Q1.

**Figure 1** shows three charges \(+q, -q\) and \(Q\) along with net force \(F\) on charge \(-q\). If \(\theta = 45^\circ\), the value of charge \(Q\) is:

A) \(+4q\)
B) \(-4q\)
C) \(-3q\)
D) \(+3q\)
E) \(+2q\)

**Ans:**

\(Q\) must be (+).

Otherwise, \(\vec{F}\) will be in the second quadrant.

Since \(\theta = 45^\circ\):

\[ F_1 = F_2 \]

\[ \frac{k \cdot q \cdot Q}{4d^2} = \frac{k \cdot q \cdot q}{d^2} \Rightarrow Q = +4q \]

Q2.

Four identical metal spheres (A, B, C, D) have charges of \(q_A = -8.0 \, \mu C\), \(q_B = -2.0 \, \mu C\), \(q_C = +5.0 \, \mu C\), and \(q_D = +12.0 \, \mu C\). Then, three of the metal spheres are brought together so that they touch each other simultaneously, and then they are separated. Which of the three spheres were touched together, if the final charge on each of the three spheres is \(+3.0 \, \mu C\)?

A) A, C, D
B) A, B, C
C) B, C, D
D) A, B, D
E) none of the other answers

**Ans:**

\(Q_f = 3 \times 3.0 = +9.0 \, \mu C\)

\[ \therefore Q_i = +9.0 \, \mu C \leftarrow \text{charge conservation} \]

A + B + C = \(-5.0 \, \mu C\) ×
A + C + D = \(+9.0 \, \mu C\) ✓
B + C + D = \(+15 \, \mu C\) ×
A + B + D = \(+2 \, \mu C\) ×
Q3.

Three charges \((-q, -q, \text{ and } Q)\), with \(q = 2.5 \mu\text{C}\), are located at equal distance \(d\) from the origin, as shown in Figure 2. If the resultant electric field at \(P_1\) due to the three charges is zero, what are the magnitude and sign of charge \(Q\)?

A) + 7.1 \mu\text{C}  
B) + 1.7 \mu\text{C}  
C) − 7.1 \mu\text{C}  
D) − 1.7 \mu\text{C}  
E) + 2.5 \mu\text{C}  

Ans:

Q must be (+) for the electric field to be zero at point P.

\[ E_1 = E_{2y} + E_{3y} = 2E_{2y} \quad \text{(since } E_2 = E_3) \]

\[ \frac{kQ}{4d^2} = 2 \frac{kq}{2d^2} \cdot \frac{\sqrt{2}}{2} \Rightarrow Q = +2\sqrt{2}q = +7.1 \mu\text{C} \]

Q4.

An electron enters a region of uniform electric field with an initial velocity of 4.2 km/s in the same direction as the electric field, which has a magnitude of 12 N/C. What is the speed of the electron 2.0 ns after entering this region?

A) 0.0 km/s  
B) 2.2 km/s  
C) 1.3 km/s  
D) 3.3 km/s  
E) 1.7 km/s  

Ans:

\[ a = \frac{qE}{m} = \frac{eE}{m} \]

\[ v_f = v_i - at \]

\[ = 4.2 \times 10^3 - \frac{1.6 \times 10^{-19} \times 12 \times 2.0 \times 10^{-19}}{9.11 \times 10^{-31}} \]

\[ = 4.2 \times 10^3 - 4.2 \times 10^3 = 0.0 \times 10^3 \text{ m/s} = 0.0 \text{ km/s} \]
Q5.

A torque of magnitude 0.1 N.m. has been applied to orient an electric dipole at a particular angle with respect to a uniform electric field. When the dipole moment is oriented along the field, the electric potential energy of the dipole is \(-0.2\) J. What was the initial angle between the dipole moment and the electric field?

A) \(30^\circ\)
B) \(90^\circ\)
C) \(45^\circ\)
D) \(10^\circ\)
E) \(0\)

Ans:

when \(\vec{p} \parallel \vec{E}: \theta = 0\) \(\Rightarrow U = -\vec{p} \cdot \vec{E} = -\vec{p} \cdot \vec{E} = -pE = -0.2\) J
\[\therefore pE = 0.2\] J
\[\tau = pE \sin \theta \Rightarrow \sin \theta = \frac{\tau}{pE} = \frac{0.1}{0.2} = 0.5 \Rightarrow \theta = 30^\circ\]

Q6.

Figure 3 shows three Gaussian surfaces A, B and C, with corresponding electric flux \(\Phi_A = -q/\varepsilon_0\), \(\Phi_B = +3q/\varepsilon_0\) and \(\Phi_C = -2q/\varepsilon_0\) through them, respectively. What is the value of the charge \(q_1\)?

A) \(+2q\)
B) \(+q\)
C) \(-3q\)
D) \(+3q\)
E) \(-2q\)

Ans:

\(\Phi_A = -\frac{q}{\varepsilon_0} = \frac{1}{\varepsilon_0}(q_1 + q_3) \Rightarrow q_1 + q_3 = -q \rightarrow (1)\)
\(\Phi_B = +\frac{3q}{\varepsilon_0} = \frac{1}{\varepsilon_0}(q_1 + q_2) \Rightarrow q_1 + q_2 = +3q \rightarrow (2)\)
\(\Phi_C = -\frac{2q}{\varepsilon_0} = \frac{1}{\varepsilon_0}(q_2 + q_3) \Rightarrow q_2 + q_3 = -2q \rightarrow (3)\)

From (1): \(q_3 = -q - q_1\)
From (2): \(q_2 = +3q - q_1\)
From (3): \(+3q - q_1 - q - q_1 = -2q\)
\(4q = 2q_1\)
\[\therefore q_1 = +2q\]
Q7. A charged conducting spherical shell has an inner radius of 6.0 cm and an outer radius of 10 cm. A point charge is placed at the center of the shell such that the resulting surface charge densities on the inner and outer surfaces of the shell are –100 nC/m² and +100 nC/m², respectively. What is the electric field at a distance of 12 cm from the center of the shell?

A) $7.9 \times 10^3$ N/C, outward
B) $7.9 \times 10^3$ N/C, inward
C) $9.7 \times 10^3$ N/C, outward
D) $9.7 \times 10^3$ N/C, inward
E) $5.3 \times 10^3$ N/C, outward

Ans:

$r = 12$ cm is outside the shell
$\therefore \vec{E}$ is supplied by $q_{\text{out}} \Rightarrow$ outward

$$E = \frac{kq_{\text{out}}}{r^2} = \frac{k}{r^2} \cdot (\sigma_{\text{out}} \cdot A_{\text{out}})$$
$$= \frac{k}{r^2} \cdot (\sigma_{\text{out}} \cdot 4\pi R_{\text{out}}^2) = 7.9 \times 10^3 \text{ N/C}$$

Q8. An electron experiences a force of magnitude $F$ when it is 2 cm away from a very long, charged wire that has a uniform linear charge density $+\lambda$. If the linear charge density is increased to $+2\lambda$, at what distance from the wire will the electron experience a force of the same magnitude $F$?

A) 4 cm
B) 1 cm
C) 3 cm
D) 2 cm
E) 6 cm

Ans:

$$E = \frac{2k\lambda}{r}$$
$$F = qE = \frac{2kq\lambda}{r}$$
$\therefore r = \frac{2kq\lambda}{F}$

If $\lambda$ is doubled but $F$ is the same, then $r$ is doubled.
Q9. Figure 4 shows cross sections through two large parallel non-conducting sheets with surface charge densities $\sigma_1 = -1.8 \ \mu C/m^2$ and $\sigma_2 = +1.2 \ \mu C/m^2$. What is the electric field at point P (in units of $10^4$ N/C)?

A) $-3.4 \ \hat{i}$
B) $-6.8 \ \hat{i}$
C) $+3.4 \ \hat{i}$
D) $+6.8 \ \hat{i}$
E) $+1.7 \ \hat{i}$

Ans:
\[
\vec{E}_1 = \frac{\sigma_1}{2\varepsilon_0} (-\hat{i})
\]
\[
\vec{E}_2 = \frac{\sigma_2}{2\varepsilon_0} (-\hat{i})
\]
\[
\therefore \ \vec{E}_{net} = \vec{E}_1 + \vec{E}_2 = \left( \frac{\sigma_2 - \sigma_1}{2\varepsilon_0} \right) \hat{i}
\]
\[
= \left( \frac{1.2 \times 10^{-6} - 1.8 \times 10^{-6}}{2 \times 8.85 \times 10^{-12}} \right) \hat{i}
\]
\[
= -3.4 \times 10^4 \ \hat{i} \ (N/C)
\]

Q10. A uniformly charged solid insulating sphere has a radius of 5.0 cm. If the magnitude of the electric field due to this sphere at $r = 8.0 \ \text{cm}$ is $2.0 \times 10^5 \ \text{N/C}$, what is the magnitude of the field at $r = 3.0 \ \text{cm}$? [$r$ is the distance from the center of the sphere]

A) $3.1 \times 10^5 \ \text{N/C}$
B) $1.8 \times 10^5 \ \text{N/C}$
C) $9.0 \times 10^4 \ \text{N/C}$
D) $2.7 \times 10^5 \ \text{N/C}$
E) $7.2 \times 10^5 \ \text{N/C}$

Ans:
\[
R = 5.0 \ \text{cm}, r_0 = 8.0 \ \text{cm}, r_1 = 3.0 \ \text{cm}
\]
\[
E_0 = \frac{kq}{r_0^2} \Rightarrow kq = E_0 \cdot r_0^2
\]
\[
E_i = \frac{kq}{R^3} \cdot r_i = \frac{E_0 \cdot r_0^2 \cdot r_i}{R^3} = \frac{2.0 \times 10^5 \times 64 \times 3.0}{125} = 3.1 \times 10^5 \ \text{N/C}
\]
Q11.

In Figure 5, seven charged particles are fixed in place to form a square with an edge length of 5.0 cm. How much work must we do to bring a particle of charge $+5e$ initially at rest from an infinite distance to the center of the square?

A) $+1.4 \times 10^{-25}$ J  
B) $-1.4 \times 10^{-25}$ J  
C) $-2.8 \times 10^{-25}$ J  
D) 0  
E) $+2.8 \times 10^{-25}$ J  

Ans:

The only charge that contributes the potential at the center of the square is the $+3e$ charge at the center of the bottom line.

$$V_C = \frac{kq}{r} = \frac{(k)(+3e)}{d} = \frac{+3ke}{d}$$

$$W = q \cdot V_C = (+5e) \cdot \left(\frac{+3ke}{d}\right)$$

$$W = q \cdot V_C = (+5e) \cdot \left(\frac{+3ke}{d}\right)$$

$$= + \frac{15 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}{0.025}$$

$$= + 1.4 \times 10^{-25} \text{ J}$$

Q12.

In a certain region of space, the electric field is given by $\vec{E} = 0.40 \hat{x}$ (N/C). If the electric potential at the origin is $+5.0$ V, what is the electric potential at the point $(3.0, 0, 0)$ m?

A) $+3.2$ V  
B) $+1.8$ V  
C) $-1.8$ V  
D) $+6.8$ V  
E) $-6.2$ V  

Ans:

$$\Delta V = -\int \vec{E} \cdot d\vec{s} = -\int_0^3 0.4 \, dx = -0.2[x^2]_0^3 = -1.8 \text{ V}$$

$$V_3 - V_0 = -1.8 \Rightarrow V_3 = V_0 - 1.8 = 5.0 - 1.8 = +3.2 \text{ V}$$
Q13.

Two point charges lie along the x axis. One charge \( q_1 \), located at the origin, has a magnitude of \( +2q \). The other charge \( q_2 \) is located at \( x = +5 \) cm. If the electric potential, due to the two charges, at \( x = +4 \) cm is equal to zero, what are the magnitude and sign \( q_2 \)?

\[
\begin{align*}
\text{A)} & \ -q/2 \\
\text{B)} & \ -q/4 \\
\text{C)} & \ -2q \\
\text{D)} & \ +q/2 \\
\text{E)} & \ +2q \\
\end{align*}
\]

Ans:

\[
V_4 = \frac{kq_1}{4} + \frac{kq_2}{1} = 0 \\
\Rightarrow q_2 = -\frac{q_1}{4} = -\frac{2q}{4} = -\frac{q}{2}
\]

Q14.

In a certain situation, the electric potential varies along an x axis as shown in Figure 7. For which range of \( x \) is the magnitude of the electric field the largest?

\[
\begin{align*}
\text{A)} & \ \text{from } x = 2 \ \text{to } x = 4 \ \checkmark \\
\text{B)} & \ \text{from } x = 4 \ \text{to } x = 6 \ \xmark \\
\text{C)} & \ \text{from } x = 0 \ \text{to } x = 2 \ \xmark \\
\text{D)} & \ \text{from } x = 5 \ \text{to } x = 6 \ \xmark \\
\text{E)} & \ \text{from } x = 0 \ \text{to } x = 1 \ \xmark \\
\end{align*}
\]

Ans:

\[
E = \frac{dV}{dx} = \text{slope}
\]
Q15.

Two particles have the same charge of +1 µC. Initially, they are held at rest, separated by a distance \(d = 1\) cm. One of the particles is released and moves away from the other fixed particle. When the moving particle is a distance of \(3d\) from the other particle, what is its kinetic energy?

A) 0.6 J  
B) 0.2 J  
C) 0.3 J  
D) 0.1 J  
E) 0.0 J

Ans:

\[
K_i + U_i = K_f + U_f  \\
K_f = U_i - U_f  \\
= \frac{kq^2}{d} - \frac{kq^2}{3d} = \frac{2kq^2}{3d} = \frac{2}{3} \times \frac{9 \times 10^9}{0.01} \times 10^{-12} = 0.6 J
\]

Q16.

A conducting sphere of radius 16 cm has a net charge of \(2.0 \times 10^{-8}\) C. If the electric potential is zero at infinity, at what distance from the sphere’s surface has the electric potential decreased by 500 V from its value on the surface?

A) 13 cm  
B) 29 cm  
C) 36 cm  
D) 11 cm  
E) 22 cm

Ans:

\[
V_s = \frac{kq}{R} = \frac{9 \times 10^9 \times 2 \times 10^{-8}}{0.16} = 1125 V
\]

\[
V_x = V_s - 500 = 625 V
\]

\[
V_x = \frac{kq}{r} \Rightarrow r = \frac{kq}{V_x} = \frac{9 \times 10^9 \times 2 \times 10^{-8}}{625} = 0.288 m = 28.8 cm
\]

\[
\Rightarrow x = r - R = 28.8 - 16 = 12.8 cm \Rightarrow 13 cm
\]
Q17.
The potential difference between the plates of a parallel plate capacitor is 35 V, and the electric field between the plates has a magnitude of 750 V/m. If the plate area is 400 cm², what is the capacitance of this capacitor?

A) $7.6 \times 10^{-12}$ F
B) $7.6 \times 10^{-14}$ F
C) $7.6 \times 10^{-11}$ F
D) $7.6 \times 10^{-10}$ F
E) None of the other choices is correct

Ans:

\[ V = E \cdot d \Rightarrow d = \frac{V}{E} = \frac{35}{750} = 0.047 \text{ m} \]

\[ C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 400 \times 10^{-4}}{0.047} = 7.6 \times 10^{-12} \text{ F} \]

Q18.
Four capacitors, with capacitances $C_1 = 3.0 \mu F$, $C_2 = 2.0 \mu F$, $C_3 = 5.0 \mu F$, and $C_4 = 4.0 \mu F$, are connected in a circuit to a 10 V battery, as shown in Figure 6. How much energy is stored by the combination?

A) 97 $\mu J$
B) 64 $\mu J$
C) 53 $\mu J$
D) 59 $\mu J$
E) 25 $\mu J$

Ans:

Series: $C_{23} = \frac{C_2 C_3}{C_2 + C_3} = \frac{10}{7} \mu F$

Parallel: $C_{234} = C_{23} + C_4 = \frac{10}{7} + 4 = \frac{38}{7} \mu F = 5.4 \mu F$

\[ C_{eq} = \frac{C_{234} \times C_1}{C_{234} + C_1} = \frac{5.4 \times 3.0}{5.4 + 3.0} = 19.3 \mu F \]

\[ U = \frac{1}{2} C_{eq} V^2 \]

\[ = \frac{1}{2} \times 1.93 \times 10^{-6} \times 100 \]

\[ = 9.7 \times 10^{-5} J = 97\mu J \]
Q19. When the potential difference between the plates of a parallel-plate capacitor is $V$, the energy density in the capacitor is $u$. If the potential difference is doubled, which of the following changes would keep the energy density equal to its previous value $u$?

A) doubling the spacing between the plates ✓

B) doubling the area of the plates ✗

C) reducing the area of the plates by half ✗

D) reducing the spacing between the plates ✗

E) The energy density is unaffected by a change in the potential difference ✗

Ans: A

Q20. An isolated parallel-plate capacitor stores an energy of 3.4 J. How much work is required by an external agent to insert a dielectric of dielectric constant $\kappa = 2.8$ between the plates of the capacitor?

A) $-2.2$ J

B) $+2.2$ J

C) $-1.2$ J

D) $+1.2$ J

E) $-3.5$ J

Ans:

$U_i = \frac{q_i^2}{2C}$

$U_f = \frac{q_i^2}{2kC} = \frac{U_i}{U}$

$W = \Delta U = U_f - U_i = \left(\frac{1}{\kappa} - 1\right)U_i = \left(\frac{1}{2.8} - 1\right)(3.4) = -2.2$ J