Name: Solutions

ID:

Physics 203

Midterm 2

5/14/2025

Collaboration is not allowed. Allowed on your desk are: ten 8.5 x 11 inch doubled sided sheets of notes that are bound together, non-communicating graphing scientific calculator, a page of scratch paper, writing utensils, a straight edge or ruler, and the exam. You will have 80 minutes to complete this exam.

Constants:

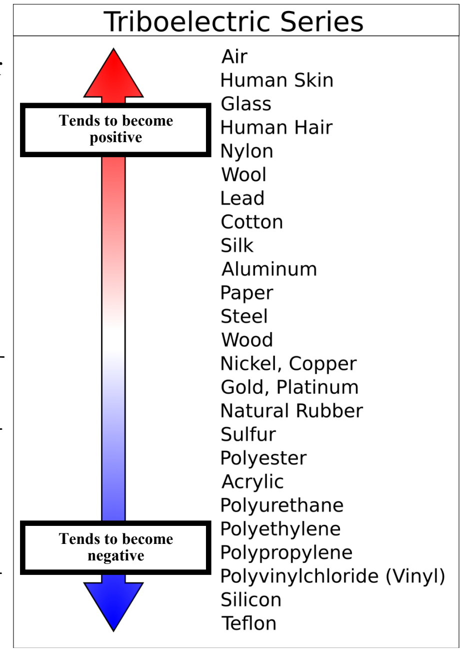
$k = 8.99 \times 10^{9}\, N \frac{m^2}{C^2}$

$m_e = 9.11 \times 10^{-31}\, kg$

$m_p = 1.67 \times 10^{-27}\, kg$

$e = 1.602 \times 10^{-19}\, C$

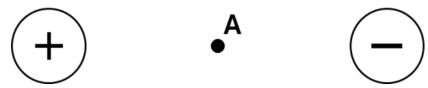
For questions 1 through 3 select next to all correct answers. A given problem may have more than one correct answer. Each correctly selected answer will receive two points. There are **8** correct answers in this section and only the first **8** filled in answers will be graded. There is no partial credit.



1. A block of pine wood is rubbed with a polyester sock. Which of the following situations will result?

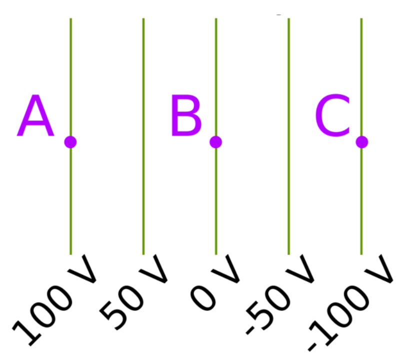
   ☐ (a) The block of wood will have a net **negative** charge while the polyester sock will have a net **positive** charge.
   ☐ (b) The block of wood will have a net **neutral** charge while the polyester sock will have a net **positive** charge.
   ☑ (c) The block of wood will have a net **positive** charge while the polyester sock will have a net **negative** charge.
   ☐ (d) The block of wood will have a net **neutral** charge while the polyester sock will have a net **negative** charge.

2. Two charges, a positive and negative charge are placed near each other and held stationary. Which of the following statements are true about location A in the diagram, which is equidistant from each charge?



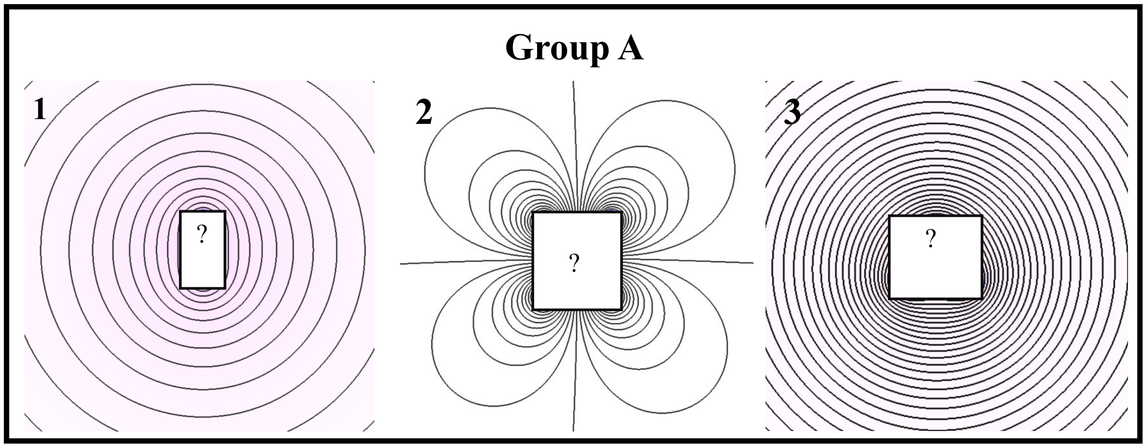
   ☐ (a) The electric potential at location A is **non-zero**.
   ☑ (b) The electric potential at location A is **zero**.
   ☐ (d) The electric potential at location A is a vector that points to the **right**.
   ☐ (e) The electric potential at location A is a vector that points to the **left**.
   ☑ (f) The electric field at location A is **non-zero**
   ☐ (g) The electric field at location A is **zero**
   ☑ (h) The electric field at location A is a vector that points to the **right**.
   ☐ (i) The electric field at location A is a vector that points to the **left**.

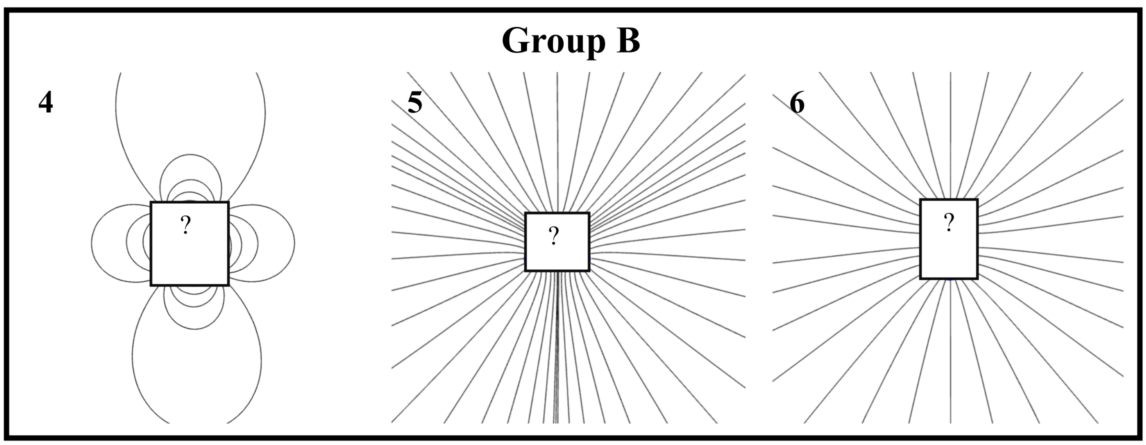
3. Which of the following statements are true considering the equipotential lines in the figure.



   ☑ (a) An electron that moves from A to B will **increase** the potential energy.
   ☐ (b) An electron that moves from A to B will **decrease** the potential energy.
   ☐ (c) An electron that moves from **A to B** will experience the same potential energy difference as a proton that moves from **A to B**.
   ☑ (d) An electron that moves from **A to B** will experience the same potential energy difference as a proton that moves from **C to B**.
   ☑ (e) An electron that moves from **A to B** will experience the same potential energy difference as electron that moves from **B to C**.
   ☐ (f) An electron that moves from **A to C** will experience the same potential energy difference as electron that moves from **C to A**.
   ☑ (g) The change in electric potential from **A to B** is the same as from **B to C**.
   ☐ (h) The change in electric potential from **A to B** is different than as from **B to C**.

4. (6 points) The figures show field patterns for three charge configurations: (i) two positive charges, (ii) three positive charges in an equilateral triangle, and (iii) a quadrupole (four charges, 2 positive, 2 negative, in a square). One of the groups is the electric field lines, the other is the equipotential lines for these three charge distributions. The order in a group is mixed up, e.g. the left-most (1) in group A is not necessary the same charge configuration as the left-most (4) in group B.





(a) Match each field in group A with it's associated field in group B. Briefly explain how you decided to match them.
(b) For each pairing in part (a), identify which charge configuration it comes from.
(c) Does group B represent:
(i) the electric field for all the charges configurations, or
(ii) the electric potential for all the charge configurations?
Explain your reasoning.

(a)

A	B	Config.
1 ↔	6	→ two positive charges
2 ↔	4	→ quadrupole
3 ↔	5	→ three charge triangle

(b) ⟶ (arrow to Config. column)

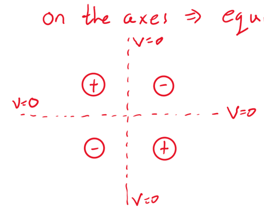
The symmetry of each field must match. 2 & 4 have four-fold symmetry ⇒ are lines of symmetry.

1, 6 ⇒ two-fold sym. ⇒

3, 5 ⇒ three fold sym. ⇒

(c) Group B ⇒ electric fields

$\vec{E}$ lines radiate out from positive charges, 4, 5, & 6 all show this. Equipotential lines are circle-ish around positive charges, especially further away. 1 & 3 show this. 2 has lines of V=0 on the axes ⇒ equidistant from each pair of +, −



5. (6 points) The most common isotope of iron, ^{56}**Fe**, has a nuclei which consists of **26 Protons** and **30 neutrons**. The average distance from the atomic center to the outermost electrons is about **0.25 nm**. This is known as the atomic radius.

(a) What is the magnitude of the electric field created by this iron nucleus at the location of its outermost electrons?

$$|\vec{E}| = k\frac{q}{|\Delta\vec{r}|^2} = 9\times10^9 \frac{(26\times1.6\times10^{-19})}{(0.25\times10^{-9})^2}$$

$$|\vec{E}| = 5.99\times10^{11}\ \text{N/C}$$

(b) In which direction does this electric field, from part (a), point?

✓ (i) outwards, away from the nucleus
(ii) inwards, towards the nucleus
(iii) it does not have a direction, it is a scalar quantity

(c) If an electron were placed at that location, in which direction would the force from the electric field, in part (a), point?

(i) outwards, away from the nucleus
✓ (ii) inwards, towards the nucleus
(iii) it does not have a direction, it is a scalar quantity

(d) (2 points extra credit) For now, assume the Bohr model of an atom, where electrons are point particles which orbit their nuclei in uniform circular motion (UCM), is accurate. The net radial force needed to keep the electron in UCM is $\mathbf{F_{net,r} = m\,v^2 / r}$. How fast would an electron, at iron's atomic radius, orbit the nucleus if the only force acting on it were caused by the electric field from the iron nucleus? (ignore the other electrons in the atom)

$\hat{r}$

$$\Sigma F_r = m a_r$$

$$F^E = F_{net,r}$$

$$qE = \frac{mv^2}{r}$$

$$v^2 = \frac{qEr}{m}$$

$$v = \sqrt{\frac{(1.6\times10^{-19})(6\times10^{11})\,0.25\times10^{-9}}{9.11\times10^{-31}}}$$

$$v = 5.13\times10^{6}\ \text{m/s}$$

↑ very fast!

1.7% the speed of light!

6. (10 points) Consider the experiment by Rutherford in your challenge homework assignment where an alpha particle, having charge **+2e** and mass **6.64x10[-27] kg**, is fired at a stationary gold nucleus. The nucleus has a charge of **+79e** and mass of **3.27x10[-25] kg**. Assume the alpha particle is fired from very far away and has an initial velocity of **2.00x10[7] m/s**. At one point in the collision, the alpha particle is momentarily at rest while the nucleus recoils with **2%** of the alpha particle's initial kinetic energy.

(a) What is the recoil speed of the nucleus at the moment the alpha particle is stationary?
(b) If the alpha particle is momentarily at rest, and the nucleus only has **2%** of the initial kinetic energy, where is the remainder of the initial kinetic energy? Explain.
(c) What is the distance between the alpha particle and the nucleus at the moment the alpha particle is momentarily at rest?
(d) Do you expect your answer in part (c) to be less than, greater than, or equal to the distance for an alternative case where the nucleus remains stationary the entire time? Explain your reasoning.

(a) $KE_{recoil} = (2\%)(KE_i)$

$\frac{1}{2} m_{nuc} v_{recoil}^2 = (0.02) \frac{1}{2} m_\alpha v_i^2$

$\frac{1}{2}(3.27\times10^{-25} kg) v_{rec}^2 = 2.66\times10^{-14} J$

$\Rightarrow v_{recoil} = 4.03\times10^5 m/s$

(b) Conservation of energy says it goes to electric potential energy as the charges get closer together

$\Rightarrow$ Initial Energy = Final Energy

$\Rightarrow KE_i = U_{12}^E + KE_{recoil}$

(c) $\left.\begin{array}{l} KE_i = U_{12}^E + KE_{recoil} \\ KE_{recoil} = (2\%) KE_i \end{array}\right\} \Rightarrow 98\% KE_i = U_{12}^E$

$\Rightarrow U_{12}^E = (98\%)(KE_i)$

$\Rightarrow k\frac{q_1 q_2}{|\Delta\vec{r}_{12}|} = (0.98)(\frac{1}{2} m_\alpha v_i^2)$

$\Rightarrow |\Delta\vec{r}_{12}| = \frac{k q_1 q_2}{(0.98)(\frac{1}{2} m_\alpha v_i^2)}$

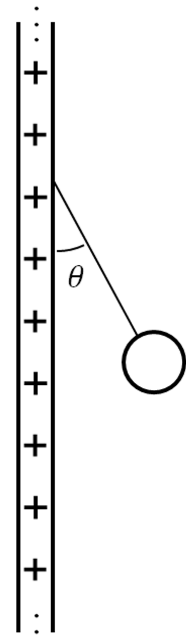
$\Rightarrow |\Delta\vec{r}_{12}| = 2.80\times10^{-14} m$

(d) I expect the distance is greater in this case. If the gold nucleus is not allowed to move, then KE_i would go entirely into U_{12}^E instead of 98% of KE_i.

$U^E = k\frac{q_1 q_2}{|\Delta\vec{r}_{12}|}$ ↑ ↓

If U_{12}^E increases, $|\Delta\vec{r}_{12}|$ should decrease

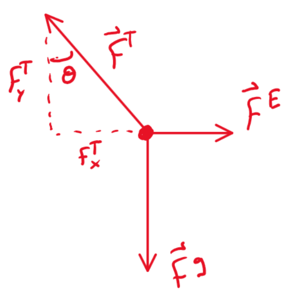
7. (10 points) A Styrofoam ball with mass, **m**, and a magnitude of charge, **q**, is hung from a string of length, **L**. The string is attached at one end to a vertical sheet of uniform charge. The ball hangs in equilibrium such that the string makes an angle, **θ**, with the sheet. This situation happens near the surface of the Earth (acceleration due to gravity **g**). The sheet has charge per area **σ** (this is a two dimensional charge density). The magnitude of the electric field close to a sheet of uniform charge is **E = 2πkσ**, where k is the Coulomb constant. Assume that the sheet is large enough and the ball stays sufficiently close to the sheet such that the sheet can be treated as effectively infinite and this relationship for electric field holds true. Note: the diagram is not drawn to scale.



(a) Is the charge on the ball positive, negative, or is it not possible to know? Explain.
(b) Draw a free-body diagram for the ball and label each force.
(c) Find an expression for the angle, θ, made between the string and the sheet. Express this in terms of the given quantities (**m**, **q**, **σ**, **k**, **g**, **π**).
(d) If the rope were to increase in length, how would the angle change? Explain.

(a) positive. If ball were negative, it would be attracted to the wall $\Rightarrow \theta \approx 0$.

(b) FBD



(c)

x/ $F_x^T + F_x^E = 0$ $\quad$ y/ $F_y^g + F_y^T = 0$

$\Rightarrow F_x^T = qE$ $\quad \Rightarrow F_y^T = mg$

$F^T \sin\theta = q\sigma 2\pi k$ $\quad F^T \cos\theta = mg$

$F^T = \frac{q\sigma 2\pi k}{\sin\theta}$ $\quad F^T = \frac{mg}{\cos\theta}$

$$F^T = F^T$$

$$\frac{q\sigma 2\pi k}{\sin\theta} = \frac{mg}{\cos\theta}$$

$$\Rightarrow \frac{q\sigma 2\pi k}{mg} = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

$$\Rightarrow \theta = \tan^{-1}\left(\frac{2\pi k q\sigma}{mg}\right)$$

Short version of (d): none of these change

(d) if rope length changes, F^E will stay the same since $\vec{E}$ does not depend on the distance from the wall. F^g will also be the same, since it does not depend on distance from the earth.

$\Rightarrow F_x^T$ & F_y^T will stay the same

$\Rightarrow$ angle stays the same!