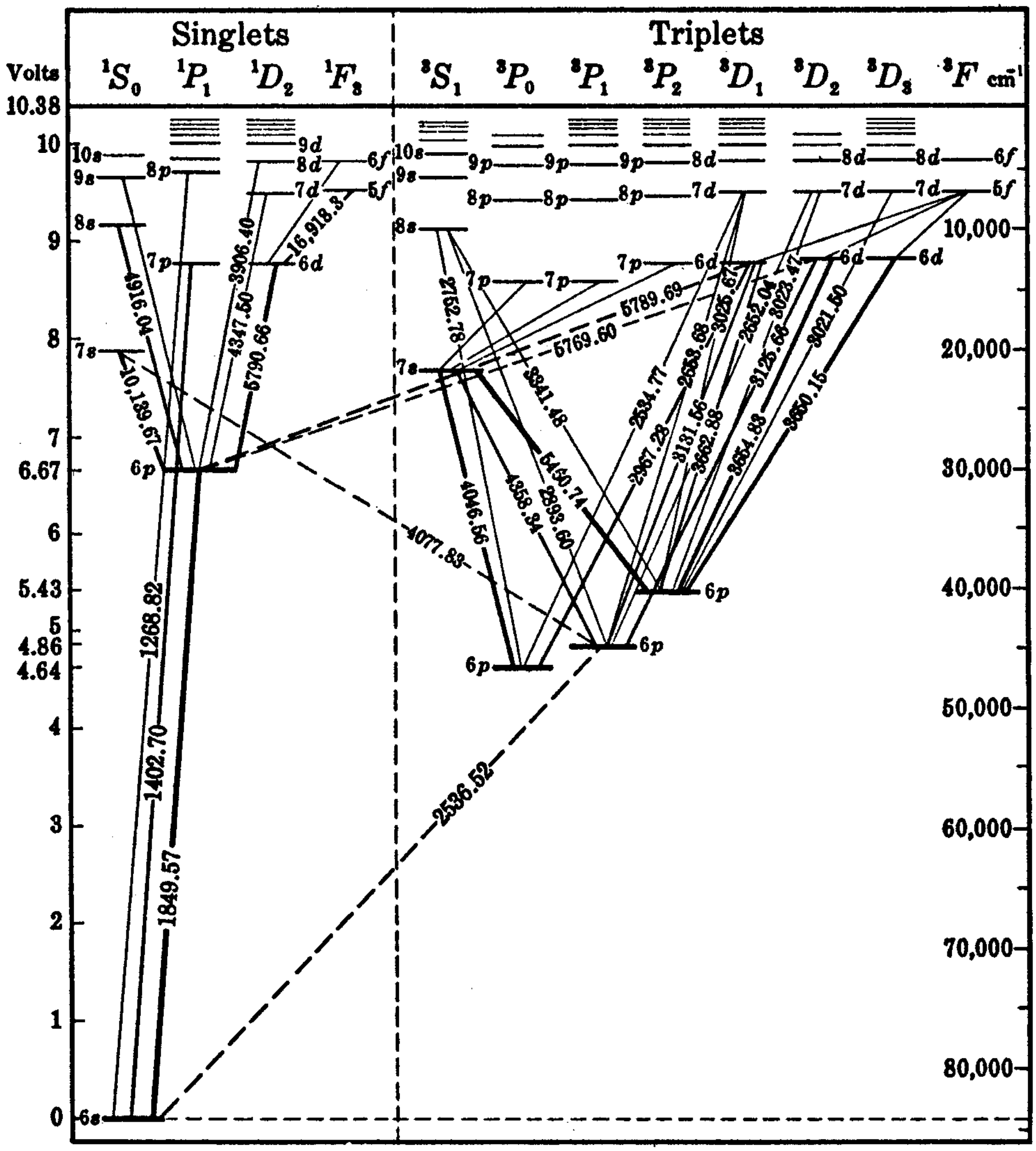
   The current at low potential differences is the thermionic current proportional to $V^{3/2}$. Consequently a graph of $I^{2/3}$ against V should be a straight line, and the point where the data depart significantly from this line can be taken as the ionization potential. You will notice that the graphs for the currents when the switch is in the different positions have the same slope but different intercepts. The intercepts are important for determining the actual energy of the electrons; the electron energy will depend on the effective point on the filament where the electrons are emitted as well as the voltage read from the DMM.

2. For the second part of the experiment use a DMM to measure the voltage across the mercury vapour diode and an electrometer to measure the photomultiplier current. The photomultiplier should be operated at 800 to 900 V. With the mercury diode horizontal, check that the blue glow from the end of

the tube falls on the entrance slit of the monochromator. Note that both the entrance slit and exit slit of the monochromator must be set at a narrow width so that individual spectral lines can be separated.

With the diode conducting heavily (~ 80 mA) locate at least 3 strong lines from the mercury spectrum that have different upper energy levels (see energy level diagram). Some strong lines occur near 365, 404, 436, 546 and 577 nm. In each case chosen, measure the intensity of the line with the electrometer as the accelerating voltage is decreased. To find the extinction potential accurately it is important to continue the measurements to low enough voltages (and in the absence of a visible blue glow from the filament) to establish the background photomultiplier current on a sensitive electrometer range. This background can be decreased by turning off the room lights. Determine the voltage at which the line is extinguished and, from a consideration of data from part 1 to get the intercept for that setting of the reversing switch, determine the extinction potential for each line.

Compare your extinction potentials with expected values according to the attached mercury energy level diagram. Comment on your observations as they relate to the selection rules in atomic spectroscopy.



Energy level diagram of Hg (from Herzberg)