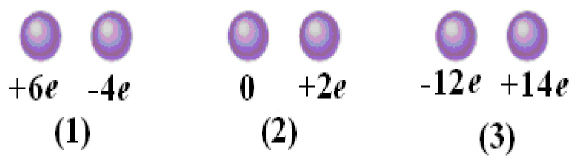
**Q1.**

**Figure 1** shows three pairs of identical conducting spheres that are to be touched together and then separated. The initial charges on them before the touch are indicated. Rank the pairs according to the magnitude of the charge transferred during touching, **greatest first**?

A) 3, 1, 2
B) 1, 2, 3
C) 2, 1, 3
D) 3, 2, 1
E) 2, 3, 1

Figure 1




**Ans:**

(1) $Q_f = \frac{6-4}{2} = +1e$ (2) $Q_f = \frac{0+2e}{2} = +1e$ (3) $Q_f = \frac{-12e+14e}{2} = +1e$

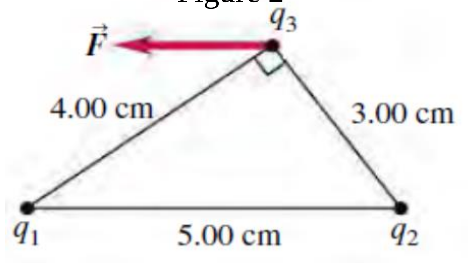
$\Delta e = +5e$ $\Delta e = +1e$ $\Delta e = +13e$

= 3, 1, 2

**Q2.**

Three point charges are placed as shown in **Figure 2.** The magnitude of $q_1$ is 5.00 μC but its sign is not known. The charge $q_2$ is not known while charge $q_3$ is +7.00 μC. The net force $\vec{F}$ on $q_3$ is in the negative $x$-direction. Calculate the magnitudes of $q_2$ and the force $\vec{F}$, respectively?

Figure 2




A) 2.11 μC , 246 N
B) 1.22 μC , 164 N
C) 5.51 μC , 291 N
D) 3.65 μC , 462 N
E) 3.05 μC , 299 N

**Ans:**

Since F is towards left, $q_3$ is +ve, $q_1$ is –ve and $q_2$ is +ve

$$\theta_1 = \frac{3}{5}; \quad \theta_2 = \frac{4}{5}$$

$$F_y = 0 = kq_3\left(\frac{q_2}{(0.03)^2}\times\sin\theta_2 - \frac{q_1}{(0.04)^2}\times\sin\theta_1\right) = 0$$

$$q_2 = q_1\times\left(\frac{0.03}{0.04}\right)^2\times\frac{\sin\theta_1}{\sin\theta_2} = 5\times10^{-6}\times\left(\frac{0.03}{0.04}\right)^2\times\frac{3/5}{4/5}$$

$$q_2 = 2.109\times10^{-6}\ \text{C}$$

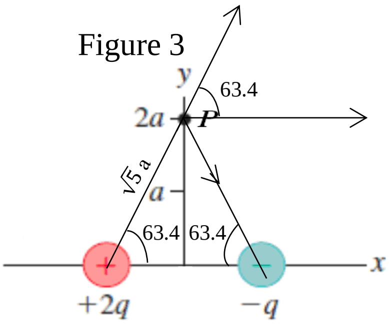
$$|F| = kq_3\left[\frac{q_2}{(0.03)^2}\cos\theta_2 + \frac{q_1}{(0.04)^2}\cos\theta_1\right]$$

$$= 9\times10^9\times7\times10^{-6}\left[\frac{2.109}{(0.03)^2}\times\frac{3}{5} + \frac{5}{(0.04)^2}\times\frac{4}{5}\right]\times\pi = 246.12\ \text{N}$$

**Q3.**

Charges $-q$ and $+2q$ in **Figure 3** are located at $x = \pm a$. If q = 5.00 pC and $a$ = 10.0 cm, find the magnitude of the net electric field at point ***P*** due to these charges.

Figure 3




A) 1.45 N/C
B) 1.01 N/C
C) 2.55 N/C
D) 3.05 N/C
E) 4.45 N/C

**Ans:**

$$E_x = \frac{k\times(2q+q)}{5a^2}\times\cos\ 63.4 = \frac{9\times10^9\times3\times5\times10^{-12}}{5\times(0.1)^2}\times\cos\ 63.4 = 1.209\ \text{N/C}$$

$$E_y = \frac{k\times(2q-q)}{5a^2}\times\sin\ 63.4 = \frac{9\times10^9\times5\times10^{-12}}{5\times(0.1)^2}\times\sin\ 63.4 = 0.805\ \text{N/C}$$

$$|E| = \sqrt{E_x^2+E_y^2} = \sqrt{(1.209)^2+(0.805)^2} = 1.4523\ \text{N/C}$$

---

**Q4.**

A proton moving with a velocity $\vec{v}$ =3.80×10$^6$ m/s $\hat{i}$ enters a region ($x\geq 0$) containing a uniform electric field $\vec{E}$ = – 5.60×10$^4$ N/C $\hat{i}$ . How far will the proton travel in this region before it momentarily stops?

A) 1.35 m
B) 0.221 m
C) 0.562 m
D) 2.42 m
E) 0.770 m

**Ans:**

$$a = \frac{qE}{m_p} = \frac{1.6\times10^{-19}\times(-5.6\times10^4)}{1.67\times10^{-27}} = -5.365\times10^{12}\ \text{m/s}$$

$$X = \frac{v_f^2 - v_i^2}{2a} = \frac{-v_i^2}{2a} = \frac{-(3.80\times10^6)^2}{2\times(-5.365\times10^{12})} = 1.346\ \text{m}$$

---

**Q5.**

An electric dipole with dipole moment of magnitude 25.0 nC.m makes an angle of 30.0° with a uniform electric field of strength 4.00 × $10^6$ N/C. Find the work done by an external agent to rotate the dipole until it is antiparallel to the field.

A) $1.87\times10^{-1}$ J
B) $1.00\times10^{-1}$ J
C) $4.55\times10^{-1}$ J
D) $6.33\times10^{-1}$ J
E) $9.81\times10^{-1}$ J

**Ans:**

$$W_{app} = U_f - U_i = pE\left(-\cos\theta_f + \cos\theta_i\right)$$

$$= 25\times10^{-9}\times4\times10^{6}\left(-\cos180° + \cos30°\right) = 0.1866 \text{ J} = 1.87\times10^{-1} \text{ J}$$

---

**Q6.**

A spherical conducting shell has a net charge of $+12\times10^{-6}$ C. If a point charge q = $-5.0\times10^{-6}$ C is placed inside the spherical shell, find the charges on the inside and outside surfaces of the conducting shell, respectively?

A) $+5.0\times10^{-6}$ C , $+7.0\times10^{-6}$ C
B) $+5.0\times10^{-6}$ C , $-7.0\times10^{-6}$ C
C) $+7.0\times10^{-6}$ C , $+5.0\times10^{-6}$ C
D) $-7.0\times10^{-6}$ C , $+7.0\times10^{-6}$ C
E) $+8.0\times10^{-6}$ C , $+8.0\times10^{-6}$ C

**Ans:**

$$q_{in-shell} = -(q) = -\left(-5\times10^{-6}\right) = 5\times10^{-6} \text{ C}$$

$$q_{out-shell} = q_{net} - q_{in-shell} = +12\times10^{-6} - 5\times10^{-6} \text{ C}$$

$$q_{in-shell} = +7\times10^{-6} \text{ C}$$

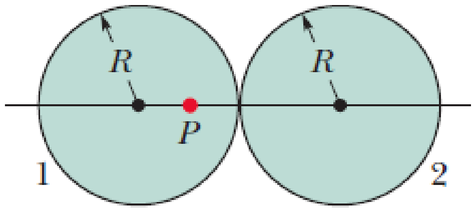
---

**Q7.**

**Figure 4** shows, in cross section, two solid insulating spheres with uniformly distributed charge throughout their volumes. Each sphere has radius R=0.600 m. Point *P* lies on a line connecting the centers of the spheres, at radial distance *R*/2 from the center of sphere 1 which carries a charge $q_1$=40.0 μC . If the net electric field at point *P* is zero, what is the charge $q_2$ on the sphere 2?

A) 45.0 μC
B) 20.8 μC
C) 11.5 μC
D) 49.5 μC
E) 40.0 μC

Figure 4




**Ans:**

At P, $|E_1| = |E_2|$

$$\frac{kq_1}{R^3} \cdot \frac{R}{2} = \frac{kq_2}{\left(\frac{3R}{2}\right)^2}$$

$$\frac{q_1}{2R^2} = \frac{4q_2}{9R^2} \Rightarrow q_2 = \frac{9}{8}q_1 = \frac{9}{8} \times 40 \times 10^{-6} = 45 \times 10^{-6}\,\text{C}$$

---

**Q8.**

An infinitely long insulating solid rod with 4.5 cm radius carries a uniform volume charge density. If the magnitude of the electric field at the surface of the rod is 1.6 × $10^4$ N/C, what is the magnitude of the volume charge density of the rod?

A) 6.3 ×$10^{-6}$ C/$m^3$
B) 1.2 ×$10^{-6}$ C/$m^3$
C) 4.3 ×$10^{-6}$ C/$m^3$
D) 5.8 ×$10^{-6}$ C/$m^3$
E) 9.9 ×$10^{-6}$ C/$m^3$

**Ans:**

$$E_R = \frac{2k\lambda}{r} \Rightarrow \lambda = \frac{E_R . r}{2k} = \frac{1.6 \times 10^4 \times 0.045}{2 \times 9 \times 10^9} = 4 \times 10^{-8}\ \text{C/m}$$

$$\lambda = \frac{q}{l} \text{ and } \rho = \frac{q}{\pi r^2 \times l}$$

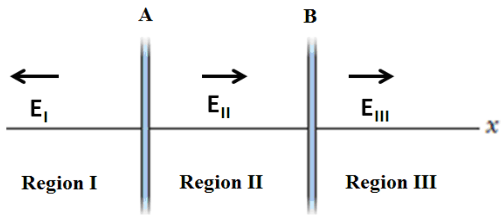
$$\rho = \frac{\lambda}{\pi r^2} = \frac{4 \times 10^{-8}}{\pi \times (0.045)^2} = 6.29 \times 10^{-6}\ \text{C/m}^3$$

---

**Q9.**

Two vertical insulating charged planes A and B with negligible thickness are parallel. The magnitude of the electric field $\vec{E}_I$ in region I is $\frac{3\sigma}{2\varepsilon_o}$ while the magnitude of electric field $\vec{E}_{III}$ in the region III is $\frac{3\sigma}{2\varepsilon_o}$, where $\sigma$ is a positive surface charge density. The magnitude of electric field $\vec{E}_{II}$ in the region II is $\frac{\sigma}{2\varepsilon_o}$, **Figure 5** shows the **directions** of the electric field in each of the regions. Determine the surface charge density on planes A and B, respectively.

Figure 5




A) $2\sigma, \sigma$

B) $\frac{-\sigma}{2}, \sigma$

C) $\frac{+\sigma}{2}, \sigma$

D) $\sigma, \frac{-\sigma}{2}$

E) $\sigma, \frac{+\sigma}{2}$

**Ans:**

In the region II

$$\frac{\sigma_A}{2\varepsilon_0} - \frac{\sigma_B}{2\varepsilon_0} = \frac{\sigma}{2\varepsilon_0}$$

$$\sigma_A - \sigma_B = \sigma \quad \rightarrow (1)$$

In the region III

$$\frac{\sigma_A}{2\varepsilon_0} + \frac{\sigma_B}{2\varepsilon_0} = \frac{3\sigma}{2\varepsilon_0}$$

$$\sigma_A + \sigma_B = 3\sigma \quad \rightarrow (2)$$

*From* (1) and (2) we have

$\sigma_A = 2\sigma$

$\sigma_B = \sigma$

**Q10.**

An electron is released from rest between the plates of a charged parallel-plate capacitor very close to the negative plate. Just as it reaches the positively charged plate, its speed is *v*. If the distance between the capacitor plates was reduced to half without changing the electric potential difference between them, then the speed of the electron when it reaches the positive plate would be

A) $v$
B) $\left(\frac{2}{3}\right)v$
C) $\left(\sqrt{2}\right)v$
D) $\left(\frac{1}{\sqrt{2}}\right)v$
E) $\left(\frac{1}{2}\right)v$

**Ans:**

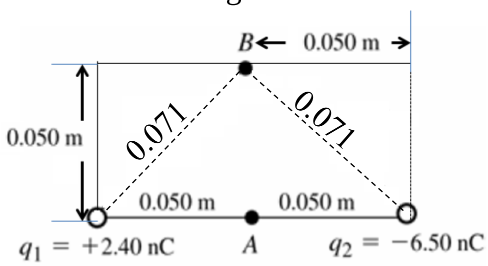
$\Delta K = -q\Delta V,\ \Delta K = 0 \text{ since } \Delta V = 0$

---

**Q11.**

Two point charges $q_1$=+2.40 nC and $q_2$= −6.50 nC, separated by 0.100 m, are located at two corners of a rectangle. Point A is midway between them; while point B is located on the opposite side of the rectangle, as shown in **Figure 6.** If the work done by the electric field of both charges on a third charge Q in moving it from point B to point A is $5.25 \times 10^{-4}$ J, what is the magnitude of the charge Q? Take the electrical potential to be zero at infinity.

Figure 6




A) $2.43 \times 10^{-6}$ C
B) $1.00 \times 10^{-6}$ C
C) $3.52 \times 10^{-6}$ C
D) $7.20 \times 10^{-6}$ C
E) $9.05 \times 10^{-6}$ C

**Ans:**

$$V_A = \frac{k}{0.05}(q_1 + q_2) = \frac{9\times10^9}{0.05}[2.4 - 6.5]\times10^{-9} = -738\ \text{V}$$

$$V_B = \frac{k}{0.071}(q_1 + q_2) = \frac{9\times10^9}{0.07}[2.4 - 6.5]\times10^{-9} = -521.8\ \text{V}$$

$$W_E = 5.25\times10^{-4} = -q(V_A - V_B) = q(-738 + 521.8)$$

$$q = \frac{5.25\times10^{-4}}{-738 + 521.8} = 2.428\times10^{-6}\ \text{C}$$

---

**Q12.**

A proton is fired from infinity directly towards a fixed point charge $q = 1.28 \times 10^{-16}$ C. If the initial speed of the proton is $2.40 \times 10^5$ m/s, what is the distance of closest approach of the proton to the fixed charge? (Assume the potential energy of the proton is zero at infinity).

A) $3.83 \times 10^{-9}$ m
B) $1.10 \times 10^{-9}$ m
C) $2.22 \times 10^{-9}$ m
D) $2.81 \times 10^{-9}$ m
E) $3.00 \times 10^{-9}$ m

**Ans:**

$$K_i + U_i = K_f + U_f \quad \Rightarrow K_i = U_f \left(K_f = U_i = 0\right)$$

$$U_f = \frac{kq_p.q}{d} = \frac{1}{2} m_p.v_p^2$$

$$d = \frac{2kq_p.q}{m_p.v_p^2} = \frac{2 \times 9 \times 10^9 \times 1.6 \times 10^{-19} \times 1.28 \times 10^{-16}}{\left(1.67 \times 10^{-27}\right) \times \left(2.4 \times 10^5\right)^2} = 3.832 \times 10^{-9}\, m$$

---

**Q13.**

In a certain region of space, the electric potential is given by $V(x,y)=5xy - 12x^2 + 5y$, where x, and y are in meters. Which set of coordinates (x, y) corresponds to a point where the electric field is zero?

A) x = −1.0 m, y = −4.8 m
B) x = −1.5 m, y = −3.5 m
C) x = −3.5 m, y = −3.5 m
D) x = +4.8 m, y = −1.8 m
E) x = −5.3 m, y = −3.8 m

**Ans:**

$$E_x = -\frac{\partial V}{\partial x} = -5y + 24x = 0 \cdots\cdots\cdots\cdots (1)$$

$$E_y = -\frac{\partial V}{\partial y} = -5x - 5 = 0 \Rightarrow x = -1.0\, m \cdots\cdots\cdots (2)$$

$$From\ (1), y = -\frac{24x}{5} = -\frac{24}{5} = -4.8 \text{ m}$$

$$x = -1.0 \text{ m} ;\ \text{y} = -4.8 \text{ m}$$

---

**Q14.**

Two parallel-plate capacitors, 6.0 μF each, are connected in series to a 10 V battery. Then, the plate separation of one of these capacitors is reduced to half while it is still connected with the other capacitor and the battery. How much charge is now stored in the equivalent capacitor.

A) 40 μC
B) 25 μC
C) 20 μC
D) 11 μC
E) 34 μC

**Ans:**

$$C_1 = 6.0\ \mu F = \frac{\varepsilon_0 A}{d};\ C_2 = \frac{\varepsilon_0 A}{d/2} = 2.\frac{\varepsilon_0 A}{d} = 2 \times 6 = 12\ \mu\text{F}$$

$C_1$ *and* $C_2$ *in* series

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \left(\frac{6 \times 12}{6 + 12}\right) 10^{-6} = 4 \mu F$$

$$q_{eq} = C_{eq} \times V = 4 \times 10^{-6} \times 10 = 40 \times 10^{-6} C$$

---

**Q15.**

Initially, a capacitor $C_1$ is connected to a battery of potential difference V. Then a second capacitor $C_2$ ($\boldsymbol{C_2 > C_1}$) is added in series. Does the charge $q_1$ and voltage $V_1$ on $C_1$ now increase, decrease or remains constant as compared to their initial values?

A) $q_1$ decreases, $V_1$ decreases
B) $q_1$ remains constant, $V_1$ remains constant
C) $q_1$ increases, $V_1$ increases
D) $q_1$ increases, $V_1$ decreases
E) $q_1$ decreases, $V_1$ increases

**Ans:**

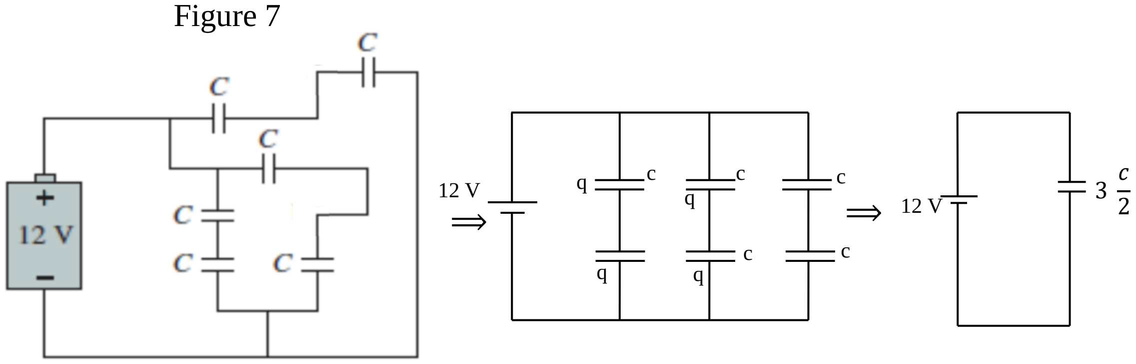
A

---

**Q16.**

A total of $1.1\times10^{-4}$ J of energy is stored in six identical capacitors each with capacitance $C$ and connected as shown in **Figure 7**. How much charge is stored in each capacitor?

Figure 7




A) $6.1\times10^{-6}$ C
B) $1.3\times10^{-6}$ C
C) $2.0\times10^{-6}$ C
D) $3.3\times10^{-6}$ C
E) $9.5\times10^{-6}$ C

**Ans:**

$$U=\frac{1}{2}C_{eq}V^2=\frac{1}{2}\times3\times\frac{C}{2}\times(12)^2=1.1\times10^{-4}\,\text{J}$$

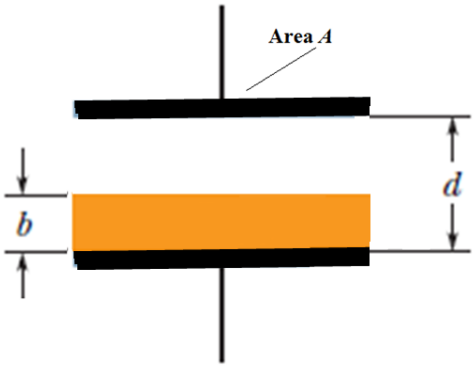
$$C=\frac{1.1\times10^{-4}\times4}{3\times144}=1.0185\times10^{-6}\,\text{F}$$

$$q=\frac{C}{2}\times V=\frac{1.0185\times10^{-6}}{2}\times12=6.11\times10^{-6}\,\text{C}$$

**Q17.**

A dielectric slab of thickness $b$ = 0.3 cm and dielectric constant κ = 5.0 is inserted between the plates of a parallel plate capacitor having plate area $A$ = 0.5 m$^2$ and plate separation $d$ = 0.5 cm, as shown in **Figure 8**. What is the capacitance of this capacitor?

Figure 8




A) $1.7\times10^{-9}$ F
B) $1.0\times10^{-9}$ F
C) $1.2\times10^{-9}$ F
D) $1.4\times10^{-9}$ F
E) $2.5\times10^{-9}$ F

**Ans:**

$$C_1 = \frac{\varepsilon_0 A}{d-b} \;;C_k = \frac{\kappa\varepsilon_0 A}{d-b}$$

$$C_{eq} = \frac{C_1 C_k}{C_1 + C_k} = \frac{\left(\frac{\varepsilon_0 A}{d-b}\right)\times\frac{\kappa\varepsilon_0 A}{b}}{\frac{\varepsilon_0 A}{d-b}+\frac{\kappa\varepsilon_0 A}{b}}$$

$$= \frac{\varepsilon_0 A\kappa}{b+k(d-b)} = \frac{8.85\times10^{-12}\times0.5\times5}{\left(3+5(5-3)\right)\times10^{-3}} = 1.702\times10^{-9}\,\text{F}$$

---

**Q18.**

A uniform cylindrical copper wire has to be manufactured out of 1.00 g of copper. If the wire is to have a resistance R= 0.500Ω, what will be the length of the wire? (mass density $D_{cu}$ = 8.94 × 10$^3$ kg/m$^3$; electrical resistivity $\rho_{cu}$ = 1.70 × 10$^{-8}$ Ω.m)

A) 1.81 m
B) 0.330 m
C) 0.476 m
D) 0.880 m
E) 1.55 m

**Ans:**

$$\rho_{cu} = \frac{RA}{l} \;; D_{cu} = \frac{m}{Al}$$ , where A is the cross sectional area

$$A = \frac{l.\rho_{cu}}{R} = \frac{m}{\rho_{cu}\times l} \Rightarrow l^2 = \frac{mR}{\rho_{cu}\times D_{cu}}$$

$$l = \sqrt{\frac{mR}{\rho_{cu}\times D_{cu}}} = \frac{10^{-3}\times0.5}{1.7\times10^{-8}\times8.94\times10^{3}} = 1.81\text{ m}$$

---

**Q19.**

If the drift velocity of free electrons in a copper wire is $7.84 \times 10^{-4}$ m/s, what is the electric field in the conductor ($n = 8.49 \times 10^{28}$ electrons /m$^3$; electrical resistivity $\rho_{cu} = 1.70 \times 10^{-8}$ Ω.m)

A) 0.181 V/m
B) 0.432 V/m
C) 1.55 V/m
D) 3.03 V/m
E) 5.35 V/m

**Ans:**

$$E = \rho J = \rho n q v_d$$

$$E = 1.70 \times 10^{-8} \times 8.49 \times 10^{28} \times 1.6 \times 10^{-19} \times 7.84 \times 10^{-4} = 0.181 \text{ V/m}$$

---

**Q20.**

What is the required resistance of a heater that increases the temperature of 1.50 kg of water from 10.0 °C to 50.0 °C in 10.0 min while operating at 110 V?
(Specific heat of water = 4190 J/kg.K)

A) 28.9 Ω
B) 11.3 Ω
C) 15.9 Ω
D) 18.0 Ω
E) 21.2 Ω

**Ans:**

$$P = \frac{\Delta Q}{\Delta t} = \frac{mc\Delta T}{\Delta t} = \frac{1.5 \times 4190 \times 40}{10 \times 60} = 419 \text{ J/S}$$

$$P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{R} = \frac{(110)^2}{419} = 28.88\ \Omega$$

---

$$F = k\frac{q_1 q_2}{r^2}$$

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}} = m\vec{\mathbf{a}}$$

$$U = -\vec{\mathbf{p}}.\vec{\mathbf{E}}$$

$$\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}}\times\vec{\mathbf{E}}$$

$$\Phi = \int_{Surface} \vec{\mathbf{E}}.d\vec{\mathbf{A}}$$

$$\Phi_c = \oint \vec{\mathbf{E}}.d\vec{\mathbf{A}} = \frac{q_{in}}{\varepsilon_0}$$

$$E = \frac{\sigma}{2\varepsilon_o} \quad \text{(sheet of charge)}$$

$$E = \frac{\sigma}{\varepsilon_o} \quad \text{(conducting surface)}$$

$$E = k\frac{q}{r^2}$$

$$E = k\frac{q}{R^3}r$$

$$E = \frac{2k\lambda}{r}$$

$$\Delta V = V_B - V_A = -\int_A^B \vec{\mathbf{E}}.d\vec{\mathbf{S}} = \frac{\Delta U}{q_0}$$

$$V = k\frac{q}{r} \quad , \quad V = \sum_{i=1}^{N}\frac{kq_i}{r_i}$$

$$E_x = -\frac{\partial V}{\partial x}, \quad E_y = -\frac{\partial V}{\partial y}, \quad E_z = -\frac{\partial V}{\partial z}$$

$$U = k\frac{q_1 q_2}{r_{12}}$$

$$\Delta U = -W$$

$$Q = mc\Delta T$$

$$C = \frac{q}{V}$$

$$C = \kappa C_{air}$$

$$C_{air} = \frac{\varepsilon_o A}{d}$$

$$U = \frac{1}{2}CV^2$$

$$u = \frac{1}{2}\varepsilon_o E^2$$

$$I = \frac{dQ}{dt} = JA$$

$$R = \frac{V}{I} = \rho\frac{L}{A}$$

$$J = nev_d$$

$$J = \sigma E$$

$$\rho = \rho_0\,[1 + \alpha(T - T_0)]$$

$$P = IV$$

$v = v_o + at$

$$x - x_o = v_o t + \frac{1}{2}a t^2$$

$v^2 = v_o^2 + 2a(x - x_o)$

Volume of a sphere = $\frac{4}{3}\pi r^3$

**Constants:**

$g = 9.8$ m/s$^2$

$k = 9.00 \times 10^9$ N.m$^2$/C$^2$

$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2$/N.m$^2$

$e = 1.60 \times 10^{-19}$ C

$m_e = 9.11 \times 10^{-31}$ kg

$m_p = 1.67 \times 10^{-27}$ kg

$c_w = 4190$ J/kg.K

m = milli = $10^{-3}$

μ = micro = $10^{-6}$

n = nano = $10^{-9}$

p = pico = $10^{-12}$

k = kilo = $10^3$

M = mega = $10^6$