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## Electrostatics

## Previous Questions (AIPMT)

2012

1. An electric dipole of moment $p$ is placed in an electric field of intensity $E$. The dipole acquires a position such that the axis of the dipole makes an angle $\theta$ with the direction of the field. Assuming that the potential energy of the dipole to be zero when $\theta=90^{\circ}$, the torque and the potential energy of the dipole will respectively be
a) $p E \sin \theta,-p E \cos \theta$
b) $p E \sin \theta,-2 p E \cos \theta$
c) $p E \sin \theta, 2 p E \cos \theta$
d) $p E \cos \theta,-p E \sin \theta$
2. What is the flux through a cube of side a, if a point charge of $q$ is at one of its corner?
a) $\frac{2 q}{\varepsilon_{0}}$
b) $\frac{q}{8 \varepsilon_{0}}$
c) $\frac{q}{\varepsilon_{0}}$
d) $\frac{q}{2 \varepsilon_{0}} 6 a^{2}$
3. A parallel plate capacitor has a uniform electric field $\mathbf{E}$ in the space between the plates. If the distance between the plates is $d$ and area of each plate is A , the energy stored in the capacitor is
a) $\frac{1}{2} \varepsilon_{0} E^{2}$
b) $\frac{E^{2} A d}{\varepsilon_{0}}$
c) $\frac{1}{2} \varepsilon_{0} E^{2} A d$
d) $\varepsilon_{0} E A d$
4. Two metallic spheres of radii 1 cm and 3 cm are given charges of $-1 \times 10^{-2} \mathrm{C}$ and $5 \times 10^{-2} \mathrm{C}$, respectively. If these are connected by a conducting wire, the final charge on the bigger sphere is
a) $2 \times 10^{-2} \mathrm{C}$
b) $3 \times 10^{-2} \mathrm{C}$
c) $4 \times 10^{-2} \mathrm{C}$
d) $1 \times 10^{-2} \mathrm{C}$

5 A charge $Q$ is enclosed by a Gaussian spherical surface of radius $R$. If the radius is doubled, then the outward electric flux will
a) Increase four times
b) Be reduced to half
c) Remain the same
d) Be doubled
6. A parallel plate condenser has a uniform electric field $E(V / m)$ in the space between the plates. If the distance between the plates is $\mathbf{d}(\mathrm{m})$ and area of each plate is $\mathbf{A}\left(\mathbf{m}^{2}\right)$ the energy (joules) stored in the condenser is
a) $E^{2} A d / \varepsilon_{0}$
b) $\frac{1}{2} \varepsilon_{0} E^{2}$
c) $\varepsilon_{0} E A d$
d) $\frac{1}{2} \varepsilon_{0} E^{2} A d$
7. Four electric charges $+\mathbf{q},+q,-q$ and $-q$ are placed at the corners of $a$ square of side 2 L (see figure). The electric potential at point $A$, midway between the two charges $+q$ and $+q$, is

a) $\frac{1}{4 \pi \varepsilon_{0}} \frac{2 q}{L}(1+\sqrt{5})$
b) $\frac{1}{4 \pi \varepsilon_{0}} \frac{2 q}{L}\left(1+\frac{1}{\sqrt{5}}\right)$
c) $\frac{1}{4 \pi \varepsilon_{0}} \frac{2 q}{L}\left(1-\frac{1}{\sqrt{5}}\right)$
d) Zero
8. Three charges, each $+q$ are placed at the corners of an isosceles triangle $A B C$ of sides $B C$ and $A C, 2 a$. $D$ and $E$ are the mid points of $B C$ and CA. The work done in taking a charge $Q$ from $D$ to $E$ is

a) $\frac{3 p Q}{4 \pi \varepsilon_{0} a}$
b) $\frac{3 p Q}{8 \pi \varepsilon_{0} a}$
c) $\frac{q Q}{4 \pi \varepsilon_{0} a}$
d) Zero
9. The electric potential $V$ at any point $(x, y, z)$, all in metres in space is given by $V=4 \mathbf{x}^{\mathbf{2}}$ volt. The electric field at the point $(\mathbf{1}, \mathbf{0}, 2)$ in volt/meter, is
a) 8 along negative $X-$ axis
b) 8 along positive X -axis
c) 16 along negative $X$-axis
d) 16 along positive X -axis

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10. Two positive ions, each carrying a charge $q$ are separated by a distance $d$. If $F$ is the force of repulsion between the ions, the number of electrons missing from each ion will be (e being the charge on an electron)
a) $\frac{4 \pi \varepsilon_{0} F d^{2}}{e^{2}}$
b) $\sqrt{\frac{4 \pi \varepsilon_{0} F e^{2}}{a^{2}}}$
c) $\sqrt{\frac{4 \pi \varepsilon_{0} F d^{2}}{e^{2}}}$
d) $\frac{4 \pi \varepsilon_{0} F d^{2}}{q^{2}}$
11. A square surface of side $L$ meter in the plane of the paper is placed in a uniform electric field E (volt/m) acting along the same plane at an angle $\theta$ with the horizontal side of the square as shown in figure. The electric flux linked to the surface, in units of is
a) $E L^{2}$
b) $E L^{2} \cos \theta$
c) $E L^{2} \sin \theta$
d) Zero
12. A series combination of $n_{1}$ capacitors, each of value $C_{1}$, is charged by a source of potential difference 4 V . When another parallel combination of $\mathbf{n}_{\mathbf{2}}$ capacitors, each of value $C_{2}$, is charged by a source of potential difference V , it has the same (total) energy stored in it, as the first combination has. The value of $\mathrm{C}_{2}$, in terms of $\mathrm{C}_{1}$, is then
a) $\frac{2 C_{1}}{n_{1} n_{2}}$
b) $16 \frac{n_{2}}{n_{1}} C_{1}$
c) $2 \frac{n_{2}}{n_{1}} C_{1}$
d) $\frac{16 C_{1}}{n_{1} n_{2}}$
13. Two parallel metal plates having charges $+Q$ and $-Q$ face each other at a certain distance between them. If the plates are now dipped in kerosene oil tank, the electric field between the plates will
a) Become zero
b) Increase
C) Decrease
D) Remain same
14. The electric field at a distance $\frac{3 R}{2}$ from the centre of a charged conducting spherical shell of radius $R$ is $E$. The electric field at a distance $\frac{R}{2}$ from the centre of the sphere is
a) Zero
b) E
c) $\frac{E}{2}$
d) $\frac{E}{3}$

Key

1. a
2. d
3. b

C $3 . \mathrm{c}$
4.b
5.c.
6.d
7.c
$9 . a$
10.c
11.d
12.d
13.c
$14 . \mathrm{a}$

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## Solutions

1. (a) Torque, $\tau=\mathrm{pE} \sin \theta$

Potential energy, $\mathrm{U}=-\mathrm{pE} \cos \theta$
2. (b)


Eight identical cubes are required so that the given charge $q$ appears at the centre of the bigger cube. From Gauss law, the electric flux passing through the given cube is $\phi=\frac{1}{8}\left(\frac{q}{\varepsilon_{0}}\right)=\frac{q}{8 \varepsilon_{0}}$
3. (c)

Capacitance of a parallel plate capacitor is

$$
\begin{equation*}
C=\frac{\varepsilon_{0} A}{d} \tag{i}
\end{equation*}
$$

Potential difference between the plates is

$$
\begin{equation*}
\mathrm{V}=\mathrm{Ed} \tag{ii}
\end{equation*}
$$

The energy stored in the capacitor is

$$
U=\frac{1}{2} C V^{2}=\frac{1}{2}\left(\frac{\varepsilon_{0} A}{d}\right)(E d)^{2} \quad \text { (Using (i) and (ii)) }
$$

$$
=\frac{1}{2} \varepsilon_{0} E^{2} A d
$$

4. 

(b)

When the given metallic spheres are connected by a conducting wire, charge will flow till both the spheres acquire a common potential which is given by Common potential,

$$
\begin{aligned}
V & =\frac{q_{1}+q_{2}}{C_{1}+C_{2}}=\frac{-1 \times 10^{-2}+5 \times 10^{-2}}{4 \pi \varepsilon_{0} R_{1}+4 \pi \varepsilon_{0} R_{2}} \\
& =\frac{4 \times 10^{-2}}{4 \pi \varepsilon_{0} \times 4 \times 10^{-2}}
\end{aligned}
$$

$\therefore$ Final charge on the bigger sphere is
$q_{2}^{\prime}=C_{2} V=4 \pi \varepsilon_{0} R_{2} V$
$=3 \times 10^{-2} \mathrm{C}$
5. (c) According to Gauss's law

$$
\phi_{E}=\frac{Q_{\text {enclused }}}{\varepsilon_{0}}
$$

If the radius of the Gaussian surface is doubled, the outward electric flux will remain the same. This is because electric flux depends only on the charge enclosed by the surface.
6. (d) Capacitance of a parallel plate condenser is

$$
\begin{equation*}
C=\frac{\varepsilon_{0} A}{d} \tag{i}
\end{equation*}
$$

Potential difference across the plates is

$$
\begin{equation*}
\mathrm{V}=\mathrm{Ed} \tag{ii}
\end{equation*}
$$

Energy stored in the condenser is

$$
U=\frac{1}{2} C V^{2}
$$

$$
\begin{aligned}
& =\frac{1}{2}\left(\frac{\varepsilon_{0} A}{d}\right)(E d)^{2} \quad(\text { Using (i) and (ii)) } \\
& =\frac{1}{2} \varepsilon_{0} E^{2} A d
\end{aligned}
$$

7. (c)

A is the midpoint of PS
$\therefore \quad \mathrm{PA}=\mathrm{As}=\mathrm{L}$
$\mathrm{AR}=\mathrm{AQ}=\sqrt{(S R)^{2}+(A S)^{2}}=\sqrt{(2 L)^{2}+(L)^{2}}=L \sqrt{5}$
Electric potential at point A due to the given charge configuration is

$$
\begin{aligned}
& V_{A}=\frac{1}{4 \pi \varepsilon_{0}}\left[\frac{q}{P A}+\frac{q}{A S}+\frac{(-q)}{A Q}+\frac{(-q)}{A R}\right] \\
& =\frac{1}{4 \pi \varepsilon_{0}}\left[\frac{q}{L}+\frac{q}{L}+\frac{(-q)}{L \sqrt{5}}+\frac{(-q)}{L \sqrt{5}}\right] \\
& =\frac{1}{4 \pi \varepsilon_{0}}\left[\frac{2 q}{L}-\frac{2 q}{L \sqrt{5}}\right]=\frac{1}{4 \pi \varepsilon_{0}} \frac{2 q}{L}\left[1-\frac{1}{\sqrt{5}}\right]
\end{aligned}
$$

8. (d)


Given, $\mathrm{AC}=\mathrm{BC}=2 \mathrm{a}$
D and E are the midpoints of BC and AC
$\therefore \mathrm{AE}=\mathrm{EC}=\mathrm{a}$ and $\mathrm{BD}=\mathrm{DC}=\mathrm{a}$
In $\triangle A D C,(A D)^{2}=(A C)^{2}-(D C)^{2}$

$$
\begin{aligned}
& =(21)^{2}-(1)^{2}=4 \mathrm{a}^{2}-\mathrm{a}^{2}=3 \mathrm{a}^{2} \\
& \mathrm{AD}=a \sqrt{3}
\end{aligned}
$$

Similarly, $\mathrm{BE}=a \sqrt{3}$
Potential at point D due to the given charge configuration is

$$
\begin{align*}
V_{D} & =\frac{1}{4 \pi \varepsilon_{0}}\left[\frac{q}{B C}+\frac{q}{D C}+\frac{q}{A D}\right] \\
& =\frac{q}{4 \pi \varepsilon_{0}}\left[\frac{1}{a}+\frac{1}{a}+\frac{1}{\sqrt{3} a}\right]=\frac{q}{4 \pi \varepsilon_{0} a}\left[2+\frac{1}{\sqrt{3}}\right] \tag{i}
\end{align*}
$$

Potential at point E due to the given charge configuration is $V_{E}=\frac{1}{4 \pi \varepsilon_{0}}\left[\frac{q}{A E}+\frac{q}{E C}+\frac{q}{B E}\right]$

$$
\begin{equation*}
=\frac{q}{4 \pi \varepsilon_{0}}\left[\frac{1}{a}+\frac{1}{a}+\frac{1}{a \sqrt{3}}\right]=\frac{q}{4 \pi \varepsilon_{0} a}\left[2+\frac{1}{\sqrt{3}}\right] \tag{ii}
\end{equation*}
$$

From the (i) and (ii), it is clear that

$$
V_{D}=V_{E}
$$

The work done in taking a charge Q and D to E is

$$
\mathrm{W}=\mathrm{Q}\left(\mathrm{~V}_{\mathrm{E}}=\mathrm{V}_{\mathrm{D}}\right)=0
$$

$$
\left(\therefore \mathrm{V}_{\mathrm{D}}=\mathrm{V}_{\mathrm{E}}\right)
$$

9. (1) $\vec{E}=-\vec{\nabla} V$

Where $\vec{\nabla}=\hat{i} \frac{\partial}{\partial x}+\hat{j} \frac{\partial}{\partial y}+\hat{k} \frac{\partial}{\partial z}$
$\therefore \quad \vec{E}=-\left[\hat{i} \frac{\partial V}{\partial x}+\hat{j} \frac{\partial V}{\partial y}+\hat{k} \frac{\partial V}{\partial z}\right]$
Here, $V=4 x^{2}$
$\therefore \quad \vec{E}=-8 x \hat{i}$
The electric field at point $(1,0,2)$ is

$$
\vec{E}_{(1,0,2)}=-8 \hat{i} V m^{-1}
$$

So electric field is along the negative X -axis

10: (c) According to Coulomb's law, the force of repulsion between the two positive ions each of charge $q$, separated by a distance $d$ is given by

$$
F=\frac{1}{4 \pi \varepsilon_{0}} \frac{(q)(q)}{d^{2}}
$$

$$
F=\frac{q^{2}}{4 \pi \varepsilon_{0} d^{2}}
$$

$q^{2}=4 \pi \varepsilon_{0} F d^{2}$
$q=\sqrt{4 \pi \varepsilon_{0} F d^{2}}$
Since, $\mathrm{q}=\mathrm{ne}$
Where,
$\mathrm{n}=$ number of electrons missing from each ion
$e=$ magnitude of charge on electron

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$\therefore n=\frac{q}{e}$
$n=\frac{\sqrt{4 \pi \varepsilon_{0} F d^{2}}}{e}$
$=\frac{\sqrt{4 \pi \varepsilon_{0} F d^{2}}}{e^{2}}$

11: (d) Electric flux $\phi=\bar{E} \cdot \bar{A}=0$. The lines are parallel to the surface

12: d) A series combination of $n_{1}$ capacitors each of capacitance $C_{1}$ are connected to 4 V source as shown in the figure


Total capacitance of the series combination of the capacitors is $\frac{1}{C_{s}}=\frac{1}{C_{1}}+\frac{1}{C_{1}}+\frac{1}{C_{1}}+\ldots .$. up to $\mathrm{n}_{1}$ terms $=\frac{n_{1}}{C_{1}}$

Or $C_{s}=\frac{C_{1}}{n_{1}}$
Total energy stored in a series combination of the capacitors is
$U_{s}=\frac{1}{2} C_{s}(4 V)^{2}=\frac{1}{2}\left(\frac{C_{1}}{n_{1}}\right)(4 V)^{2}$
A parallel combination of $\mathrm{n}_{2}$ capacitors each of capacitance $\mathrm{C}_{2}$ are connected to V source as shown in the figure.


Total capacitance of the parallel combination of capacitors is
$\mathrm{C}_{\mathrm{p}}=\mathrm{C}_{2}+\mathrm{C}_{2}+\ldots$. Upto $\mathrm{n}_{2}$ terms
$\Rightarrow \mathrm{C}_{\mathrm{p}}=\mathrm{n}_{2} \mathrm{C}_{2}$

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Total energy stored in a parallel combination of capacitors is
$U_{p}=\frac{1}{2} C_{P} V^{2}=\frac{1}{2}\left(n_{2} C_{2}\right)(V)^{2}$
According to the given problem,
$\mathrm{U}_{\mathrm{s}}=\mathrm{U}_{\mathrm{p}}$
Equating the values of $\mathrm{U}_{\mathrm{s}}$ and $\mathrm{U}_{\mathrm{p}}$
$\frac{1}{2} \frac{C_{1}}{n_{1}}(4 V)^{2}=\frac{1}{2}\left(n_{2} C_{2}\right)(V)^{2}$
Or $\frac{C_{1} 16}{n_{1}}=\left(n_{2} C_{2}\right)$ or $C_{2}=\frac{16 C_{1}}{n_{1} n_{2}}$
13. (c) in vaccum electric field between two parallel plates

$$
E=\frac{\sigma}{\varepsilon_{0}}
$$

In medium of dielectric constant K

$$
E^{1}=\frac{\sigma}{\varepsilon_{0} k}
$$

For kerosene oil $\mathrm{k}>1=>\mathrm{E}^{1}<\mathrm{E}$
14: (a) Electric field inside charged conductor is always zero

