Name: Kevin

ID:

Physics 203

Quiz 2

29 August 2022

You will have 80 minutes to complete this quiz. Collaboration is not allowed for the first 60 minutes of the quiz. Collaboration will be allowed with an assigned partner for the final 20 minutes of the quiz. Allowed on your desk are: ten 8.5 × 11 inch doubled sided sheets of notes that are bound together, non-communicating graphing scientific calculator, 1 page of scratch paper, writing utensils, and the quiz.

Solutions

For questions 1 through 3 **fill in the square** next to all correct answers. A given problem may have more than one correct answer. Each correctly bubbled answer will receive two points. There are 5 correct answers in this section and only the first 5 filled in answers will be graded. There is no partial credit.

1. A sphere has a net charge of -200 C. If the sphere contains $6.02 * 10^{23}$ protons, what is the **total** number of electrons on the sphere (to three significant figures)?

☐ (a) $1.20 * 10^{26}$ electrons

☑ (b) $6.03 * 10^{23}$ electrons

☐ (c) $1.25 * 10^{21}$ electrons

☐ (d) $6.02 * 10^{23}$ electrons

2. Skin is typically a good electrical insulator, which can prevent charges from moving into or out of your body. However, this also means that you can build up charge on your skin. An electronics technician can "ground" herself by touching a conductor that is maintained near 0 Volts. Which of the following statements would be true regarding this practice?

☐ (a) Free electrons on the electrician's skin are allowed a conducting pathway to leave because the negative charges at a higher (*positive*) electric potential are attracted toward the lower 0 Volt potential.

☑ (b) Free electrons on the electrician's skin are allowed a conducting pathway to leave because the negative charges at a lower (*negative*) potential are attracted toward the higher 0 Volt potential.

☑ (c) Grounding is important because it exchanges excess free charges from the skin which could result in unwanted static discharge.

☐ (d) Grounding is bad because it prevents you from getting superpowers like Electro.

☐ (e) Free protons are allowed to be added to the electrician's skin to absorb free electrons because the positive charges at a higher (*positive*) potential are attracted toward the lower 0 Volt potential.

☐ (f) Free protons are allowed to be added to the electrician's skin to absorb free electrons because the positive charges at a lower (*negative*) potential are attracted toward the higher 0 Volt potential.

3. An electron is placed at rest in an external electric field. Which of the following are true statements?

☐ (a) The electron will begin moving in the direction of the electric field lines.

☑ (b) The electron will begin moving against the direction of the electric field lines.

☐ (c) The electron will begin moving perpendicularly to the electric field lines.

☐ (d) The electron will begin moving along the equipotential lines.

☑ (e) The electron will begin moving perpendicularly to the the equipotential lines.

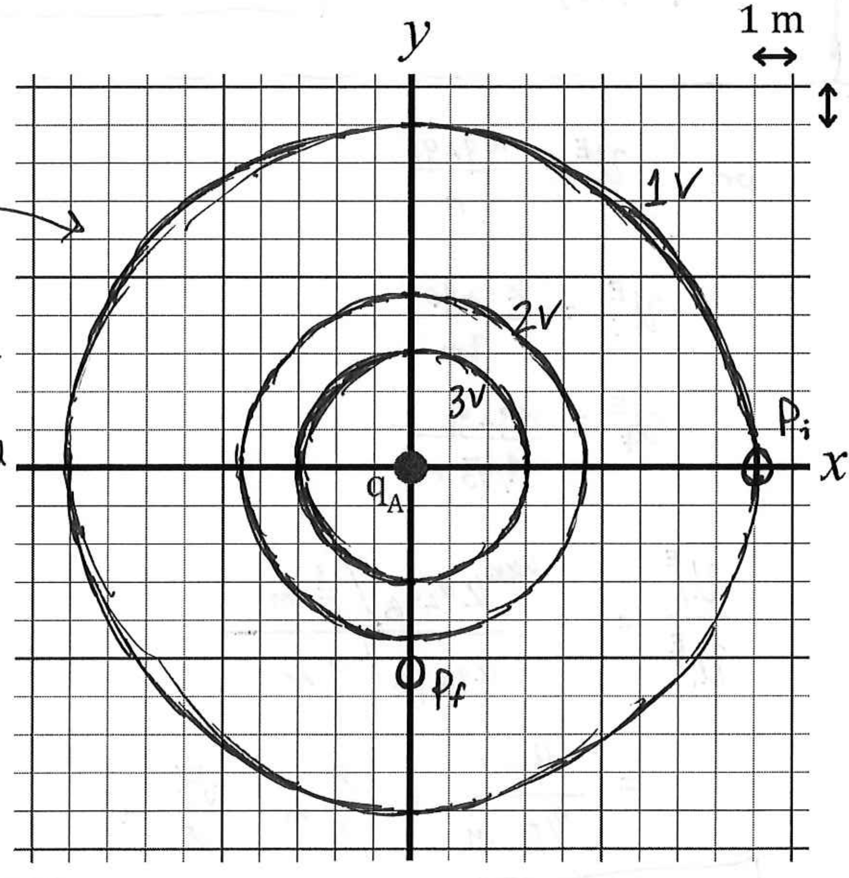
4. (9 points) Charge A, which has a charge of $q_A = 1$ nC, is fixed in place at the origin, $\langle 0,0 \rangle$ m. Use the 2-dimensional position graph below to answer the following questions.

(a) Sketch and label the three equipotential lines indicating 1 V, 2 V, and 3 V on the graph below. Ensure that these equipotential lines match the actual scale of the graph.

(b) Charge B, which has a charge of $q_B = 2$ nC, is placed at rest initially at the point $\langle 9,0 \rangle$ m in this potential field. Label this point on the graph below as P_i. To what point on the plane must we move charge B if we want to triple the magnitude of the **electric force** on it and have this force be pointed in the negative y-direction? Indicate this second point on the graph below and label it as P_f.

(c) Comparing the initial position of charge B to the new position you found in part (b), by how much (i.e. by what multiplicative factor) does the **electric potential energy** of the system change?

Equipotential Lines are concentric circles which are not equally-spaced



(a) $V = \frac{kq_A}{r}$ ← Potential for point charge

olve for r → $r = \frac{kq_A}{V}$, $k = 9E9 \frac{V \cdot m}{C}$

$q_A = 1E{-9}\,C$

V	r
1 V	9 m
2 V	4.5 m
3 V	3 m

Potential for a point charge is the same in a circle

(b) $|\vec{F}| = \frac{kq_Aq_B}{r^2}$

Both charges are positive, so the force is repulsive ⟹ q_B must move to the $\boxed{\text{negative } y\text{-axis}}$ for the force to be in the negative y-direction

Continued on back ⟶

(b) (continued) $F_i = \frac{k q_A q_B}{(9m)^2} = 2.2\text{ E}-10\text{ N}$ ← Force increasing means distance must decrease (proportional to $\sqrt{r}$)

We want $F_f = 3 \cdot F_i = 6.7\text{ E}-10\text{ N}$

$$F_f = 3\left(\frac{k q_A q_B}{(9m)^2}\right)$$ ← k, q_A, and q_B do not change, so the factor of 3 must come from changing r

Alternatively, just solve for r:

$$F = \frac{k q_A q_B}{r^2}$$

$$r = \sqrt{\frac{k q_A q_B}{F}}$$

$$r = \sqrt{\frac{k q_A q_B}{6.7\text{E}-10\text{N}}} = 5.2\,m$$

$$F_f = \frac{k q_A q_B}{\frac{1}{3}(9m)^2}$$

$$F_f = \frac{k q_A q_B}{(9m/\sqrt{3})^2} \Longrightarrow \boxed{r_f = \frac{9}{\sqrt{3}}\,m = 5.2\,m}$$

(c) $U^E = q_B V$ or $U^E = \frac{k q_A q_B}{r}$

$$U_i^E = \frac{k q_A q_B}{9m}$$

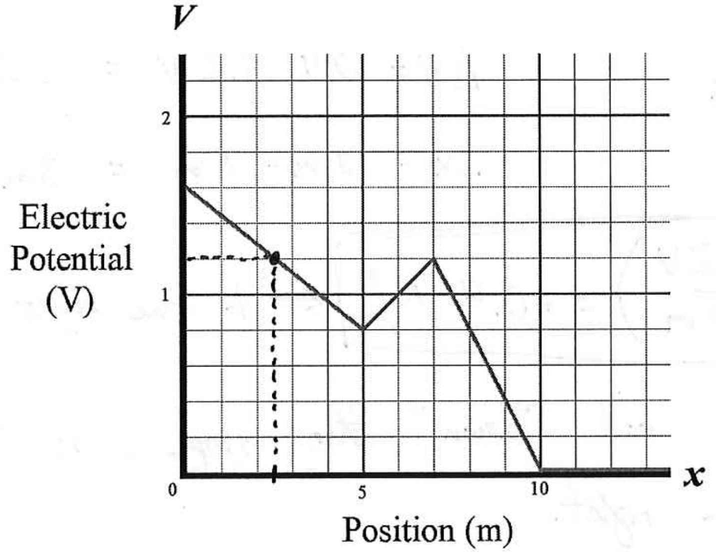
$$U_f^E = \frac{k q_A q_B}{9/\sqrt{3}\,m}$$

$$\frac{U_f^E}{U_i^E} = \frac{k q_A q_B / \frac{9}{\sqrt{3}}\,m}{k q_A q_B / 9\,m}$$

$$= \frac{9m}{9/\sqrt{3}\,m} = \frac{\cancel{9}}{1}m \cdot \frac{\sqrt{3}}{\cancel{9}}m^{-1}$$

$$\boxed{\frac{U_f^E}{U_i^E} = \sqrt{3}}, \text{ or } \boxed{U_f^E = \sqrt{3}\,U_i^E = 1.73\,U_i^E}$$

5. (10 points) An unknown configuration of electric charges creates the electric potential seen below. Use this electric potential vs. position graph below to answer the following questions.



(a) Consider the following two situations, which are done separately (so only one charged sphere is in the potential at a time):

(i) A charged sphere with a net charge of +1 C is placed at rest at $x = 2.5\,\mathrm{m}$

(ii) The charged sphere has its charge increased to a net charge of +4 C, and is again placed at rest at $x = 2.5\,\mathrm{m}$

Find and compare the electric potentials that the charged sphere is at due to the unknown charge distribution in these two situations.

(b) Using the same two situations from part (a), find and compare the electric potential energies of the sphere/charge distribution system given the location of the sphere.

(c) In what region is the magnitude of the electric field greatest? Find the magnitude and direction of this electric field.

(d) The charged sphere, which has a mass of 1 kg, is given a net charge of +4 C and now placed at $x = 8\,\mathrm{m}$ in the electric potential, initially at rest. How fast is this sphere moving after 5 seconds have passed?

(a) The electric potential from the unknown charge distribution does NOT depend on the charge placed in it. Both charges are at a potential of $\boxed{1.2\,V}$ at $x = 2.5\,m$

(b) $U^E = qV$ ← The potential energy of the system DOES depend on the charge of the sphere!

$$\boxed{U^E_i = (1C)(1.2\,V) = 1.2\,J}$$

$$\boxed{U^E_{ii} = (4C)(1.2\,V) = 4.8\,J}$$

(c) Electric field is related to the <u>slope</u> of the potential vs. position graph. The steepest slope is in the region $\boxed{7m < x < 10m}$, so this will have the strongest Electric field.

$$|\vec{E}| = -\frac{\Delta V}{\Delta x} \quad , \quad \Delta V = 0V - 1.2V = -1.2V$$

$$\Delta x = 10m - 7m = 3m$$

$$\boxed{E = -\left(\frac{-1.2V}{3m}\right) = +0.4\ N/C} \leftarrow \text{to the right (in the pos. x-direction)}$$

Positive charges roll "down" the slope, so the force is felt pulling to the right.

(d) <u>Method 1</u> - Using work

In both cases, the force is only applied in the region 8m < x < 10m.

$$F = qE = (4C)(0.4\ N/C) = 1.6\ N$$

This force is applied over a distance, so we can use work-energy theorem:

$$W = F\Delta x = (1.6N)(2m) = 3.2\ J$$

$$W = \Delta K = \frac{1}{2}m\left(v_f^2 - \overset{0}{\cancel{v_i^2}}\right)$$

$$3.2J = \frac{1}{2}m v_f^2$$

$$\boxed{v_f = \sqrt{\frac{2\cdot 3.2J}{1kg}} = 2.53\ m/s}$$

same result

Work done = change in kinetic energy.

No forces applied in region x > 10m

<u>Method 2</u> - Using kinematics

$$F = qE = 1.6\ N$$

$\sum F = ma$, only one force from E-field

$$a = \frac{F^E}{m} = \frac{qE}{m} = \frac{(4C)(0.4\ N/C)}{1kg} = 1.6\ m/s^2$$

Only accelerates in the region 8m < x < 10m

$$v_f^2 = \overset{0}{\cancel{v_i^2}} + 2a\Delta x$$

$$v_f^2 = 2(1.6\ m/s^2)(2m)$$

$$\boxed{v_f = \sqrt{2\cdot 3.2\ \frac{m^2}{s^2}} = 2.53\ m/s}$$

No force applied in region x > 10m

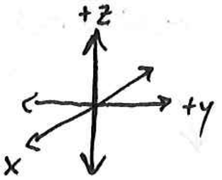
6. (10 points) A parallel plate capacitor is an electronic device that is commonly used in circuits which has the ability store charge on two separated, conducting plates. Near the center of the capacitor, it can create something very close to a uniform electric field between the two charged plates, as shown in the figure below. While these capacitors would also create more complicated electric fields near the edges (often referred to as fringe fields), we will ignore these for this problem and assume that the electric field is $\vec{0}$ everywhere outside of the capacitor.

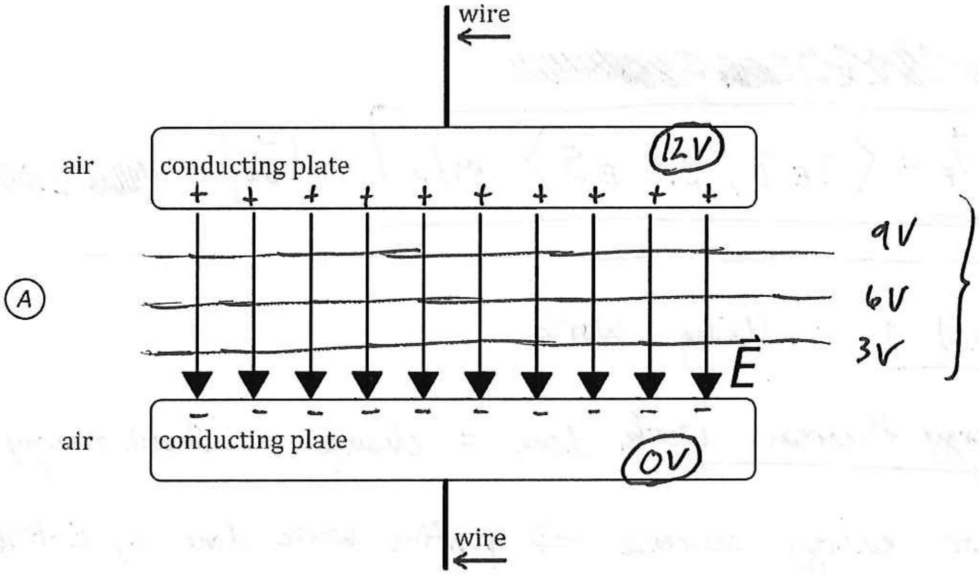
(a) Using the figure below, draw in where you would expect to find positive and negative charges that create this type of electric field, using " + " to indicate positive charges and " − " to indicate negative charges. Explain your reasoning.

(b) If the potential difference between the two plates is 12 Volts, indicate which plate is at the higher potential by labelling one at 12 V and the other at 0 V. Then, using the figure below, draw in and label where you would expect to find the 3 V, 6 V, and 9 V equipotential lines, scaling them appropriately in the figure. Explain your reasoning.

(c) An electron starting at position A on the figure below passes from left to right through the electric field. The electron initially has a velocity of $\vec{v} = \langle 2 * 10^7\,,\, 0 \rangle$ m/s, and the strength of the electric field between the plates is $|\vec{E}| = 2000$ N/C. If it takes 1 ns for the electron to pass through this electric field, what is velocity of the electron after it makes it to the other side? (*Assume that the only relevant electric field is the uniform field between the plates, and that the electric field is 0 everywhere else outside the capacitor.*)

(d) How much work was done on the electron by the electric field while the electron was passing through the field?



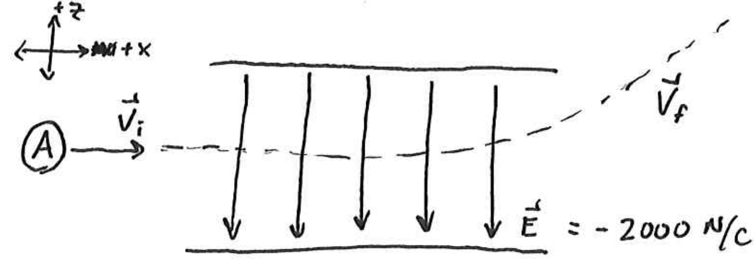


Equipotential lines are Evenly-spaced and descending

(a) E-field lines start at positive charges and end at negative charges. Having many charges in a plane causes all but the Electric-field in the z-axis to cancel. A plane of charge allows the E-field to be uniform

(b) E-field lines point from higher potential to lower potential, so the top plate should be at 12 V. In a uniform E-field, the potential decreases linearly, so equipotential lines should be equally-spaced and perpendicular to the E-field.

(c)



$\vec{E} = -2000\ N/c\ \hat{z}$ ← pointing downward (negative z-dir)

$\underline{\vec{F} = q\vec{E}} = (-1.6\,E-19\,C)(-2000\ N/c)\ \hat{z}$ ← Negative signs cancel, so force is up ↑

$\underline{\sum \vec{F} = m\vec{a}}$, only one force from E-field

$m\vec{a} = q\vec{E}$ ← only in z-direction

$$a_z = \frac{qE_z}{m} = \frac{(-1.6\,E-19\,C)(-2000\ N/c)}{(9.1\,E-31\ kg)} = 3.5\,E\,14\ m/s^2$$

$\underline{V_f = V_i + a\Delta t}$ ← acceleration only in z-direction

$V_{z,f} = \cancelto{0}{V_{z,i}} + a_z \Delta t$ ← no initial z-velocity

$\Delta V_z = (3.5\,E\,14\ m/s^2)(1\,E-9\ s) = 3.5\,E\,5\ m/s$

~3000 m/s faster!

$\boxed{\vec{V}_f = \langle 2\,E\,7,\ 3.5\,E\,5 \rangle\ m/s}$ $|\vec{V}_f| = 2.0003\,E\,7$

(d) Method 1 - Using work

Work-energy theorem: work done = change in kinetic energy

- Kinetic energy increase ⇒ positive work done by E-field on electron

$\underline{W = \Delta K = \frac{1}{2} m (v_f^2 - v_i^2)}$

$V_i = 2E7$, $V_f = 2.0003\,E\,7$

$W = \frac{1}{2}(9.1\,E-31\ kg)(4.001 - 4)\,E\,14\ \frac{m^2}{s^2}$

$\boxed{W = 5.57\,E-20\ J}$

Method 2 - Using kinematics

- Don't do it, would not recommend, but it can be done