

Numeric answers must include units. Sketches must be labeled. All short-answer questions must include your reasoning, for full credit. A correct answer with no reasoning will only receive partial credit.

Section 1. Multiple Choice

1. A glass rod that has been charged to $+8 \times 10^{-9}$ C is touched to a metal can. Afterward, the glass rod's charge is $+6 \times 10^{-9}$ C. How many electrons were transferred from the can to the rod?

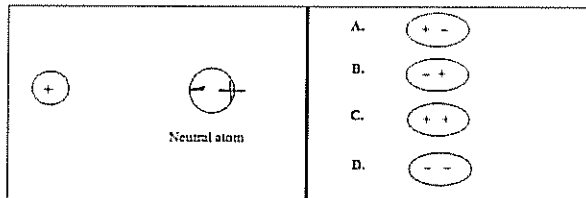
- (a) 1.25×10^{10} electrons
- (b) 1.88×10^{10} electrons
- (c) 2.00×10^9 electrons
- (d) 3.75×10^{10} electrons
- (e) 5.00×10^{10} electrons

$$\frac{2 \times 10^{-9} \text{ C}}{1.6 \times 10^{-19} \text{ C/electron}} =$$

2. In what type of material are all electrons bound to atoms and can only move within an atom?

- (a) neither a conductor nor an insulator
- (b) conductor
- (c) insulator
- (d) both a conductor and an insulator

3. A positively charged ion is near a neutral atom. Which diagram shows the polarization of the neutral atom?



- (a) A.
- (b) B.
- (c) C.
- (d) D.
- (e) None of the above because the neutral atom will not polarize.

electron cloud is attracted to the positively charged particle.

4. The ion and the neutral atom in the previous question will

- (a) attract.
- (b) repel.
- (c) not attract nor repel since the atom is neutral.

5. X and Y are two uncharged metal spheres on insulating stands, and are in contact with each other. A positively charged rod R is brought close to sphere X as shown in figure 1. Then, Sphere Y is moved away from X as shown in figure 2.

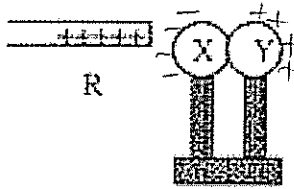


figure 1.

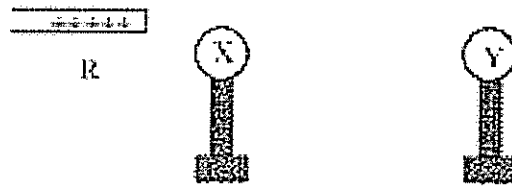
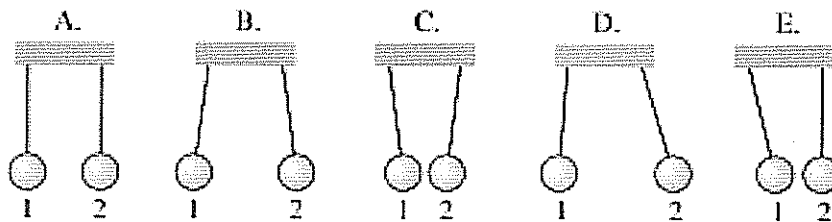


figure 2.

Sketch the surface charge on the spheres in each figure. The final charges of X and Y, respectively, are

- (a) neutral and neutral.
 - (b) positive and neutral.
 - (c) neutral and positive.
 - (d) positive and negative.
 - (e) negative and positive.
6. Two electrically neutral conducting balls hang from threads. Choose the diagram (A – E) in the figure below that shows how the balls hang after both of them are charged by touching them with a positively charged rod, but ball 2 picks up more charge than ball 1.

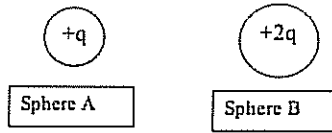


- (a) A
 - (b) B
 - (c) C
 - (d) D
 - (e) E
- Both +, so they repel.
 $F_{\text{each ball}}$ is the same.

7. Two electrically neutral conducting balls hang from threads. Choose the diagram (A – E) in the figure above that shows how the balls hang after ball 1 is charged by touching it with a positively charged rod, but ball 2 is left neutral.

- (a) A
 - (b) B
 - (c) C
 - (d) D
 - (e) E
- They will attract.
 F on each ball is the same.

8. Two metal spheres are charged. Sphere A has a charge $+Q$, and Sphere B has a charge $+2Q$, which is twice the charge as sphere A.



On which sphere is the coulomb force the greatest, in magnitude?

- (a) Sphere A
 (b) Sphere B
 (c) Neither, because the magnitude of the coulomb force on each sphere is the same.
9. The force on a negatively charged particle due to an electric field is
 (a) opposite the electric field.
 (b) in the same direction as the electric field.
 (c) neither, because it depends on the strength of the electric field.
 (d) none of the above because electric fields don't exert forces on charged particles.
10. A neutral copper block is polarized as shown, due to an electric field made by external charges (not shown). What is the direction of the *net* electric field at location B, which is inside the copper block?

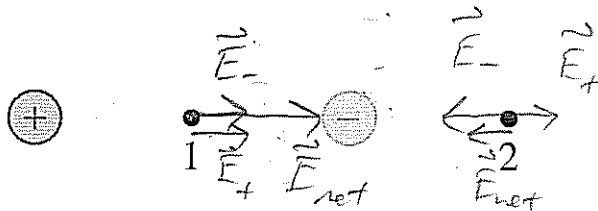
Handwritten notes:

$E_{\text{surface charge}} = E_{\text{applied}}$
 So $E_{\text{net}} = 0$; otherwise it would not be in equilibrium.

Handwritten note in a box: $E_{\text{net}} = 0$ for a conductor in equilibrium

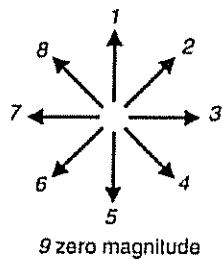
(a) 1
 (b) 4
 (c) 5
 (d) 8
 (e) 9

11. Sketch the (net) electric field at points 1 and 2 below. Compare the magnitude of the (net) electric field at points 1 and 2.



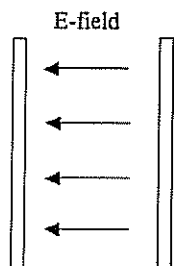
- (a) $E_1 = E_2 = 0$
 (b) $E_1 = E_2$
 (c) $E_1 < E_2$
 (d) $E_1 > E_2$

12. For the previous question, what is the direction of the electric field at point 2?



- (a) 1
- (b) 3
- (c) 5
- (d) 7
- (e) 9

13. The electric field between oppositely charged plates is shown below.

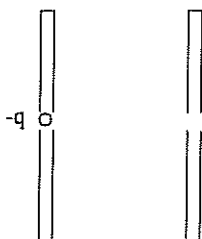


Which plate is at a higher electric potential?

- (a) the plate on the left
- (b) the plate on the right
- (c) neither, because the plates are at the same potential

14. An electron ($q = -1.6 \times 10^{-19}$ C) that is initially at rest is accelerated across plates that have a potential difference of 500 V.

$V=0$ $V=500$ V



$$U = qV \quad \text{so} \quad U_i = 0$$

$$K = \frac{1}{2}mv^2 \quad K_i = 0$$

What is the kinetic energy of the electron when it reaches the 500 V plate?

- (a) -1.6×10^{-19} J
- (b) 500 J
- (c) 313 J
- (d) 8000 J
- (e) 8×10^{-17} J

$$U_i + K_i = U_f + K_f$$

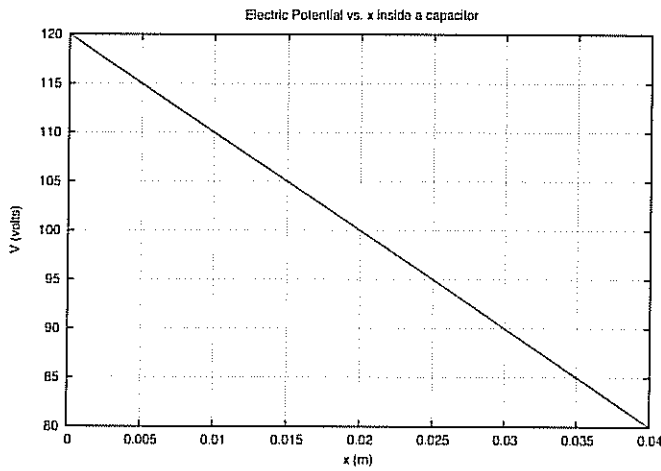
$$0 = qV_f + K_f$$

$$K_f = -qV_f$$

$$= -(-1.6 \times 10^{-19} \text{ C})(500 \text{ V})$$

$$= 8 \times 10^{-17} \text{ J}$$

15. A graph of V as a function of x across a gel in a gel electrophoresis apparatus is shown below. What is the electric field in the gel?



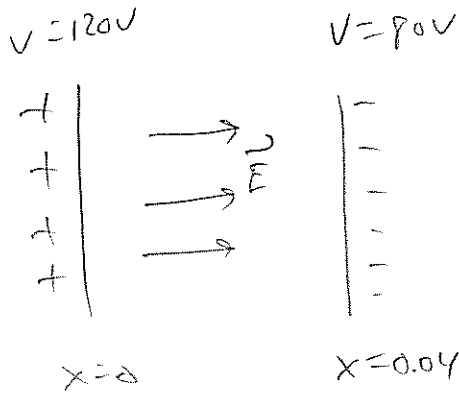
$$\text{Slope} = \frac{(80 - 120)}{0.04 - 0}$$

$$= \frac{-40}{0.04} = -1000 \frac{\text{V}}{\text{m}}$$

- (a) 2000 V/m
- (b) 3000 V/m
- (c) -3000 V/m
- (d) 1000 V/m
- (e) -1000 V/m

$$E_x = -\text{slope}$$

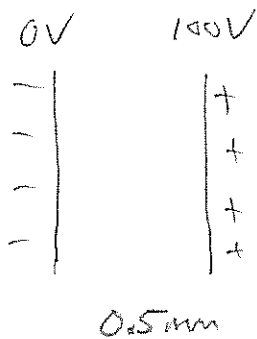
$$= 1000 \frac{\text{V}}{\text{m}}$$



\vec{E} is in +x dir.

Section 2. Problem Solving

16. Two $2.0 \text{ cm} \times 2.0 \text{ cm}$ square aluminum electrodes, spaced 0.5 mm apart, are connected to a 100 V battery. What is the charge on the positive electrode?



$$d = 0.5 \text{ mm} = 0.5 \times 10^{-3} \text{ m}$$

$$A = 2 \text{ cm} \times 2 \text{ cm} = 4 \text{ cm}^2 = 4 \times 10^{-4} \text{ m}^2$$

$$E = \frac{|\Delta V|}{d} = \frac{100 \text{ V}}{0.5 \times 10^{-3} \text{ m}} = 2 \times 10^5 \frac{\text{V}}{\text{m}}$$

$$E = \frac{Q/\epsilon_0}{A}$$

(+10)

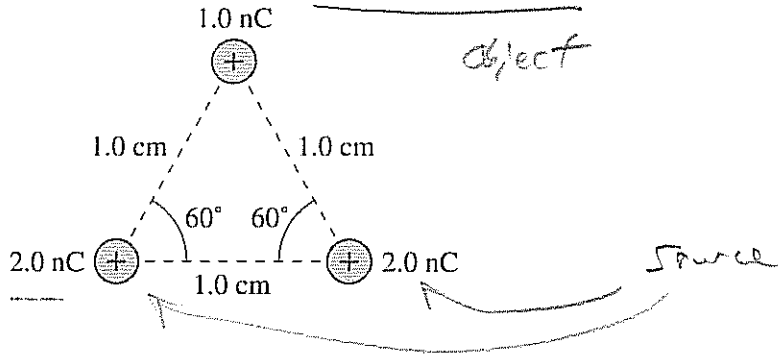
$$Q = E \epsilon_0 A$$

$$= \left(2 \times 10^5 \frac{\text{N}}{\text{C}} \right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \right) \left(4 \times 10^{-4} \text{ m}^2 \right)$$

$$Q = 7.1 \times 10^{-10} \text{ C}$$

(+10)

17. What is the force on the 1.0 nC charged sphere shown below?



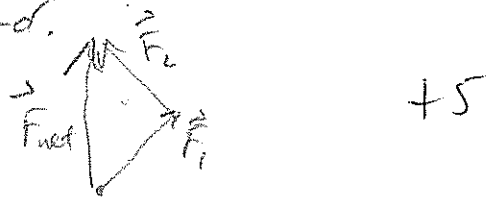
$$1 \text{ nC} = 1 \times 10^{-9} \text{ C}$$

$$2 \text{ nC} = 2 \times 10^{-9} \text{ C}$$

$$1 \text{ cm} = 1 \times 10^{-2} \text{ m}$$

Draw a force diagram:

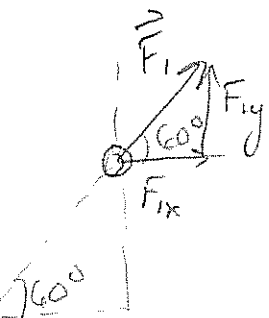
Since $|\vec{F}_1| = |\vec{F}_2|$ and since they are at the same angles, the net force is upward.



$$F_{\text{net}y} = F_{1y} + F_{2y}$$

$$= 2 F_{1y}$$

$$|\vec{F}_1| = \frac{(9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(1 \times 10^{-9} \text{ C})(2 \times 10^{-9} \text{ C})}{(0.01 \text{ m})^2} = 1.8 \times 10^{-4} \text{ N}$$



$$F_{1x} = F_1 \cos(60^\circ)$$

$$F_{1y} = F_1 \sin(60^\circ)$$

$$= 1.56 \times 10^{-4} \text{ N}$$

Thus, $F_{\text{net}y} = 2(1.56 \times 10^{-4} \text{ N}) = \boxed{3.12 \times 10^{-4} \text{ N}}$