

**Q1.**

Three identical conducting spheres (A, B, and C) are well separated from each other. Initial charges on them are  $Q_A = Q$ ,  $Q_B = -10e$ , and  $Q_C = 0$ . Sphere A is touched by Sphere C and separated. Then Sphere B is touched by Sphere C and separated. If the final charge on sphere C is  $+10e$ , find  $Q$ .

- A)  $+60e$
- B)  $-60e$
- C)  $0$
- D)  $+10e$
- E)  $-10e$

**Ans:**

$$Q'_c = \frac{Q_A + Q_c}{2}$$

$$Q''_c = \frac{Q_B + Q'_c}{2} \Rightarrow 10e = \frac{-10e + \frac{Q_A}{2}}{2} \Rightarrow Q_A = 60e$$

**Q2.**

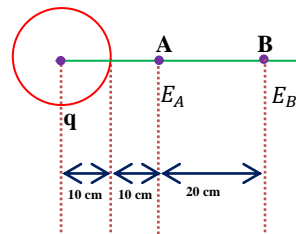
A conducting sphere of radius 10 cm carries a charge  $q$ , and produces an electric field  $E$  at a point 20 cm away from its center. The electric field at a point 30 cm radial away from its surface is:

- A)  $E/4$
- B)  $E$
- C)  $2E$
- D)  $E/2$
- E)  $4E$

**Ans:**

$$E = \frac{q}{4\pi\epsilon_0 r^2} \propto \frac{1}{r^2}$$

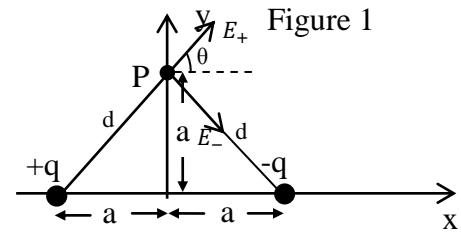
$$\Rightarrow \frac{E_B}{E_A} = \left(\frac{1}{2}\right)^2 \Rightarrow E_B = \frac{E_A}{4}$$



**Q3.**

What is the electric field at point P in **Figure 1**?

- A)  $\frac{1}{4\pi\epsilon_0} \frac{q}{\sqrt{2} a^2} \hat{i}$   
 B)  $\frac{1}{4\pi\epsilon_0} \frac{q}{\sqrt{2} a^2} \hat{j}$   
 C)  $\frac{1}{4\pi\epsilon_0} \frac{q}{a^2} \hat{i}$   
 D)  $\frac{-1}{4\pi\epsilon_0} \frac{q}{\sqrt{2} a^2} \hat{i}$   
 E) Zero



**Ans:**

$$\frac{1}{4\pi\epsilon_0} \frac{q}{d^2} = E_+$$

$$\vec{E}_{net} = (E_+ \cos\theta + E_- \cos\theta) \hat{i}$$

$$= \frac{q}{4\pi\epsilon_0} \cdot 2 \cdot \frac{1}{d^2} \cdot \frac{a}{d} \hat{i}$$

$$= \frac{q}{4\pi\epsilon_0 \sqrt{2} a^2} \hat{i}$$

$$d = \sqrt{a^2 + a^2} = \sqrt{2} a$$

$$\cos\theta = \frac{a}{d}$$

**Q4.**

An electric dipole having dipole moment of  $2.0 \times 10^{-9}$  C.m is present in a uniform external electric field of 300 N/C. The dipole moment is initially perpendicular to the field and the dipole rotates so that its dipole moment becomes parallel to the field. The work done by the field to rotate the dipole is:

- A)  $+6.0 \times 10^{-7}$  J  
 B)  $-12 \times 10^{-7}$  J  
 C)  $-6.0 \times 10^{-7}$  J  
 D)  $+12 \times 10^{-7}$  J  
 E) Zero

**Ans:**

$$\begin{aligned} W &= -\Delta u = -(u_f - u_i) \\ &= -(-pE - 0) \quad \because u = -\vec{p} \cdot \vec{E} \\ &= +6 \times 10^{-7} \text{ J} \end{aligned}$$

Q5.

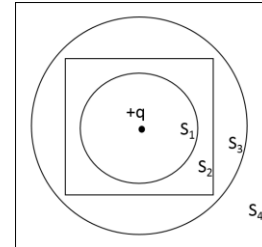
Figure 2 shows the cross section of two conducting spherical shells and two conducting hollow cubes that are centered on a particle of charge +q. If a charge -q is uniformly distributed on sphere S<sub>3</sub>, rank the magnitude of net flux through the four surfaces S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, and S<sub>4</sub>, greatest first.

- A) S<sub>1</sub> and S<sub>2</sub> tie, then S<sub>3</sub> and S<sub>4</sub> tie
- B) S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, S<sub>4</sub>
- C) S<sub>1</sub>, S<sub>2</sub>, then S<sub>3</sub> and S<sub>4</sub> tie
- D) S<sub>4</sub> and S<sub>2</sub> tie, then S<sub>1</sub> and S<sub>3</sub> tie
- E) S<sub>3</sub>, S<sub>1</sub>, S<sub>2</sub>, S<sub>4</sub>

Ans:

$$\phi = \frac{Q_{enc}}{\epsilon_0}$$

Figure 2



Q6.

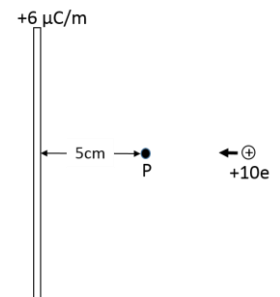
A particle of charge +10e and mass  $6.0 \times 10^{-6}$  g is fired directly toward a very long straight conducting wire of linear charge density  $+6.0 \mu\text{C/m}$  as shown in Figure 3. Find the magnitude and direction of acceleration of the charged particle when it reaches point P, 5.0 cm from the wire. Ignore the effect of gravity.

- A)  $5.8 \times 10^{-4} \text{ m/s}^2$  to the right
- B)  $5.8 \times 10^{-4} \text{ m/s}^2$  to the left
- C)  $2.6 \times 10^{-6} \text{ m/s}^2$  to the left
- D)  $2.6 \times 10^{-6} \text{ m/s}^2$  to the right
- E) Zero

Ans:

$$a = \frac{F}{m} = \frac{qE}{m} = \frac{q}{m} \cdot \frac{\lambda}{2\pi\epsilon_0 r} = 5.8 \times 10^{-4} \frac{m}{s^2} \text{ to the right}$$

Figure 3



Q7.

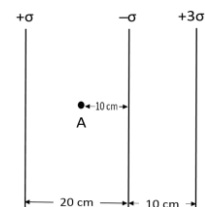
Figure 4 shows a cross section of three large insulating sheets with their surface charge densities ( $\sigma = 8.85 \text{ pC/m}^2$ ). The magnitude of the electric field at point A is:

- A)  $5.00 \times 10^{-1} \text{ N/C}$
- B)  $3.00 \times 10^{-1} \text{ N/C}$
- C)  $1.50 \times 10^{-1} \text{ N/C}$
- D)  $1.00 \times 10^{-1} \text{ N/C}$
- E)  $1.30 \times 10^{-1} \text{ N/C}$

Ans:

$$|\vec{E}_A| = \left| \frac{\sigma}{2\epsilon_0} i + \frac{\sigma}{2\epsilon_0} i - \frac{3\sigma}{2\epsilon_0} i \right| = \left| -\frac{\sigma}{2\epsilon_0} i \right| = 5.00 \times 10^{-1} \text{ N/C}$$

Figure 4



**Q8.**

An unknown charge  $q$  sits at the center of a thin conducting spherical shell of radius 10 cm which carries a charge of  $Q = -20 \mu\text{C}$  (see **Figure 5**). If the electric field at a point 15 cm from the center of the sphere is  $1.2 \times 10^6 \text{ N/C}$  radially outward, find the value of  $q$ .

- A)  $+23 \mu\text{C}$
- B)  $+30 \mu\text{C}$
- C)  $-23 \mu\text{C}$
- D)  $-30 \mu\text{C}$
- E)  $+50 \mu\text{C}$

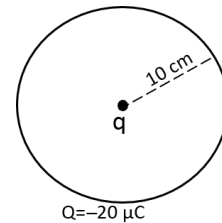
**Ans:**

$$E \cdot 4\pi(15 \times 10^{-2})^2 = \frac{q + Q}{\epsilon_0}$$

$$E = 1.2 \times 10^6, Q = -20 \times 10^{-6}$$

$$\Rightarrow q = 23 \mu\text{C}$$

Figure 5



**Q9.**

Two equal and opposite charges are placed at a certain separation. At the mid-point P between the charges, magnitude of electric field and electric potential are E and V, respectively. Assume potential at infinity is zero. Which of the following is true at P?

- A) E is not zero but V is zero
- B) Both E and V are not zero
- C) Both E and V are zero
- D) E is zero but V is not zero
- E) None of the other

**Ans:**

$$\vec{E} = \frac{kq}{a} \hat{i} + \frac{kq}{a} \hat{i}$$

$$V = \frac{kq}{a} - \frac{kq}{a} = 0$$

**Q10.**

A graph of the x-component of electric field as a function of distance x in a region of space is shown in **Figure 6**. The y and z components of the electric field are zero in the region. If the electric potential at x = 12 m is 4.0 V, what is the electric potential at x=0?

- A) 14 V
- B) 22 V
- C) 38 V
- D) 62 V
- E) 40 V

**Ans:**

$$\Delta V = - \int_0^{12} E_x \cdot dx$$

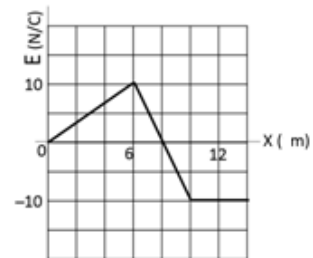
$$V_{12} - V_0 = -(\text{area under } E_x \text{ versus } x \text{ from } x = 0 \rightarrow 12)$$

$$= - \left( \frac{1}{2} \times 8 \times 10 - \frac{1}{2} \times 2 \times 10 - 2 \times 10 \right)$$

$$\Rightarrow 4 - V_0 = -10$$

$$V_0 = 14 \text{ V}$$

Figure 6



**Q11.**

Charge Q is uniformly distributed over the surface of an inflated spherical balloon of radius  $R_1 = 20$  cm. The electric potential at the surface is  $V_1$ . If you inflate the balloon to a radius  $R_2 = 50$  cm, find the new electric potential  $V_2$  at the surface of the balloon. Assume the charge Q remains uniformly distributed?

- A)  $V_2 = 0.40 V_1$
- B)  $V_2 = 1.6 V_1$
- C)  $V_2 = 0.16 V_1$
- D)  $V_2 = 6.3 V_1$
- E)  $V_2 = 2.0 V_1$

**Ans:**

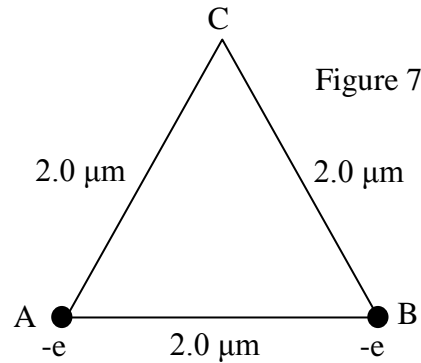
$$V = \frac{kQ}{R} \Rightarrow V \propto \frac{1}{R}$$

$$\therefore \frac{V_2}{V_1} = \frac{20}{50} = 0.4$$

**Q12.**

As shown in **Figure 7**, two electrons are fixed at the corners A and B of an equilateral triangle of side length  $2.0 \mu\text{m}$ . How much work must one do to bring a third electron to the corner C?

- A)  $2.3 \times 10^{-22} \text{ J}$
- B)  $1.4 \times 10^{-22} \text{ J}$
- C)  $2.3 \times 10^{-13} \text{ J}$
- D)  $2.3 \times 10^{-28} \text{ J}$
- E)  $1.4 \times 10^{-13} \text{ J}$



**Ans:**

$$\begin{aligned}
 W &= eV \\
 &= e \left( \frac{ke}{a} + \frac{ke}{a} \right) \\
 &= \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2 \times 2}{2 \times 10^{-6}} = 2.3 \times 10^{-22} \text{ J}
 \end{aligned}$$

**Q13.**

The capacitance of a spherical drop of a conducting liquid is  $2.0 \text{ pF}$ . If an additional identical drop is merged with the first one, what is the capacitance of the new bigger drop?

- A)  $2.5 \text{ pF}$
- B)  $2.0 \text{ pF}$
- C)  $4.0 \text{ pF}$
- D)  $1.0 \text{ pF}$
- E)  $7.6 \text{ pF}$

**Ans:**

$$\begin{aligned}
 C &= 4\pi\epsilon_0 R \propto R \\
 \frac{C_{new}}{C_{old}} &= \frac{R_{new}}{R_{old}} \\
 V_{new} &= 2V_{old} \\
 \frac{4}{3}\pi R_{new}^3 &= 2 \cdot \frac{4}{3}\pi R_{old}^3 \\
 \frac{R_{new}}{R_{old}} &= 2^{\frac{1}{3}} = 1.26 \\
 \Rightarrow \frac{C_{new}}{2.0} &= 1.26 \Rightarrow C_{new} = 2.5 \text{ pF}
 \end{aligned}$$

**Q14.**

Three capacitors are connected to a battery as shown in **Figure 8**. Their capacitances are  $C_1 = 3 \mu\text{F}$ ,  $C_2 = 2 \mu\text{F}$ , and  $C_3 = 6 \mu\text{F}$ . Rank the capacitors according to the potential differences across them, greatest first.

- A)  $C_1$ , then  $C_2$  and  $C_3$  tie
- B)  $C_2$  and  $C_3$  tie, then  $C_1$
- C)  $C_1$  and  $C_2$  tie, then  $C_3$
- D)  $C_2, C_1, C_3$
- E)  $C_3, C_1, C_2$

**Ans:**

$C_2$  and  $C_3$  are in parallel

$$\therefore V_{C_2} = V_{C_3}$$

$$C_{23} = C_2 + C_3 = 8\mu\text{C}$$

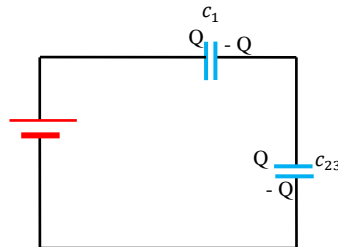


Figure 8

$$V_{C_1} = \frac{Q}{C_1}, V_{C_{23}} = \frac{Q}{C_{23}} = V_{C_2} = V_{C_3}$$

$$\Rightarrow V_{C_1} > V_{C_2} = V_{C_3}$$

**Q15.**

A parallel-plate capacitor is filled with a material of dielectric constant  $\kappa = 5.0$ . The area of each plate is  $0.024 \text{ m}^2$  and the plates are separated by  $4.0 \text{ mm}$ . If the electric field between the plates is  $100 \text{ kN/C}$ , what is the total energy stored in the capacitor?

- A)  $2.1 \times 10^{-5} \text{ J}$
- B)  $2.2 \times 10^{-2} \text{ J}$
- C)  $8.8 \times 10^{-12} \text{ J}$
- D)  $5.0 \times 10^{-7} \text{ J}$
- E)  $1.3 \times 10^{-5} \text{ J}$

**Ans:**

$$U = u \cdot V = \frac{1}{2} \kappa \epsilon_0 E^2 \cdot A \cdot d = 2.1 \times 10^{-5} \text{ J}$$

**Q16.**

Two parallel plates, each of area  $50 \text{ cm}^2$ , are separated by  $0.20 \text{ mm}$ . They are given charges of equal magnitudes  $4.5 \times 10^{-7} \text{ C}$  but opposite signs. The electric potential difference between the plates is  $560 \text{ V}$ . The dielectric constant of the material is

- A) 3.6
- B) 7.3
- C) 1.0
- D) 0.56
- E) 0.18

**Ans:**

$$\frac{Q}{V} = C = \frac{\kappa \epsilon_0 A}{d} \Rightarrow \kappa = 3.6$$

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**Q17.**

A Platinum resistance thermometer has a resistance of  $50.0 \Omega$  at  $20.0^\circ\text{C}$ . When dipped in melting indium, its resistance increases to  $76.8 \Omega$ . Ignoring the change in dimensions of platinum, determine the melting point of indium. Temperature coefficient of resistivity of platinum is  $3.92 \times 10^{-3} \text{ }^\circ\text{C}^{-1}$ .

- A)  $157^\circ\text{C}$
- B)  $137^\circ\text{C}$
- C)  $127^\circ\text{C}$
- D)  $147^\circ\text{C}$
- E)  $167^\circ\text{C}$

**Ans:**

$$R = R_0(1 + \alpha \Delta t) \Rightarrow \Delta t = 137^\circ\text{C}$$

$$\therefore T_{\text{melt}} = 137 + 20 = 157^\circ\text{C}$$

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**Q18.**

Three wires (A, B, and C) of the same cross-sectional area are connected in parallel to a constant potential difference. The length and resistivity of the wires are  $L$  and  $\rho$  for A,  $0.5 L$  and  $1.5 \rho$  for B,  $1.5L$  and  $1.2 \rho$  for C. Rank the wires according to the rate at which electric energy is transferred to thermal energy, greatest first.

- A) B, A, C
- B) A, B, C
- C) C, A, B
- D) B, C, A
- E) A, C, B

**Ans:**

Wire	$\rho$	L	$\rho L$
A	$\rho$	L	$\rho L$
B	$1.5 \rho$	$0.5 L$	$0.75 \rho L$
C	$1.2 \rho$	$1.5 L$	$1.8 \rho L$

$$P = \frac{V^2}{R} = \frac{V^2}{\rho L/A} \propto \frac{1}{\rho L} \Rightarrow P_B > P_A > P_C$$

**Q19.**

A copper wire with cross-sectional area of  $1.5 \times 10^{-5} \text{ m}^2$  and length  $0.45 \text{ m}$  carries a current of  $300 \text{ A}$ . What is the drift speed of the electrons in the wire if the number of conduction electrons per unit volume in copper is  $8.5 \times 10^{28} \text{ m}^{-3}$ ?

- A)  $1.5 \times 10^{-3} \text{ m/s}$
- B)  $3.2 \times 10^{-3} \text{ m/s}$
- C)  $8.5 \times 10^{-3} \text{ m/s}$
- D)  $2.8 \times 10^{-3} \text{ m/s}$
- E)  $4.5 \times 10^{-3} \text{ m/s}$

**Ans:**

$$\frac{I}{A} = J = nev_d \Rightarrow v_d = 1.5 \times 10^{-3} \text{ m/s}$$

**Q20.**

An accelerator used for research on the treatment of tumors eject protons at a rate of  $2.0 \times 10^{13}$  protons/s. What is the current carried by this beam of protons?

A)  $3.2 \times 10^{-6}$  A

B)  $2.0 \times 10^{+13}$  A

C)  $1.6 \times 10^{-19}$  A

D)  $1.2 \times 10^{-6}$  A

E)  $4.0 \times 10^{+13}$  A

**Ans:**

$$I = \frac{Q}{t} = 2 \times 10^{13} \times 1.6 \times 10^{-19} = 3.2 \times 10^{-6} \text{ A}$$

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