ELECTRON INTERACTION WITH A MAGNETIC FIELD

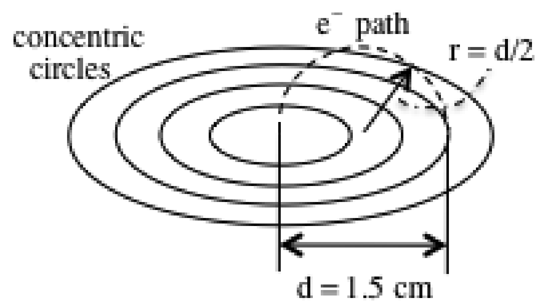
(L-24)

When electrons are made to move in a vertical beam through a horizontal magnetic field, a centripetal force acts upon the electrons due to the interaction of their motion and the ***B****-field*. Knowledge of this phenomenon will allow us to experimentally determine the mass *m* of an electron.

PROCEDURE--DATA

Part A: (the setup)

a.) The device is shown on the next page. It is there for two reasons. First, it is there so you will know what you are about to play with. Second, it is there so the following discussion will make sense. Look at the sketch now.



b.) Design: A beam of electrons is provided by a vacuum tube that works as follows: Electrons are excited off a cathode plate and accelerated through a known, *power supply provided* electrical potential difference of V_p volts, to an anode plate (this voltage is called *the plate voltage*). The anode is disk-shaped with a pin hole at its center. As the accelerated electrons reach the anode, they pass through the hole and into the upper part of the tube. Once in this region, the electrons collide with an inert gas producing a stream of ionizations and, hence, a blue beam of light. This beam is what will allow you to track the electrons as they pass through the tube. The velocity of the electrons can be determined using energy considerations.

Under normal circumstances (i.e., with no external forces acting save gravity), the beam will travel in a straight, vertical line. But when a horizontal magnetic field is applied (provided by Helmholtz coils), the beam will respond by moving into a semi-circular path the radius of which will depend upon the electron's *charge* and *speed* and on the *magnitude of the magnetic field* (gravity ignored). The magnitude of such a force is easily calculable. Furthermore, we can use N.S.L. and the fact that the electron's acceleration is centripetal to derive a general algebraic expression for the mass *m* of the electron in terms of the magnitude of the magnetic field *B*, the electron's charge *q*, the electron's velocity *v*, and the electron's radius of curvature *r*.

The magnitude of a magnetic field generated by the Helmholtz coils is

$$B = 8\mu_o Ni/[(125)^{1/2}R],$$

where R is the radius of the Helmholtz coil, N is the number of winds per coil, "i" is the current in the coil and μ_o is a constant equal to $1.26\text{x}10^{-6}$ H·m. (Although you can use this relationship in your calculations, you will have the opportunity to derive this expression using Biot Savart as Extra Credit.)

Part B: (the setup and data taking)

d.) The circuit is shown on the next page. It has been included in deference to whoever sets the apparatus up.

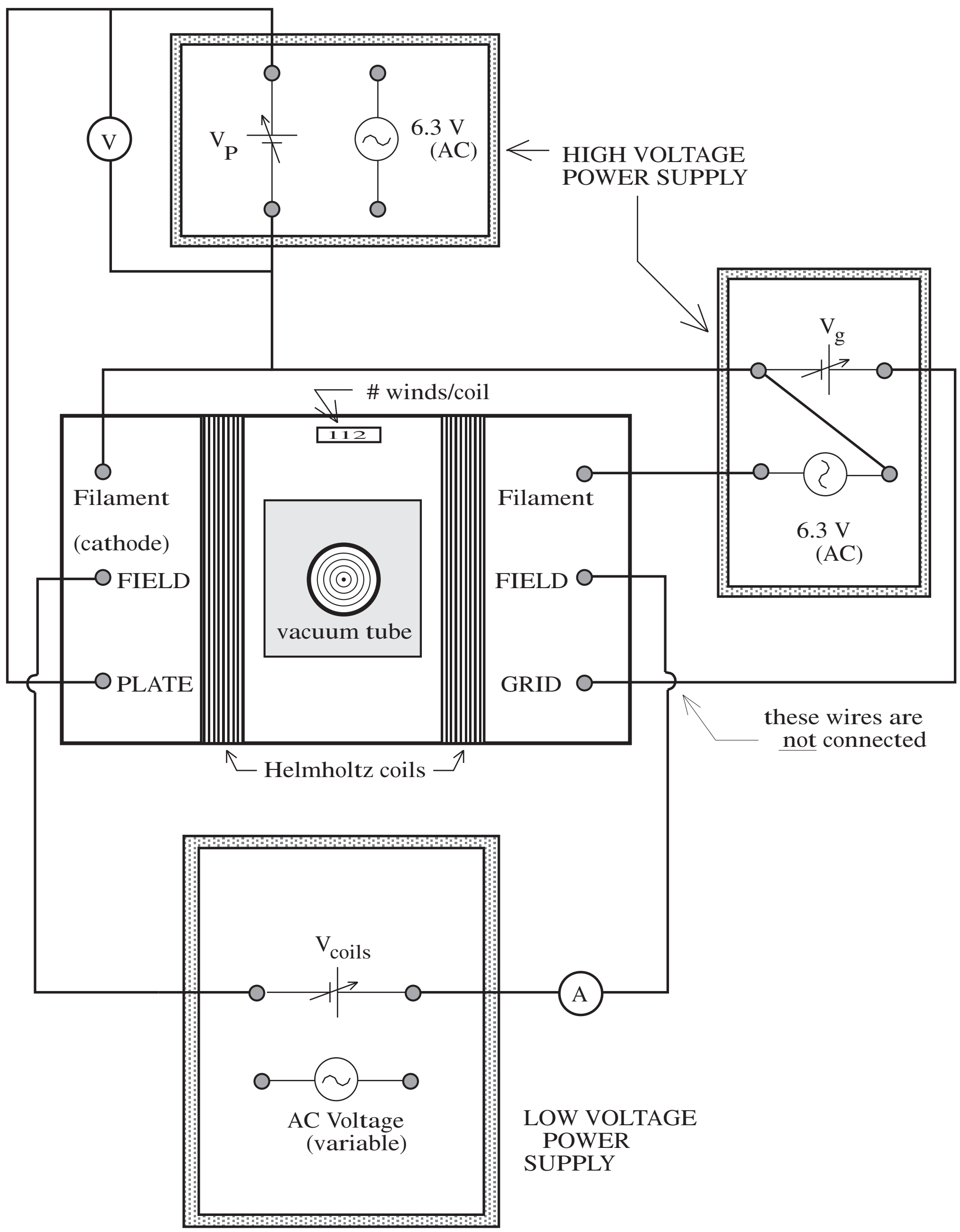
e.) As for data taking, you will need the following bits of information:

i.) The number of winds in the Helmholtz coil (this should be printed on the device).

ii.) The radius *R* of the Helmholtz coil.

iii.) The "plate voltage" that accelerates the electrons.

iv.) The current required to make the beam bend into an arc of radius .01 meter. (The fluorescent circles on the tube's plate will help you with this when the time comes—you will be shooting at the outside circle.)


V
VP
6.3 V
(AC)
HIGH VOLTAGE
POWER SUPPLY
Vg
winds/coil
112
Filament
(cathode)
FIELD
PLATE
Filament
FIELD
GRID
6.3 V
(AC)
vacuum tube
these wires are
not connected
Helmholtz coils
Vcoils
A
AC Voltage
(variable)
LOW VOLTAGE
POWER
SUPPLY

CALCULATIONS

1.) Using energy considerations, derive an algebraic expression for the velocity of the electrons. This should be in terms of the electron mass m, its charge q (this will be the charge on an electron) and the plate voltage V_p. Do this algebraically—do not put numbers in yet.

2.) Using the expression provided in the preamble to determine the magnetic field B required to bend the electron beam into an arc of radius r.

NOTE: In subsequent derivations, you should use B for the magnetic field, putting its value in only after the final relationship has been derived.

3.) Use Newton's Second Law to derive an expression for the mass m of the electron. This will be in terms of the electron's charge q, its velocity v, the magnetic field B and the radius of the arc of electrons r.

4.) Combine the algebraic relationships from 1, 2 and 3 to generate a complete expression for the mass m of an electron.

5.) Using the algebraic expression derived in #4, put numbers in and determine the mass of an electron (note that our equipment is very old and you may end up with a number that is 15% to 20% off.)

6.) The accepted value for the mass of an electron is $9.1\text{x}10^{-31}$ kilograms. Showing your work, do a % comparison between the value you determined above and the actual value. Comment on discrepancy.

7.) Do a summary and error analysis.

Extra Credit: Use Biot Savart to derive an expression for the magnetic field at the center of the Helmholtz coils. This should be in terms of the number of winds in a coil N, the current in the coil "i", the radius of the coil R and any appropriate constants.