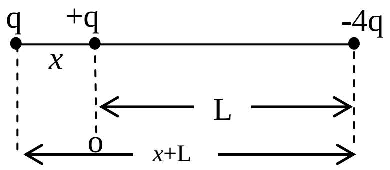
Q1.

Two point charges $+q$ and $-4q$ are at $x = 0$ and L, respectively. A third charge q is to be placed such that the net force on it is zero. What is the coordinate of the third charge?

A) $x = -L$
B) $x = -L/3$
C) $x = +L/3$
D) $x = +2L/3$
E) $x = +2L$



Ans:

The third charge has to be along the line joining the two charges, outside the two charges, and closer to the weaker.

$\therefore$ It is to the left of $(+q)$, a distance x from it

Equate the forces: $\frac{kq \cdot q}{x^2} = \frac{kq(4q)}{(x+L)^2} \Rightarrow \left(\frac{x+L}{L}\right)^2 = 4$

$\frac{x}{L} + 1 = 2 \Rightarrow \frac{x}{L} = 1 \Rightarrow x = L$

$\therefore$ The coordinate is $x = -L$

Q2.

Two identical neutral very small copper spheres are separated by a center to center distance of 10.0 cm. The same amount of charge is removed from each sphere. How many electrons need to be removed from each sphere for the spheres to repel each other with a force of 10.0 N?

A) 2.08×10^{13}
B) 3.19×10^{5}
C) 1.60×10^{19}
D) 3.60×10^{19}
E) 4.10×10^{5}

Ans:

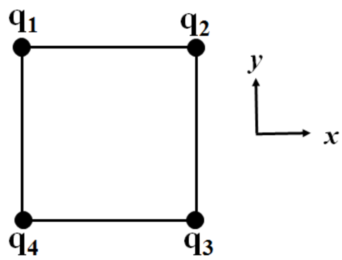
$$F = \frac{kq^2}{r^2} \Rightarrow q = \sqrt{\frac{F}{k}} \cdot r = \sqrt{\frac{10}{9\times10^9}} \times 0.1 = 3.33\times10^{-6}\text{ C}$$

$$q = N\,e \Rightarrow N = \frac{q}{e} = \frac{3.33\times10^{-6}}{1.60\times10^{-19}} = 2.08\times10^{13}$$

Q3.

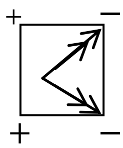
Four point charges are placed at the corners of a square, as shown in **Figure 1**. All charges have the same magnitude. If the net electric field at the center of the square is in the positive *x* direction, what are the signs of the charges q_1, q_2, q_3, q_4, respectively?

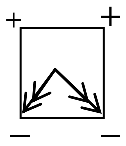
Figure 1

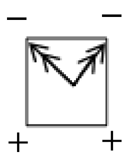


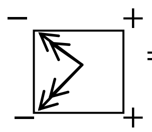
A) + , – , – , +
B) + , + , – , –
C) – , – , + , +
D) – , + , + , –
E) + , – , + , –

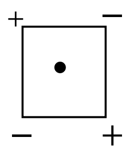
Ans:

A)  $\Rightarrow E_{net} \rightarrow +x$ direction ✓

B)  $\Rightarrow E_{net} \rightarrow -y$ direction

C)  $\Rightarrow E_{net} \rightarrow +y$ direction

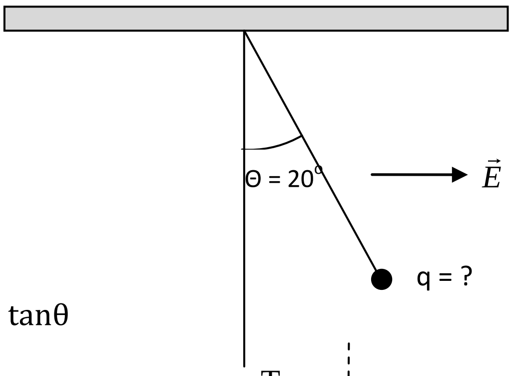
D)  $\Rightarrow E_{net} \rightarrow -x$ direction

E)  $\Rightarrow E_{net} = 0$

Q4.

An electric field $\vec{\mathbf{E}}$ =100,000 $\hat{\mathbf{i}}$ (N/C) causes the 5.00 g point charge in **Figure 2** to be in equilibrium θ = 20.0°. What is the charge on the ball?

Figure 2

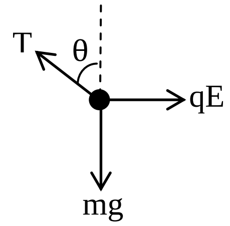


A) 178 nC
B) 281 nC
C) 98.0 nC
D) 105 nC
E) 981 nC

Ans:

$$x - \text{comp}: qE = T \cdot \sin\theta$$
$$y - \text{comp}: mg = T \cdot \cos\theta$$
$$\div \rightarrow \frac{qE}{mg} = \tan\theta$$

$$\therefore q = \frac{mg}{E} \cdot \tan\theta = \frac{5 \times 10^{-3} \times 9.8}{10^5} \times \tan 20^\circ = 178 \text{ nc}$$



Q5.

Point charges q_1 = + 5.0 μC and q_2 = – 5.0 μC are separated by 5.0 mm, forming an electric dipole. The charges are placed in a uniform electric field whose direction makes an angle of 40° with the line connecting the charges. What is the magnitude of this field if the torque exerted on the dipole has a magnitude of 7.5×10^{-9} N.m?

A) 0.47 N/C
B) 0.39 N/C
C) 0.20 N/C
D) 0.23 N/C
E) 0.33 N/C

Ans:

$$\tau = p \cdot E \cdot \sin\theta = q \cdot d \cdot E \cdot \sin\theta$$

$$E = \frac{\tau}{q \cdot d \cdot \sin\theta} = \frac{7.5 \times 10^{-9}}{5 \times 10^{-6} \times 5 \times 10^{-3} \times \sin 40^\circ} = 0.47 \text{ N/C}$$

Q6.

You are given a large insulating object that has a uniform charge density of 2.5 $\mu C/m^3$. Now imagine a sphere of radius 20 cm inside the material. What is the net flux through the surface of the sphere?

A) 9.5×10^3 Nm^2/C
B) Zero
C) 2.7×10^3 Nm^2/C
D) 8.1×10^3 Nm^2/C
E) It cannot be found since we do not know the size and shape of the object.

Ans:

$$q_{enc} = \rho V$$

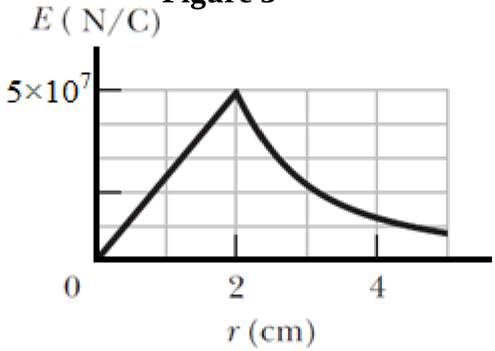
$$\Phi = \frac{q_{enc}}{\varepsilon_0} = \frac{\rho V}{\varepsilon_0} = \frac{(\rho)\left(\frac{4\pi}{3}R^3\right)}{\varepsilon_0} = \frac{4\pi\rho R^3}{3\varepsilon_0}$$

$$= (4\pi)(2.5\times10^{-6})\times\frac{(20\times10^{-2})^3}{(3\times8.85\times10^{-12})} = 9.5\times10^3\ Nm^2/C$$

Q7.

Figure 3 gives the magnitude of the electric field inside and outside sphere **A** with a positive charge distributed uniformly throughout its volume. A Gaussian spherical surface **B** is concentric with sphere **A** and has a radius of 20.0 cm. What is the net flux through surface **B**?

Figure 3



A) 2.51×10^5 Nm^2/C
B) 4.22×10^6 Nm^2/C
C) 8.21×10^4 Nm^2/C
D) 3.11×10^4 Nm^2/C
E) Zero

Ans:

$R_A = 2$ cm (from the graph)

$R_B = 20$ cm

Since $R_B > R_A$

$q_{enc}(B) = q_A$

From the graph: $E_{max} = E\ (\text{surface}) = \frac{kq_A}{R_A^2}$

$$\Rightarrow q_A = \frac{E_{max}\cdot R_A^2}{k}$$

$$\Rightarrow \Phi_B = \frac{q_{enc}}{\varepsilon_0} = \frac{q_A}{\varepsilon_0} = \frac{E_{max}\cdot R_A^2}{k\cdot\varepsilon_0}$$

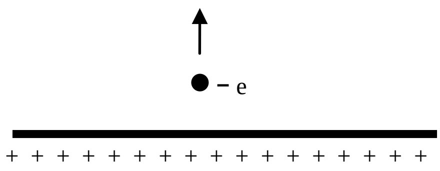
$$= (4\pi)\times5\times10^7\times4\times10^{-4} = 2.51\times10^5\ Nm^2/C$$

Q8.

In **Figure 4**, an electron is shot directly away from a uniformly charged sheet. It moves with an acceleration of 2.86×10^{4} m/s^2. The sheet is non-conducting, flat and very large. What is the sheet's surface charge density? Ignore the gravitational force.

A) 2.88×10^{-18} C/m^2
B) 3.85×10^{-18} C/m^2
C) 9.85×10^{-18} C/m^2
D) 18.2×10^{-18} C/m^2
E) 1.21×10^{-18} C/m^2

Figure 4



Ans:

$$ma = qE$$

$$ma = \frac{q\sigma}{2\varepsilon_0}$$

$$\sigma = \frac{2\varepsilon_0 ma}{q}$$

$$= \frac{2 \times 8.85 \times 10^{-12} \times 9.11 \times 10^{-31} \times 2.86 \times 10^{4}}{1.60 \times 10^{-19}} = 2.88 \times 10^{-18}\ \mathrm{C/m^2}$$

Q9.

An infinitely long line of charge carries a uniform charge per unit length of 2.5×10^{-7} C/m. The line is surrounded by an infinitely long conducting cylindrical shell of radius 2.0 cm. The shell carries a net linear charge density of -2.0×10^{-7} C/m, with the line as the axis of the shell as shown in **Figure 5**. What is the magnitude of the electric field at a distance of 1.00 cm from the line?

A) 4.5×10^{5} N/C
B) 8.1×10^{5} N/C
C) 9.0×10^{4} N/C
D) 3.6×10^{5} N/C
E) 0

Figure 5

Ans:

The requested distance is between the line and the shell.

$\therefore$ Only the line contributes to the electric field.

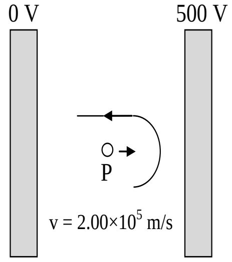
$$E = \frac{2k\lambda}{r} = \frac{2 \times 9 \times 10^{9} \times 2.5 \times 10^{-7}}{1.00 \times 10^{-2}} = 45 \times 10^{4}\ \mathrm{N/C}$$

Q10.

In **Figure 6**, a proton is fired with a speed of 2.00×10^5 m/s from the midpoint of the two parallel plates toward the right plate. The proton does not reach the right plate, and returns as shown in the Figure. What is the proton's speed as it collides with the left plate? Ignore the gravitational force.

A) 2.96×10^5 m/s
B) 2.00×10^5 m/s
C) 0
D) 8.18×10^5 m/s
E) 1.41×10^5 m/s

Figure 6



Ans:

$$K = \frac{1}{2}\,mv^2$$

$$U = qV$$

Apply conservation of energy with:

i = initial point (midway)

f = final point (left plate)

$$K_i + U_i = K_f + U_f$$

$$K_f = K_i + U_i - U_f$$

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + qV_i - qV_f$$

$$v_f^2 = v_i^2 - \frac{2q}{m}\,\Delta V$$

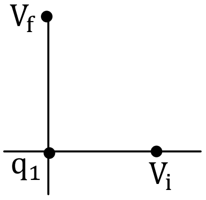
$$v_f^2 = 4\times10^{10} - \frac{(2)(+1.6\times10^{-19})(-250)}{1.67\times10^{-27}} = 8.79\times10^{10}$$

$$\Rightarrow\ v_f = 2.96\times10^5\ \text{m/s}$$

Q11.

A point charge $q_1 = -2.5\ \mu C$ is held at rest at the origin. A second point charge $q_2 = +4.0\ \mu C$ moves from the point (0.20, 0) m to the point (0, 0.15) m. How much work is done by the electric force on q_2?

A) + 0.15 J
B) – 0.15 J
C) – 1.05 J
D) + 1.05 J
E) 0



Ans:

$$V_i = \frac{kq_1}{r_i} = \frac{(9\times10^9)(-2.5\times10^{-6})}{0.2} = -112.5\ \text{kV}$$

$$V_f = \frac{kq_1}{r_f} = \frac{(9\times10^9)(-2.5\times10^{-6})}{0.15} = -150\ \text{kV}$$

$$W = -q_2\Delta V = -q_2(V_f - V_i) = (-4\times10^{-6})(-150+112.5)\times10^3$$

$$= +150\times10^{-3}\ \text{J} = +0.15\ \text{J}$$

Q12.

A charge of 3.00×10^{-8} C lies on an isolated metal sphere of radius 20.0 cm. With V = 0 at infinity, what is the electric potential at a point that is 10.0 cm from the center of the sphere?

A) 1350 V
B) 675 V
C) 1200 V
D) 600 V
E) 843 V

Ans:

The requested point is inside the sphere.

$$\therefore V = V\,(\text{surface}) = \frac{kq}{R} = \frac{9\times10^9\times3\times10^{-8}}{0.2} = 1350\ \text{V}$$

Q13.

In a certain region of space, the electric field points in the positive *x* direction. In this field, an electron is moved along the *x* axis from *x* = 2 m to *x* = 5 m. Which of the following statements is correct?

A) The electric potential energy of the electron-field system increases.
B) The electric potential energy of the electron-field system decreases.
C) The electric potential energy of the electron-field system remains the same.
D) The electron moves to a region of higher electric potential.
E) The electric potential is the same everywhere.

Ans:

Electric potential increases in the $(-)$ x direction.

$\therefore \ \Delta V < 0$

$\Delta U = 9 \cdot \ \Delta V$

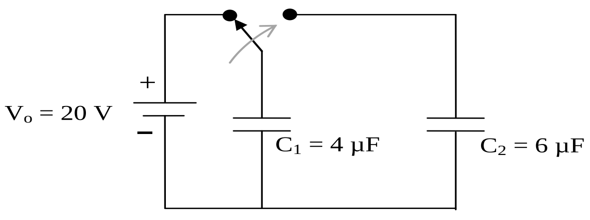
$(-) \cdot (-) \rightarrow (+)$

Q14.

Figure 7 shows a 20 V battery and two uncharged capacitors C_1 = 4.0 μF and C_2 = 6.0 μF. The switch is thrown to the left side until capacitor 1 is fully charged. Then, the switch is thrown to the right. What is the final charge on capacitor 1?

A) 32 μC
B) 64 μC
C) 16 μC
D) 8.0 μC
E) 80 μC

Figure 7



Ans:

$Q_i = C_1 \cdot V_0 = 4 \times 20 = 80 \ \mu C$

When the switch is thrown to the right, charge flows until the potential difference across each capictor is the same.

$$\left.\begin{matrix} q_1 = C_1 V_f \\ q_1 = C_2 V_2 \end{matrix}\right\} \oplus \rightarrow \underbrace{q_1 + q_2}_{Q_i = (C_1 + C_2)V_f} = (C_1 + C_2)V_f$$

$$\Rightarrow V_f = \frac{Q_i}{C_1 + C_2} = \frac{80}{10} = 8.0 \ V$$

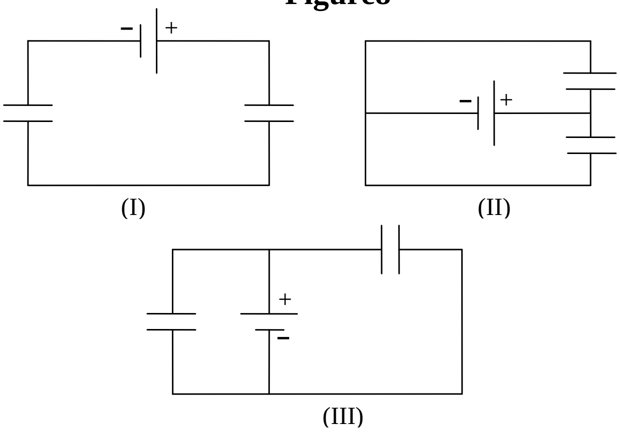
$$\Rightarrow q_1 = 4 \times 8 = 32 \mu C$$

Q15.

Figure 8 shows three combinations of capacitors connected in series, parallel or neither. The combinations in (I), (II), and (III) respectively are

A) series, parallel, parallel
B) series, series, series
C) parallel, parallel, series
D) series, neither, neither
E) parallel, neither, neither

Figure8



Ans:

A

Q16.

Two capacitors, C_1 = 2.00 μF and C_2 = 5.00 μF are connected in series with a 20.0 V battery. Find the energy stored in capacitor C_1.

A) 204 μJ
B) 181 μJ
C) 490 μJ
D) 137 μJ
E) 253 μJ

Ans:

$$C_{eq} = \frac{2 \times 5}{2 + 5} = \frac{10}{7}\ \mu F$$

$$q = C_{eq} \cdot V = \frac{10}{7} \times 20 = \frac{200}{7}\ \mu C$$

$$\Rightarrow q_1 = \frac{200}{7}\ \mu C = 2.86 \times 10^{-5}$$

$$U_1 = \frac{q_1^2}{2C_1} = \frac{(2.86 \times 10^{-5})^2}{4 \times 10^{-6}} = 204\ \mu J$$

Q17.

A parallel plate capacitor with a dielectric sheet inserted between its plates has a capacitance of 50 pF. If the plate separation is 0.10 mm, find the maximum operating potential difference. (For the dielectric: dielectric constant = 6.0, dielectric strength = 150×10^6 V/m).

A) 15 kV
B) 230 kV
C) 88 kV
D) 21 kV
E) 210 kV

Ans:

$$E = \frac{V}{d} \Rightarrow V = E\cdot d$$

$$V_{max} = E_{max}\cdot d = 150\times10^6\times1.0\times10^{-4} = 15\text{ kV}$$

Q18.

The heating element of a heater is rated at 1000 W when operating at 120 V. What would its power consumption be if operating at 110 V? Assume that the resistance remains constant.

A) 840 W
B) 1000 W
C) 220 W
D) 110 W
E) 1200 W

Ans:

$$P = \frac{V^2}{R}$$

$$\left.\begin{aligned} P_f &= \frac{v_f^2}{R} \\ P_i &= \frac{v_i^2}{R} \end{aligned}\right\} \frac{P_f}{P_i} = \left(\frac{V_f}{V_i}\right)^2$$

$$\Rightarrow P_f = \left(\frac{V_f}{V_i}\right)^2\cdot P_i = \left(\frac{110}{120}\right)^2\times10^3 = 840\text{ W}$$

Q19.

A 120 V potential difference is applied to a heater. There are 2.6×10^{19} electrons flowing through any cross section of the heater every second. How much energy is consumed by the heater every hour?

A) 1.8 MJ
B) 2.5 MJ
C) 5.1 MJ
D) 2.1 MJ
E) 8.5 MJ

Ans:

$$I = \frac{q}{t} = \frac{Ne}{t} = \frac{2.6\times10^{19}\times1.6\times10^{-19}}{1.0} = 4.16\ A$$

$$P = I \cdot V$$

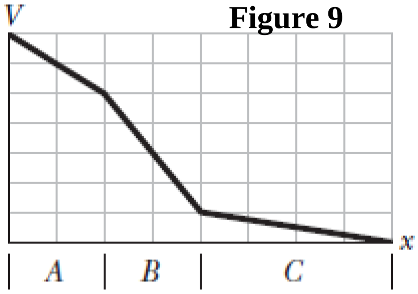
$$\text{Energy} = \text{Power} \times \text{time} = I\cdot V\cdot t = 4.16\times120\times3600 = 1.8\times10^{6}\ J$$

Q20.

Figure 9 gives the electric potential *V*(*x*) versus position *x* along a copper wire carrying current. The wire consists of three sections (A, B, C) that differ in radius. Rank the sections according to the magnitude of the current density, greatest first.

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

Figure 9



Ans:

$$E_A = \frac{2}{2} = 1 \rightarrow \text{medium}$$

$$E_B = \frac{4}{2} = 2 \rightarrow \text{maximum}$$

$$E_C = \frac{1}{4} = 0.25 \rightarrow \text{lowest}$$

$$E = \rho J \Rightarrow J = \frac{E}{\rho} = \sigma E$$

$$\Rightarrow J \text{ is propotional to } E \Rightarrow B, A, C$$
