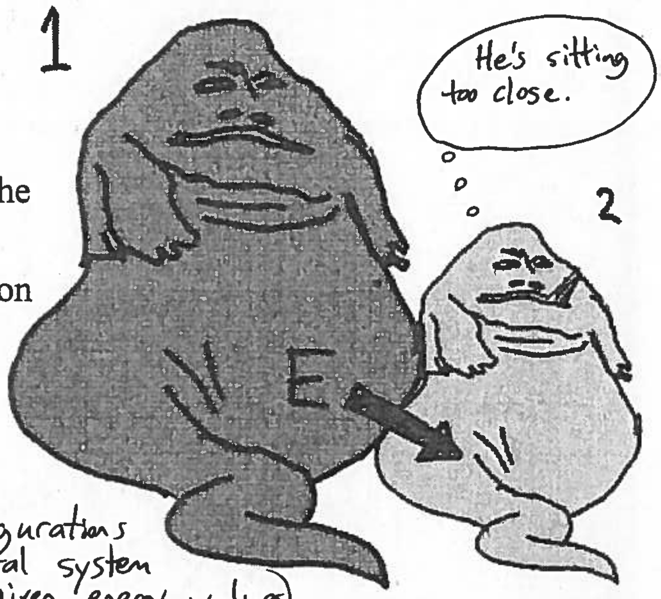
uestion 1) When two systems are placed in ermal contact, energy will be observed to flow from the left system to the right system



A) if this increases the entropy of the system on the left.

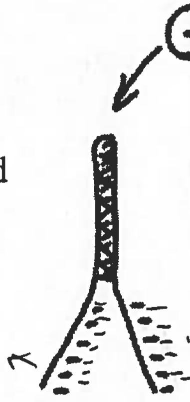
B) if this moves the system towards a configuration where the energies are equal on the two sides.

C) if the heat capacity of the left system is larger.

[✓ D)] if this increases the total number of available microscopic configurations for the combined system. total entropy = $k_B \ln$(# of conigurations of total system with given energy values)

E) if and only if all of the above are true.

Question 2) The electroscope shown consists of two foil leaves connected to a conductor. Initially, the electroscope has a net negative charge and the leaves are seen to repel. If another negative charge is brought close to but not touching the top of the electroscope, we would find that



pushes more − charges to bottom ∴ more outward force

A) The two leaves move closer together

[✓ B)] The two leaves move further apart

C) The leaves don't move.

Question 3)

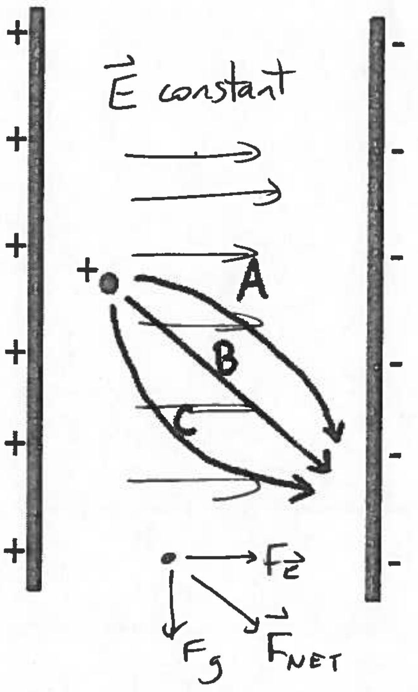
A charged dust grain is initially at rest between two parallel charged plates.

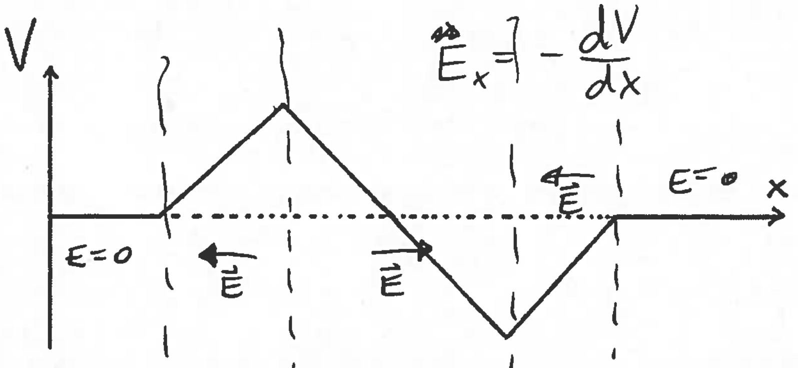
Which path best represents the subsequent motion of the dust grain due to gravity and electrostatic forces?

Answer A, [✓ B] C, or

D: None of the above

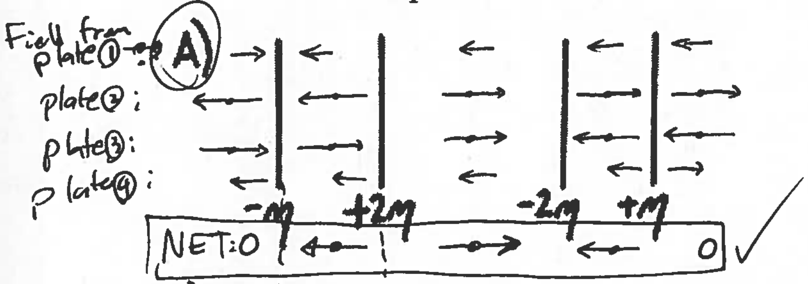
Force is the same everywhere ∴ Particle keeps moving in direction of $\vec{F}_{NET}$

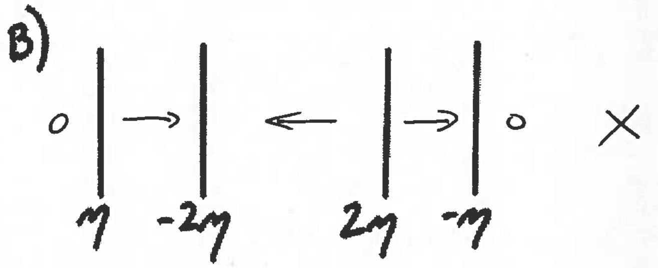


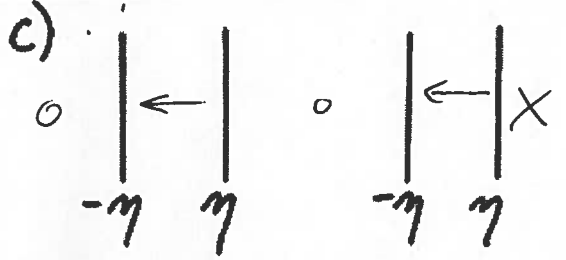


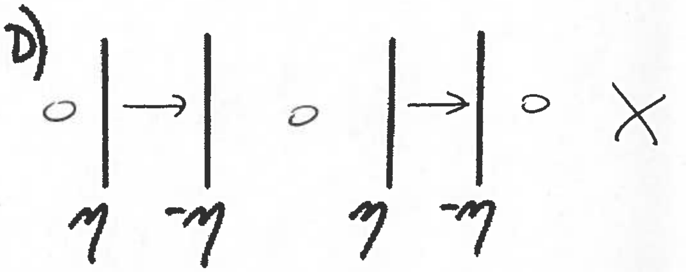
Each plate gives a constant $\vec{E}$ field. prop. to charge density.

Question 4) Consider the potential above. Which configuration of charged planes below could be responsible for it?





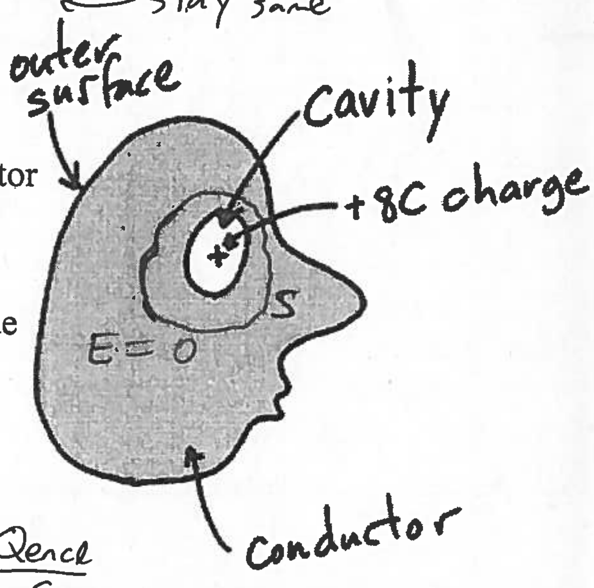




Question 5) When the current in a wire doubles, which of the following quantities below also doubles?

- A) The typical speed of an individual electron. ← drift velocity doubles but this is much smaller than individual speed
- B) The density of electrons. X
- [✓ C)] The electric field in the wire. ✓ $E = \frac{J}{\sigma} = \frac{I}{A\sigma}$ ← doubles; $A\sigma$ ← stay same
- D) The conductivity of the wire X
- E) More than one of the above. x
- F) None of the above. x

Question 6) Consider the irregularly shaped conductor with a hollow cavity shown. If the conductor has an overall charge of -12 C and there is a +8 C point charge in the cavity, what is the charge on the outside surface of the conductor?



A) -12 C B) - 8 C [✓ C) - 4 C]
D) +4 C E) +8 C

Gauss Law: Flux through S = $\frac{Q_{enc}}{\varepsilon_0}$

↑ zero since E=0 in cond.

∴ Q = - 8C on inner surface

Outer surface has -4C (since total is -12 C)

Problem 7) Two dipoles that are aligned with one another interact with each other at some distance. Increasing the distance s between the charges that make up each dipole while keeping the separation between their centers fixed

[✓ A)] increases the force between the dipoles.
B) doesn't change the force between the dipoles.
C) decreases the force between the dipoles.
D) The problem doesn't have enough information.

For monopole-dipole

$$F_{MD} = \frac{2kQ\cdot(qs)}{r^3}$$

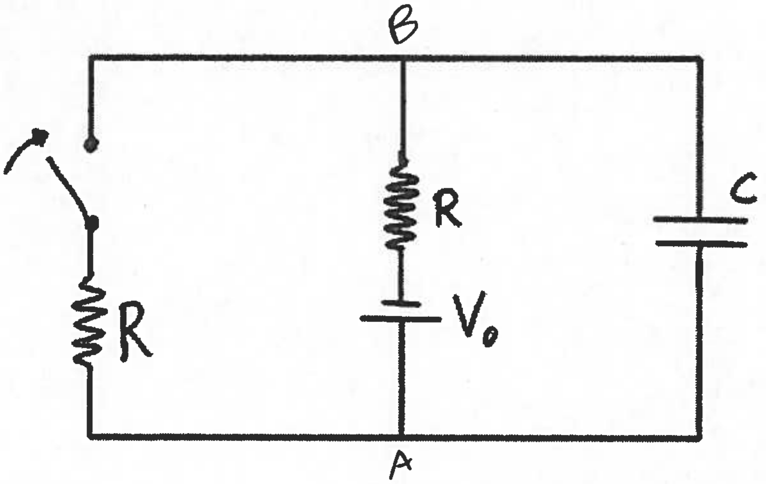
∴ increasing s increases force.

For dipole-dipole, effect is even stronger

$F_{DD} \sim F_{MD}(x+s) - F_{MD}(x) \approx s\cdot F'_{MD}(x)$ so F_{DD} is prop. to s_1 and s_2

Problem 8) The circuit shown has been set up for a long time so that the voltage across the capacitor is constant. When the switch is closed,

A) the voltage across the capacitor will decrease to zero.
[✓ B)] the voltage across the capacitor will decrease to some other value.
C) the voltage across the capacitor will increase.
D) the voltage across the capacitor will stay the same.



Initially current is zero

∴ $V_{cap} = V_{AB} = V_0$ since no voltage drop across resistor.

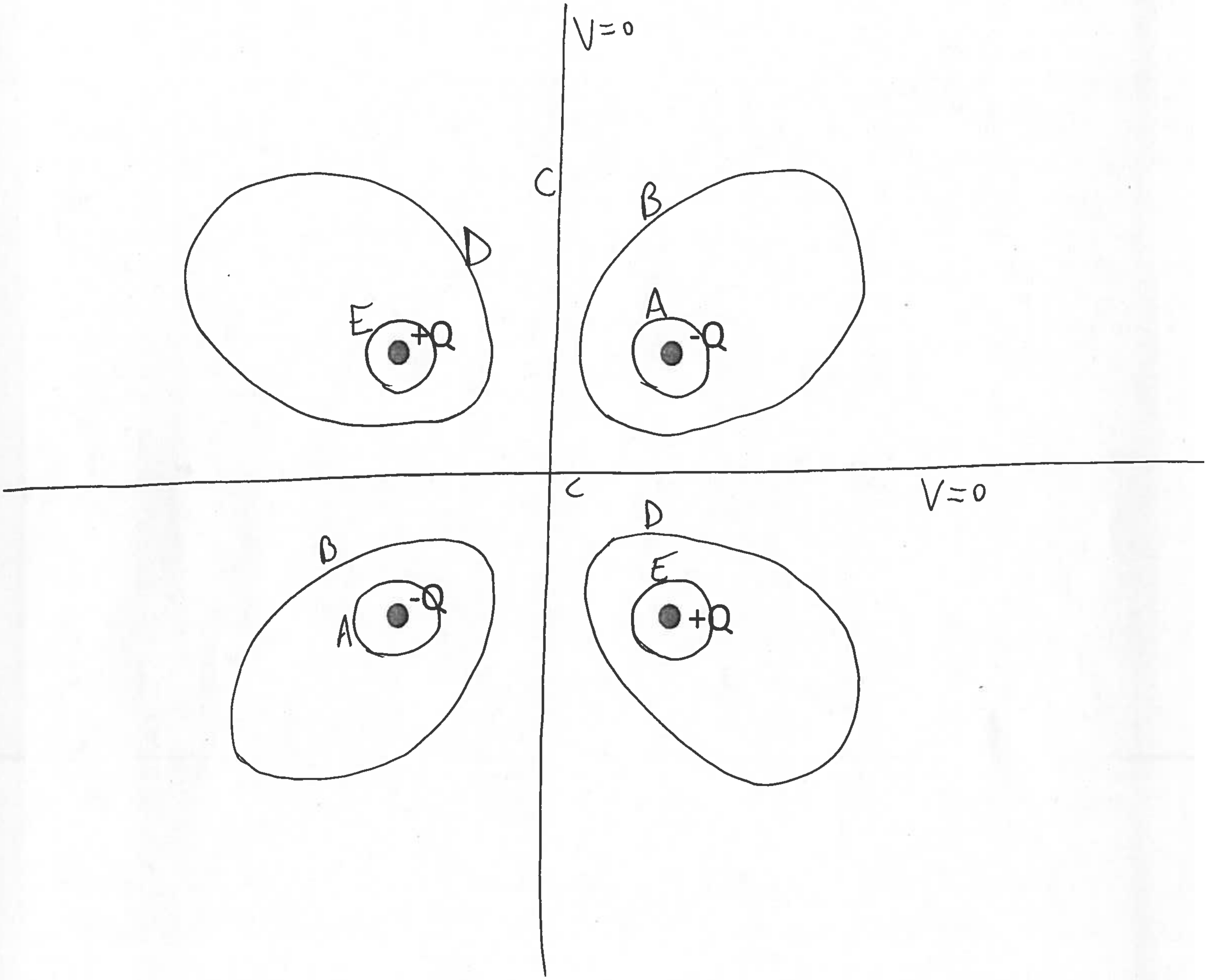
After: current flows in left loop.

∴ $V_{CAP} = V_{AB} = V_0 - IR$

This is less than V_0 but greater than 0.

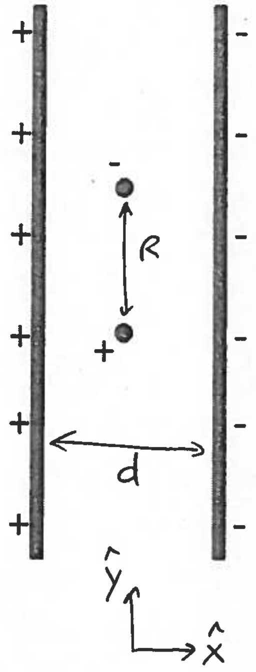
Question 9) For the charge configuration below, draw the equipotential for 0 V, and four other equipotentials (for two positive and two negative values of V). Label these A,B,C,D,E from lowest potential to highest potential. (*Note: some equipotentials may have different disconnected parts.*) **(3 points)**

V = 0 : points equidistant from ±Q pairs



Question 10

a) Two water droplets with mass M = 1g have opposite charges ±Q = 10^{-12}C. If the charges (separated by 1mm) are located in the middle of parallel plates (also separated by 1mm) with a potential difference V = 9V, determine the initial acceleration (magnitude and direction) of the positively charged droplet. Ignore gravity.
(4 points)



The acceleration of the + charge is determined by:

$$\vec{a} = \frac{1}{m} \vec{F}_{NET}$$

The force on the charge is the sum of the force from the - charge:

$$\vec{F}_- = k\frac{Q^2}{R^2}\hat{y} = 9\times10^9\,N\,m^2/C^2 \cdot \frac{(10^{-12}C)^2}{(0.001m)^2}\hat{y} = 9\times10^{-9}N$$

and the force from the plates:

$$\vec{F}_{plates} = \vec{E}Q$$

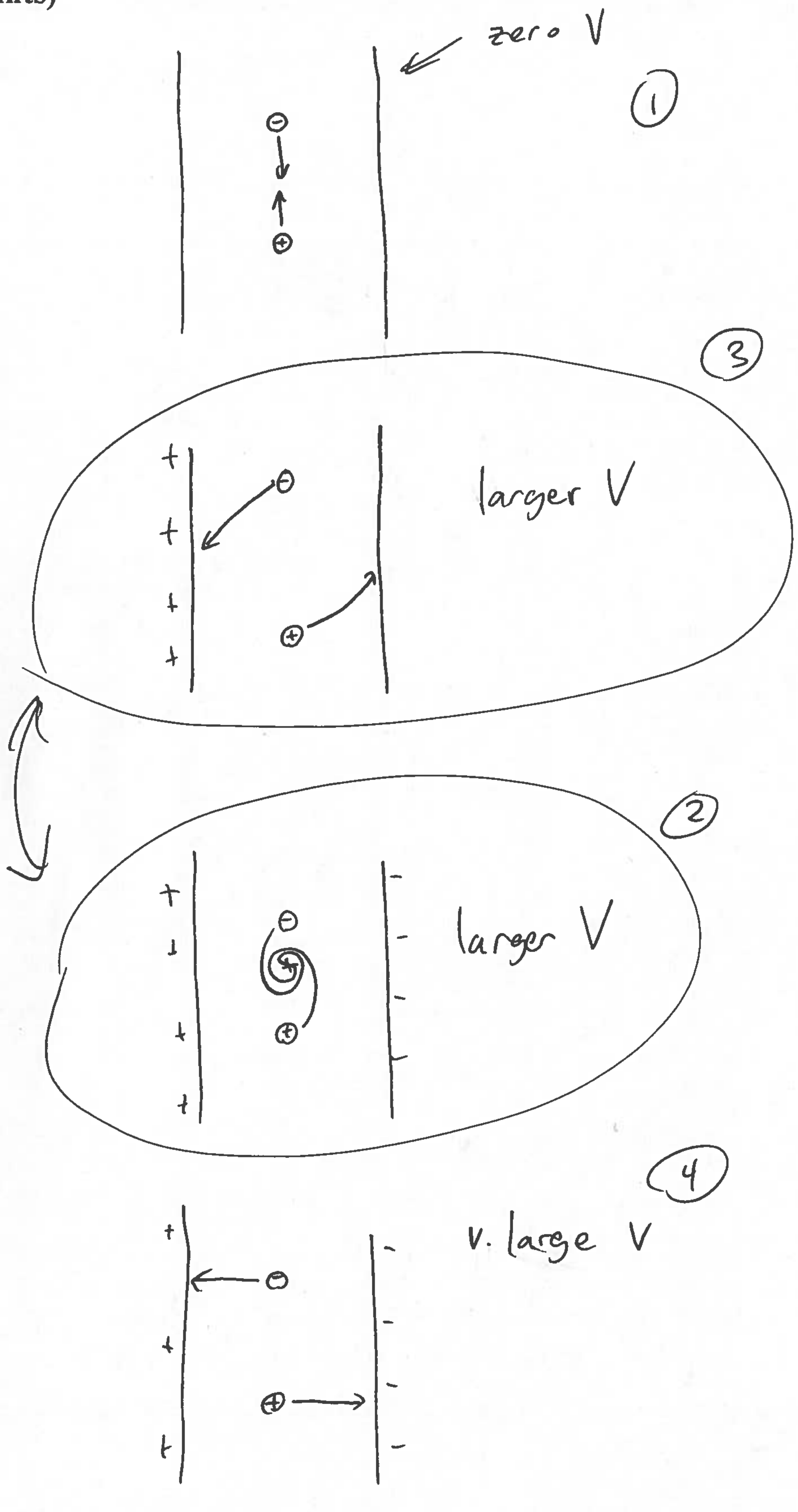
$$= \frac{VQ}{d}\hat{x} = 10^{-12}C\,\frac{9V}{0.001m}\,\hat{x} = 9\times10^{-9}N$$

Thus, the acceleration is

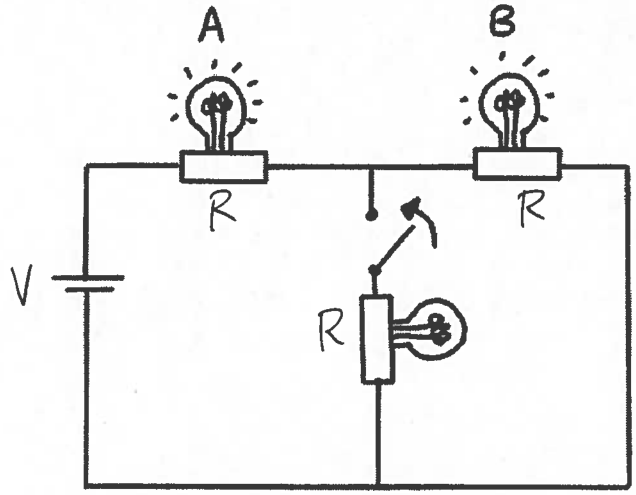
$$\vec{a} = \left(9\times10^{-6}\frac{m}{s^2},\ 9\times10^{-6}\frac{m}{s^2}\right)$$ since $m = 0.001kg$.

The initial acceleration is $1.27\times10^{-5}\,m/s^2$ at a 45° angle up & to the right.

b) Describe qualitatively (and/or sketch) how the trajectories of the water droplets would look for various values of V ranging from zero V up to very large V.
(2 points)



Question 11) The circuit below contains three identical lightbulbs, two of which are initially illuminated. Relative to their initial brightness (i.e. power output), how bright are the bulbs A and B after the switch is closed? (**6 points**)



Let V be the battery voltage and R be the bulb resistance.

Initially, the current in the circuit is

$$I = \frac{V}{R_{NET}} = \frac{V}{R+R} = \frac{1}{2}\frac{V}{R}$$

The power is $P = I^2 R = \frac{1}{4}\frac{V^2}{R}$ for each bulb.

After closing the switch, we have a net resistance of:

$$R_{NET} = R + \frac{1}{\frac{1}{R} + \frac{1}{R}} = R + \frac{R}{2} = \frac{3R}{2}$$

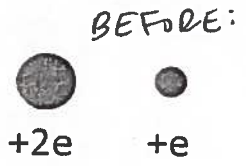
The current from the battery (and thus the current through A) is

$$I_A = \frac{V}{\left(\frac{3}{2}R\right)} = \frac{2}{3}\frac{V}{R} \qquad \text{So } P_A = I_A^2 R = \frac{4}{9}\frac{V^2}{R}$$

By symmetry, half of this current flows through B, so:

$$I_B = \frac{1}{3}\frac{V}{R}, \qquad P_B = \frac{1}{9}\frac{V^2}{R}.$$

Thus: bulb A + bulb B have brightness $\frac{16}{9}$ and $\frac{4}{9}$ of their initial values.



12) A He^{2+} ion and an H^+ ion are initially at rest, separated by 10^{-10}m. Find the final speed of each ion. (*Note:* $M_{He} = 6.65 \times 10^{-27}kg$, $M_H = 1.67 \times 10^{-27}kg$)

(4 points)

Let v_1 and v_2 be the final speeds.
Energy + momentum are conserved:

$$P_{after} = P_{before} = 0 \qquad \therefore -m_{He}V_2 + m_H V_1 = 0$$

$$\Rightarrow V_2 = \frac{m_H}{m_{He}} V_1 \qquad ①$$

$E_{after} = E_{before} \Rightarrow$

$$\frac{1}{2} m_{He} V_2^2 + \frac{1}{2} m_H V_1^2 = k\frac{(e)(2e)}{R_o} \qquad ②$$

Use ① to subs for v_2 in ②

$$\Rightarrow \frac{1}{2} V_1^2 \left(m_H + \frac{m_H^2}{m_{He}}\right) = 2k\frac{e^2}{R_o}$$

$$\Rightarrow V_1 = 6.64 \times 10^4 \, m/s$$

$$V_2 = \frac{m_H}{m_{He}} V_1 = 1.67 \times 10^4 \, m/s$$

The H^+ and He^{++} travel at 6.64×10^4 m/s and 1.67×10^4 m/s respectively. These are much less than c, so our use of non-relativistic formulae is justified.

★ NOTE: it's not true that the energy of each ion is individually conserved ★