Energy Levels of Helium

Introduction

In this experiment you will verify the quantization of energy levels in the helium atom, and measure the energy levels, using a critical potential tube.

All electrons within atoms are restricted by quantum theory to discrete energy levels as originally predicted by Bohr's model of the atom. These energy levels (or orbitals) correspond, more accurately, to solutions of the Schrödinger wave equation for that atom. The first experiment to really demonstrate that this was true was the historical experiment by Franck and Hertz, which employed the following concept.

In a collision between an atom and an electron, if the energy E of the *incident* electron is insufficient to raise an electron *in the atom* from an initial energy state E_1 to its next higher energy level E_2, then no kinetic energy can be transformed into internal energy, and the collision is elastic, *i.e.* the total kinetic energy is conserved. In this case, the electron loses only a small fraction of its initial kinetic energy to the atom since the latter is so much more massive; *i.e.* the electron is simply scattered by the electric field of the atom.

However, if the energy E of the incident electron is greater than the energy *difference* $E_2 - E_1$, then there is a non-zero probability that an atomic electron will be raised to this higher level. The scattered electron will then have a kinetic energy $E - \left(E_2 - E_1\right)$. If E is large enough, it may be possible to raise an atomic electron by *two* energy levels, corresponding to an energy $E_3 - E_1$, say. If $E > E_1$, where E_1 is the binding energy of the atomic electron, this electron can be completely removed, *i.e.* the atom becomes *ionized*.

The Apparatus

The apparatus for this experiment exploits the fact that as the energy of the incoming electrons is increased, it exceeds the energy difference between a greater number of atomic energy levels, resulting in an increase in the number of outgoing low energy electrons.

You are supplied with:

- 1 Teltron critical potentials tube #533
- 1 Teltron universal stand
- 1 2.5 V 1.5 A dc power supply
- 1 0-40 V variable dc power supply (bench-mounted)
- 2 1.5 V batteries
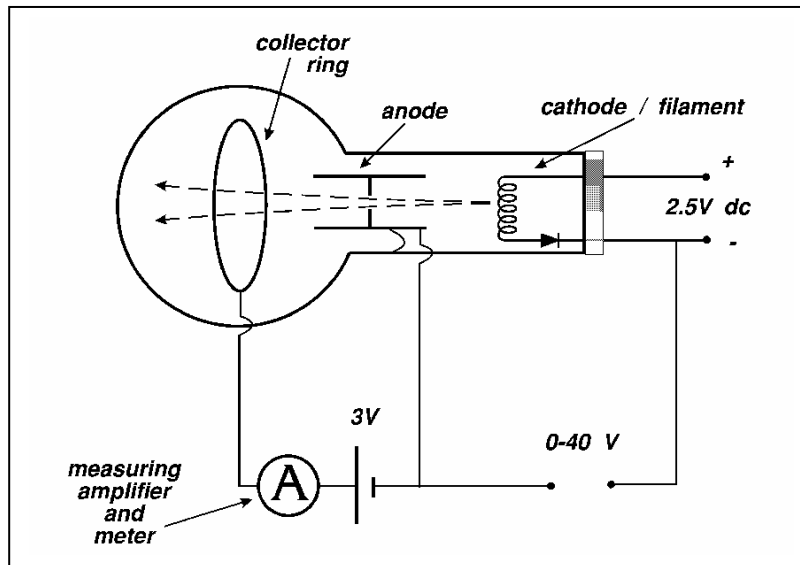- 1 Leybold measuring amplifier
- 1 dc voltmeter

Figure 1. Schematic representation of the apparatus

Figure 1 shows a schematic representation of the apparatus. Electrons are given off by the heated filament/cathode, and are accelerated to the anode through the potential difference applied by the variable power supply. Some pass through the opening in the anode and into the main chamber of the tube, which is filled with helium gas. The inside surface of the tube has a transparent conducting coating which is electrically connected to the anode, so that the region inside the tube has essentially zero electric field. This means that as they traverse the tube the electrons have essentially the same energy as they had when leaving the anode of the electron gun. Also inside the tube is a collector ring, mounted concentric with the average path of the electrons, and at a potential of +3 V relative to the anode and the tube walls. This produces a very small field along the path of the incident electron beam, and does not measurably change the electron energy (this can be verified by repeating the experiment described using only 1.5 V instead of 3 V, and observing that there is no change in the results).

Because the electric field around the collector ring is small, most of the electrons go directly to the wall of the tube, avoiding the collector ring. Given then that the design of the anode prevents electrons from reaching the collector ring directly from the electron gun, only those electrons with very low energy, or those which happen to be scattered so that they pass very close to the ring, will be collected by the collector ring. In other words, the ring is sensitive to the low-energy electrons resulting from inelastic collisions between the incoming electrons and the helium atoms. These relatively few electrons result in a very small current (a few microamperes) which can be detected by the meter connected to the measuring amplifier (together these function as a very sensitive ammeter).

Ideally we would expect to see an abrupt increase in the current from the collector ring each time the energy of the incident electrons exceeds an atomic energy level. But the electrons

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coming from the electron gun have a spread of energies because there is a potential difference between the two ends of the heated filament. For this reason, when an atomic energy level is exceeded, the current increases gradually to a maximum, and then falls off again. This decrease is due both to the increasing energy of the scattered electrons (making it less likely that they will be captured by the collector ring), and to the decreasing probability of an inelastic collision once the critical energy is exceeded. When the ionization energy is exceeded, the number of electrons increases continuously, and there is a corresponding increase in the collector current. All of these effects result in a curve of *current vs. energy* which looks somewhat as shown in Fig. 2.
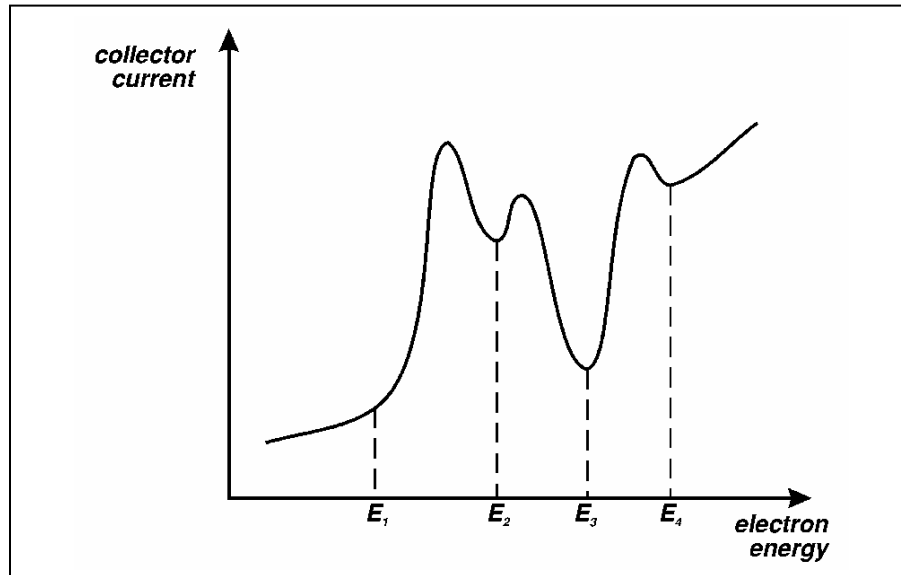

Figure 2. Typical curve of current versus energy.

The energy at which the curve starts to turn upwards represents the onset of inelastic collisions, and provides our best estimate of each energy level.

The helium atom has two electrons, but all the observed energy levels are for the excitation of only one electron. This happens due to the fact that there are no bound states in which both electrons are excited; i.e. all energy levels corresponding to the simultaneous excitation of both electrons are above the ionization energy. The following table shows the first few energy levels of helium.

State	Energy (eV)	Average energy (eV)
1^1S	0	0
2^3S	19.80	19.8
2^1S	20.61	
2^3P	20.96	20.9
2^1P	21.21	
3^3S	22.71	
3^1S	22.91	22.9
3^3P	23.00	
3^1P	23.08	
With higher energy the levels get closer together up to the binding energy E_1.		
Ionization energy	24.58	24.6

The apparatus used in this experiment is not sensitive enough to separately identify the lines in each group.

Procedure

- If it is not already on, turn on the measuring amplifier as soon as you arrive at the lab, so that it has time to warm up.

    i) Connect the 2.5 V dc supply to the filament of the electron gun, taking care that the polarity is as in the diagram.

    ii) Connect the variable 0-40V dc supply between the anode of the electron gun and the negative side of the filament, as shown in Fig.1. The two 1.5V dry cells are used to bias the collector electrode (collector ring in Fig. 1) positively with respect to the anode.

    iii) Turn both power supplies on.

    iv) Adjust the zero setting on the measuring amplifier if necessary, and adjust the range and gain so that a full-scale reading is obtained with an accelerating voltage of 30V.

- Record the collector current for accelerating voltages between 0 and 30V. Normally 0.5V intervals are sufficient, but when the current is changing rapidly it will be necessary to use a 0.1V interval.

Is it possible to be certain that the gas in the tube is helium? You may find it helpful to consult the table of the ionization potentials of the elements, in the Handbook of Chemistry and Physics. What is the significance of the special place of helium in this table?