Mass and charge of an Electron

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Date: April 3, 2013

**Objective**: To determine the ratio of charge to mass of an electron. An electron beam will be emitted by an electron gun, and a magnetic field produced by Helmholtz coils will be used to deflect the electrons. The electrons will be deflected such that their path will be circular, and the radius of the path, and voltages and currents of the electrical components can be used to determine the desired quantities.

**Theory**

An electrical potential can accelerate a charged particle, just as potential energy can be converted to accelerate an object with mass. By relating the product of charge and electrical potential to the kinetic energy of an accelerated particle, and then solving for the velocity of the object, the following expression arises:

[1]

where velocity is measured in meters per second, charge q is measured in Coulombs (C), potential difference V is measured in volts (V), and mass (of the object) in measured in kilograms (kg).

While charged particles can be accelerated by electric fields, they can also be accelerated by magnetic fields. This force, known as the Lorentz force is defined in the following manner (given a magnetic flux density):

[2]

where force F is measured in Newtons (N), and the magnetic field B is measured in Tesla (T). The second form is applicable when the velocity vector is perpendicular to the magnetic field vector, and the resulting force will be in a direction perpendicular to the previous two vectors.

The Lorentz Force in our experiment will act as a centripetal force, causing the electrons that we will be firing from an electron gun to move in a circular pattern. Recall centripetal force is modeled by:

[3]

The magnetic field that will be used in the experiment will be generated by Helmholtz coils: two circular solenoids that are mounted parallel to one another, along the same central axis. This will create a uniform magnetic field between the coils. The magnitude of this field is defined as:

[4]

where B is measured in Tesla (T), the number of coils N is a count, the resistance R is measured in Ω, and the current pushed through the coils I is measured in amps (A). The second equation is the result after the specific number of coils and the specific resistance of our particular apparatus have been included.

As a side note, the previous equation for B was the result of the magnetic field’s intensity, which by Bio-Savart’s Law, the intensity, in A/m, can be found by:

[5]

By combining [1], [2], and [3], the result is an equation that defines our quantity of interest, the ratio of charge to mass of an electron (*q* has been replaced with *e* to indicate the charge of an electron):

[6]

By combining [4] and [6], we produce a working equation that will be useful when computing our results:

[7]

**Procedure**

This experiment requires three power supplies, one rated for 0-500V that is suitable for vacuum tubes, one that is rated for 6.3V, and one that is capable of producing 0-15V DC, a DC voltmeter, a DC ammeter, a magnetic needle, and an apparatus in which to conduct the experiment constructed from a vacuum tube filled with helium and has a small length measuring device built in (to measure the radius/diameter of curved electron paths), two Helmholtz coils, and an electron gun.

The equipment is set up in the following manner: the 6.3V power supply (to be known as the “filament power supply”) is connected to the heating element of the electron gun, the 0-500V power supply (the “B-power supply”) will be connected to the B-power terminal of the unit, and the 0-15V power supply (“coil power supply”) is connected so that is powers the coils to generate the magnetic field. Note, the red terminals, labeled ‘P’, are the + terminals, and the black terminals, labeled ‘K’, are the – terminals. The voltmeter should be connected across the terminals of the B-power supply, and the ammeter should be connected in series with the + terminal of the coil power supply.

The experiment is begun by first turning on the B- and coil power supplies to low voltage settings. The filament power supply is turned on, and the experimenter waits until the heating element glows red, indicating that it is properly heated. Once the filament is heated, the B-power supply is turned up until a thin beam of electrons is seen in the vacuum tube, this will occur around 200V. Take care not to raise this voltage to the full 500V, as the vacuum tube can be damaged. Then the coil supply can be increased.

The experiment is performed by gradually increasing the coil power to increase the magnetic field until a suitable circular electron path is created. If the electron path is a spiral instead of a circle, then the electron gun needs to be reset so that it is perpendicular to the magnetic field of the coils. The voltage reading from the B-power supply, the current from the ammeter connected to the coil power supply, and the diameter of the circular path traced by the electron beam. This will be repeated 10 times: 5 times while holding current I constant and varying voltage V, and 5 times while holding V constant and varying I. Results will be displayed in tables and graphed accordingly.