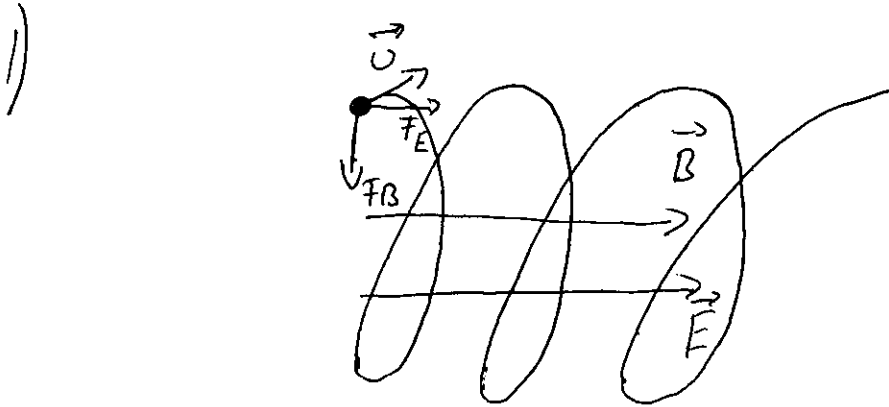


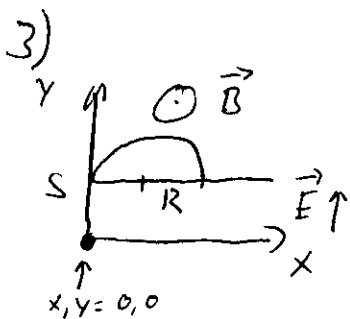
## Solutions

## Pset 7



Particle will move on a helical trajectory, accelerating in the direction of  $\vec{E}$

- 2) No.  $\vec{F}_B$  is 0 if  $\vec{v} = 0$ . More generally, a magnetic field does no work, as  $\vec{F}_B \perp \vec{v}$ .  
 $\uparrow$   
 constant



a) Particle will be accelerated straight up  $\rightarrow$  crosses plane at  $x, y = 0, S$

b) Particle will move on a semi-circle.

Energy is  $q \cdot E \cdot S$ , momentum

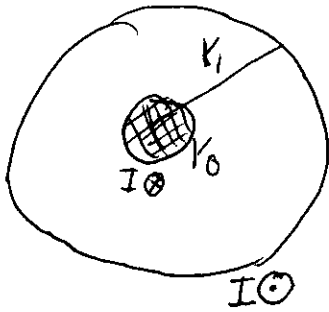
$$\text{therefore } p = \sqrt{2 \cdot K \cdot M} = \sqrt{q \cdot 2 \cdot E \cdot S \cdot M}$$

$$\Rightarrow R = \frac{p}{q \cdot B} = \frac{\sqrt{2 E S M}}{\sqrt{q} \cdot B}$$

c) At  $(2R, 0)$ .

$\Rightarrow$  Coordinate for crossing  $x, z$  plane is  $(2R, S)$

4)



Ampere  $\int \vec{B} d\vec{l} = \mu_0 I_{\text{encl}}$

a)  $r_0 < r < r_1$

$$\int \vec{B} \cdot d\vec{l} = B(r) \cdot \int dl = B \cdot 2\pi r = \mu_0 \cdot I$$

$$\Rightarrow \boxed{B(r) = \frac{\mu_0}{2\pi} \frac{I}{r}}$$

b)  $I_{\text{encl}} = 0 \Rightarrow B(r) = 0$  for  $r > r_1$

**8.02X Electricity and Magnetism****Experiment Electric Breakdown (EB) Problems  
(20 points total)**

**Lab Hours:** Mondays: 3-5 pm, Tuesday: 7:30-9:30 pm, Wednesday: 7:30-9:30 pm,  
Thursday: 3-5 pm, Fridays: 12-3 pm

**Due Date:** Check-off by April 4 in lab 4-355. To satisfy the check-off for experiment EB, you must do the following tasks.

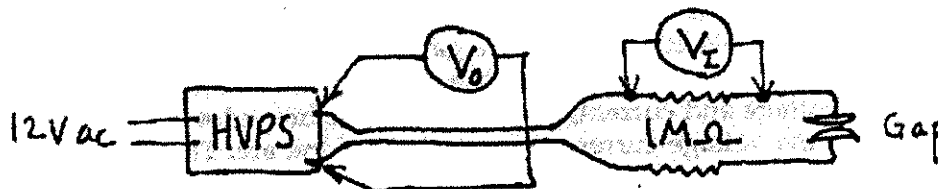
**You will be graded according to the following criteria:**

1. Your EB experiment works properly.
2. The EB experiment is set-up according to diagrams that are shown in the lab write-up.
3. You should be prepared to briefly explain the questions below.

**Bonus Points Policy:** Check-offs that are finished on Mon Mar 28 will receive 2 extra points, and check-offs on Tue Mar 29 will receive 1 extra point.

***Experiment EB (Electrical Breakdown)***

Connect MMM 1 on the 1000DCV range (use -COM and +DC1000V for the test lead inputs) across the HVPS output. We will call this voltage  $V_0$ . Connect MMM 2 on the 500DCV range (use -COM and +V- $\Omega$ -A for the test lead inputs and the same switch setting as for the 1000DCV range) across one of the  $1\text{ M}\Omega$  resistors. We will call this voltage  $V_1$ .



**Figure 1: Multimeter connections for Experiment EB**

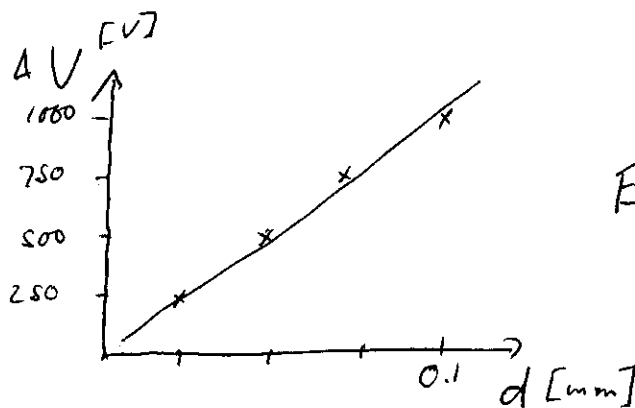
Start with the tungsten rod touching (shorted). Turn the wingnut on the clothespin smoothly to the 0.025 position, one fourth of the way to the 0.1 mm setting. Raise the HVPS voltage slowly until the second meter just begins to deflect, indicating breakdown with the formation of an arc. Record the voltage  $V_0$  with MMM 1 across the HVPS and the voltage  $V_1$  with MMM 2 across the 1 M $\Omega$  resistor at which this happens. Repeat for the three remaining gap widths, and repeat the entire procedure three times. Enter your data in the tables below.

### Analysis

Plot the average breakdown voltage vs. gap, and determine either a best single value of the breakdown electric field or a range of values. Express your results in V/mm.

*Data Table: Breakdown Voltages for Various Spark Gap Separations*

Gap Separation $d$ [mm]	Breakdown Voltage $V_0$ [V] Run 1	Breakdown Voltage $V_0$ [V] Run 2	Breakdown Voltage $V_0$ [V] Run 3	Breakdown Voltage $V_0$ [V] Average
0.025				250
0.05				500
0.075				750
0.1				1000



$$E_{crit} \approx \frac{10kV}{1mm}$$

**Problem 1: Experiment EB**

a) What is the number of particles per  $m^3$ , (the number density  $n$ ), for an ideal gas at standard temperature and pressure?

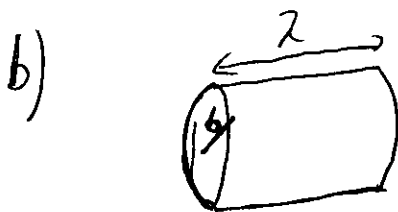
b) Define the mean free path for an electron in a gas to be the average distance  $\lambda$  an electron travels before it collides with an air molecule. If an electron travels close enough to an air molecule it will collide. The impact parameter  $b$ , is defined to be the radius of a circular cross sectional area of effective area  $\pi b^2$  that the air molecule presents as a target to the electron. This means that there must be at least one air molecule in the volume  $\lambda \pi b^2$  that the electron could collide with. Find an expression for the number density  $n$  of air molecules, in terms of the mean free path  $\lambda$ , and the impact parameter  $b$ .

c) When the electron is placed in a gap of width  $d$  and gap voltage  $\Delta V_{gap}$ , how much kinetic energy per charge does the electron acquire if it travels a distance equal to the mean free path  $\lambda$ ?

d) The energy per charge necessary to ionize air molecules, the ionization voltage, is  $\Delta V_{ion} \approx 10V$ . If the electron gains a kinetic energy per charge equal to the ionization voltage then the electron will ionize the air molecule. Using your result from part c), derive an expression for the mean free path  $\lambda$  in terms of the gap width  $d$ , gap voltage  $\Delta V_{gap}$ , and ionization voltage  $\Delta V_{ion}$ .

e) Use your experimental results where you found the breakdown electric field (average gap voltage / gap width) necessary to ionize air molecules. Use that result to calculate the mean free path  $\lambda$ .

a) Avogadro's Number  $N_A = 6.022 \cdot 10^{23}$  molecules/mol  
 $1 \text{ mol} = 22.4 \text{ l} = 0.0224 \text{ m}^3$   
 $\Rightarrow$  Density  $n = \frac{6.022 \cdot 10^{23}}{0.0224 \text{ m}^3} = \underline{\underline{2.69 \cdot 10^{25} \text{ m}^{-3}}}$



A cylinder of volume  $\lambda \cdot \pi b^2$  must contain on average 1 molecule.  
 $n = \frac{1}{\lambda \pi b^2}$  [dimensions are  $\frac{1}{\text{m} \cdot \text{m}^2}$ , ok V]

c)  $K = \Delta U = \frac{\lambda}{d} \cdot e \cdot \Delta V_{gap}$ , where  $e$  is the electron charge

d)  $K \sim \Delta V_{ion} \Rightarrow \lambda = d \cdot \frac{\Delta V_{ion}}{\Delta V_{gap}} \approx 0.1 \mu\text{m}$  ← e)