Phys2-01 Coulomb Force,E field, Gauss Law

Thursday, June 9, 2022 1:24 PM

⇒ Physics 2: Electricity & Magnetism * Young & Friedmann vol II

Source ⇒ * Serway
* Bekir Karaoglu
* Feynmann Lecture Notes

Youtube / OCW – mit

⇒ Exams ↳ midterm }?? 30 – 35
→ final 50 – 60
+
? = HW 10 – 15

- { Coulomb Law
  Electrostatic Force
- Electric field
- Gauss Law
- Electric potential
- Capacitors
- OHM's Law
  (Kirchoff)
- RC circuits
- Magnetic fields, magnetic force ≈ Rotation
- RLC circuits ; AA . . .
  ↳ (circuit analysis)

[for DK
look into saving / sharing video]

Electricity & Magnetism ⇒ Electro Magnetic Theory
↳ maxwell eqn ⇒ LIGHT ≡ EM wave

Electrostatic
(durgun)
charge
charges are stationary

$\oplus q$
$\langle \vec{v} \rangle = 0$ ~ average

{ Newton eqn $\Sigma \vec{F} = m\vec{a}$ Phys I — [m] a = ? v = ? Δ = ? K = ? W = ? P = ... }

* Electrodynamics ⇒ I = current
↳ $\oplus$ $\ominus$ move with acceleration $\vec{a}$ ⇒ create EM wave = LIGHT
+q −q
not included

wire: $\ominus \to v$, $\ominus \to v$

→ I +q →

EM Theory

CHARGE ⇒ elementary charge

$\ominus$ electron $e^- = q_e$
$\oplus$ proton $q_p = -e^- = -q_e$
$\odot$ neutron $q_n = 0$

(P, n) e⁻ cloud ↳ quantum physics

SI units = 7

- mass kg
- time s
- length m } Phys I ✓
- Phys II: current (Ampere, A) ⇒ $\frac{\text{charge}}{\text{time}}$ = current ⇒ A s = charge
- temp (kelvin)
- N_A (avogadro)
- Brightness (cd)

$q_{e^-} = -1.6 \times 10^{-19}\,C$ (C = coulomb) ; [C = A s]

$q_p = +1.6 \times 10^{-19}\,C$

$q_n = 0$

$\Rightarrow$

$R_{nucleus} \sim 10^{-15} m$

$R_{atom} \sim 10^{-10} m \sim 0.1 nm \sim 1 Å$

How full an atom is =

$$\frac{V_{nucleus}}{V_{atom}} = \frac{\frac{4}{3}\pi R_{nuc}^3}{\frac{4}{3}\pi R_{atom}^3} \sim \frac{(10^{-15})^3}{(10^{-10})^3}$$

$$= 10^{-45+30} = 10^{-15} \equiv \text{FULL}$$

0.000000000000001 FULL

99.9999999999999 % EMPTY $\Rightarrow$ FULL? EMPTY?

(BOŞLUK) VOID? VACUUM

≈ 0 FULL $\simeq$ EMPTY inside

materials $\equiv$ atoms (e^-, p, n ...)

%5 $\equiv$ materials (e^-, p, n ...)

95% dark energy, dark matter ??

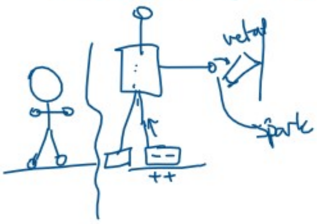
electron $\begin{cases} q_e = -1.6 \times 10^{-19} C \\ m_e = 9 \times 10^{-31} kg \sim 10^{-30} kg \end{cases}$

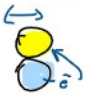
$m_e = 9 \times 10^{-31} kg$

$m_p \cong m_n \simeq 1.6 \times 10^{-27} kg$

$m_p \gg m_e$

RUBBING (sürtünme)   electron in Greek amber (kehribar)





$\Sigma q = 0$

$\Sigma q = 0$

(+) $\equiv$ given an e^-

(−) $\equiv$ taken " e^-

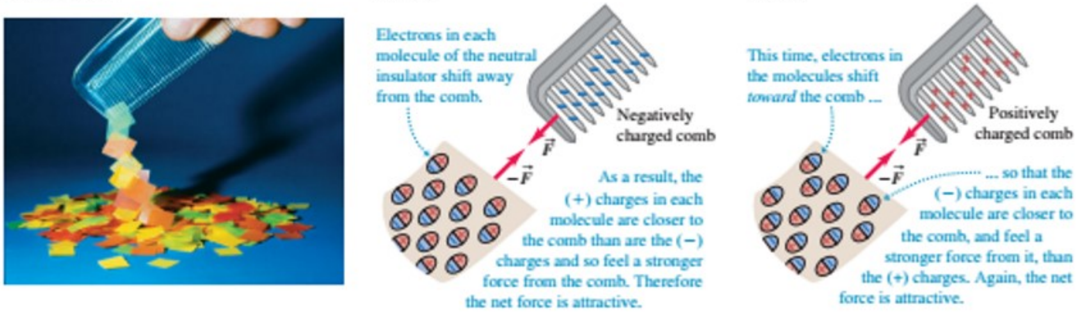
Depremlerde ışık $\Rightarrow$ sürtünme

21.8 The charges within the molecules of an insulating material can shift slightly. As a result, a comb with either sign of charge attracts a neutral insulator. By Newton's third law the neutral insulator exerts an equal-magnitude attractive force on the comb.

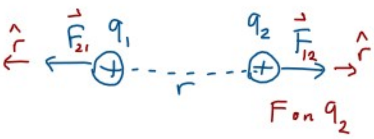
(a) A charged comb picking up uncharged pieces of plastic

(b) How a negatively charged comb attracts an insulator

(c) How a positively charged comb attracts an insulator



Electrostatic Force b/w two charges.



$$\vec{F} = k \frac{q_1 q_2}{r^2} \hat{r} \quad \text{(Coulomb's Law)}$$

$$\vec{F}_{12} = -\vec{F}_{21} \quad \text{(Newton's 3rd Law} \equiv \text{action-reaction)}$$

$k = 8.98 \times 10^9 \frac{Nm^2}{C^2} \simeq 9 \times 10^9 Nm^2/C^2 = k$ Coulomb Const.

$$k = \frac{F r^2}{q^2} = \left[\frac{Nm^2}{C^2}\right]$$

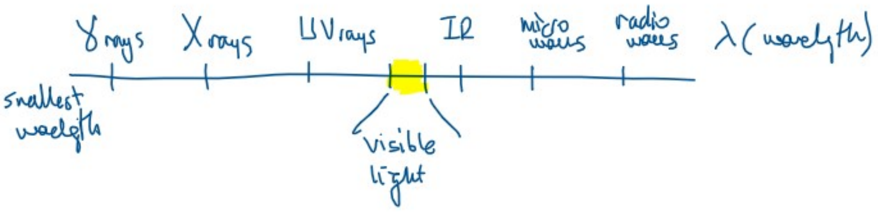
$$k = \frac{1}{4\pi\varepsilon_0}$$; $\varepsilon_0 \equiv$ Electric permittivity of space (elektrik geçirgenlik)

$$\boxed{\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}}$$

$\mu_0 =$ Magnetic permeability " " $= 4\pi \times 10^{-7} (\ldots)$ (manyetik geçirgenlik)

$$\left\{ \underbrace{C}_{\text{speed of light}} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \right\}$$

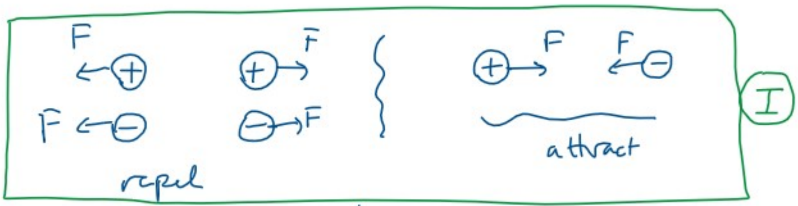
LIGHT is EM wave



} EM waves ⊆

accelerating charges create EM waves

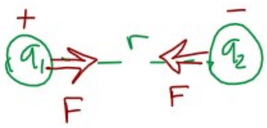
$$F = k \frac{q_1 q_2}{r^2}$$



1st find the magnitude of $F = k \frac{|q_1 q_2|}{r^2}$

2nd put direction by relation (I)

ex)



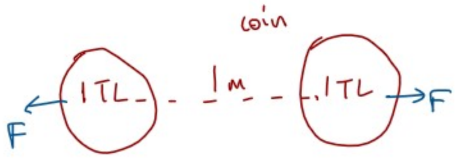
$q_1 = +25\, nC$ $q_2 = -75\, nC$ $r = 3cm$ $k = 9 \times 10^9 \frac{Nm^2}{C^2}$

$\vec{F} = ?$

$$F = 9 \times \cancel{10^9} \frac{(25 \times 10^{-9})(75 \times \cancel{10^{-9}})}{(3 \times 10^{-2})^2} N = 0.019 N$$

$$F = k \frac{q_1 q_2}{r^2} = -0.019N$$

ex)



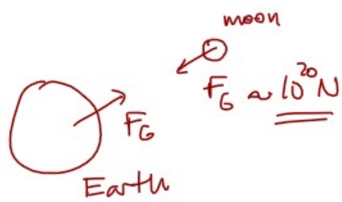
all atom in the coins gain $1e^-$ $F = ?$

$q = ?$ 1 TL ; coin has 1 moles of atom

$$q = (6 \times 10^{23})(-1.6 \times 10^{-19} C) = -9.6 \times 10^4 C \simeq -10^5 C$$

6×10^{23} atoms ← take $1e^-$ each

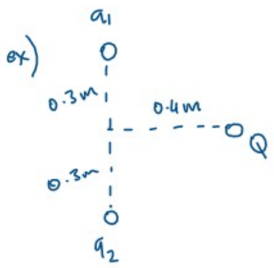
$$F = k \frac{q^2}{r^2} = 9 \times 10^9 \frac{(10^5)^2}{1} = 9 \times 10^{19} \simeq \underline{\underline{10^{20} N}}$$ HUGE force



$q = 10^5 C$ (HUGE amount of charge)

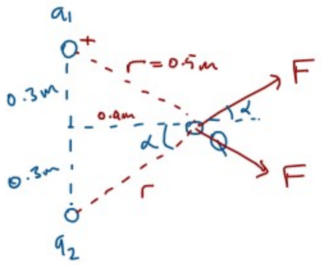
$q \Rightarrow$ in real life $\sim nC \sim 10^{-9} C$
$\sim \mu C \quad 10^{-6} C$
$\underline{\underline{mC}}$

ex)

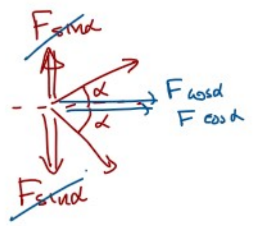


$\Sigma\vec{F}$ on Q = ? $q_1 = q_2 = +2\mu C$

$Q = +4\mu C$



$$F = 9\times10^{9}\,\frac{(2\times10^{-6})(4\times10^{-6})}{(0.5)^2} = 0.29\ N$$



$\Longrightarrow \Sigma\vec{F} \rightarrow \hat{i}$

$\Sigma F = 2F\cos\alpha$

$$\Sigma\vec{F} = 2\,(0.29)\,\frac{4}{5} = 0.46\,N\,\hat{i}$$

ELECTRIC FIELD $= E$

q_1 ① - - - r - - - ② q_2 $\rightarrow \vec{F} = k\,\frac{q_1 q_2}{r^2}\,\hat{r}$

+ +

If you remove q_2; is there something at point r?

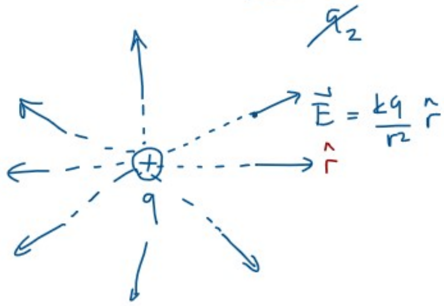
q_1 ① - - - r - - - ? $\rightarrow \vec{E}$

$$\vec{E} = \frac{\vec{F}}{q_2} = \frac{\vec{F}}{q_0} \text{ ~ test charge}$$

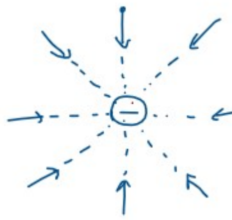
$$\vec{E} = \frac{\vec{F}}{q} \equiv \text{vector}$$

$$\vec{E} = \frac{k\,\frac{q_1 \cancel{q_2}}{r^2}\,\hat{r}}{\cancel{q_2}} = \frac{k q_1}{r^2}\,\hat{r} = \vec{E}$$

$$\vec{E} = \frac{kq}{r^2}\,\hat{r}\ \left[\frac{N}{C}\right]$$



$\vec{E} = \frac{kq}{r^2}\,\hat{r}$



$\vec{E}\ (-\hat{r})$

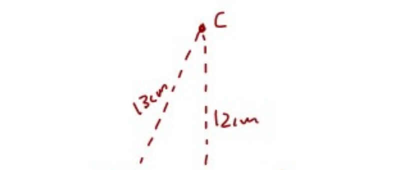
$E = \frac{kq}{r^2}\,\hat{r}$

$= \frac{k(-q)}{r^2}\,\hat{r}$

$\vec{E} = \frac{kq}{r^2}\,(-\hat{r})$

$$E = \frac{F}{q} = \left[\frac{N}{C}\right]$$

Point charges $q_1 = +12$ nC and $q_2 = -12$ nC are 0.100 m apart (Fig. 21.22). (Such pairs of point charges with equal magnitude and opposite sign are called *electric dipoles*.) Compute the electric field caused by q_1, the field caused by q_2, and the total field (a) at point a; (b) at point b; and (c) at point c.



$E = \frac{kq}{r^2}$

$\Sigma\vec{E}_a = ?\quad \vec{E}_1 + \vec{E}_2$

$$E_1 = \frac{9\times10^{9}\,(12\times10^{-9})}{(0.06)^2} = 3\times10^{-4}\ N/C$$

$$E_2 = \frac{9\times10^{9}\,|-12\times10^{-9}|}{(0.04)^2} = 6.8\times10^{-4}\ N/C$$

$$\Sigma\vec{E}_a = 9.8\times10^{-4}\ N/C\ \hat{i}$$

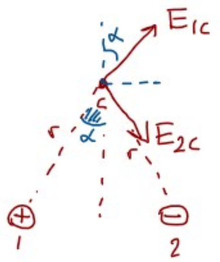
1 ⊕ $\vec{E}_2$ $\vec{E}_1$ ⊖ 2

$\Sigma\vec{E}_b = \vec{E}_{1b} + \vec{E}_{2b} \Rightarrow E_{1b} = 6.8\times10^{-4}\ N/C \quad E_{2b} = \frac{9\times10^{9}\times(12\times10^{-9})}{(0.14)^2} = 0.55\times10^{4}\ N/C$

1 2

$$(0.14)^2$$

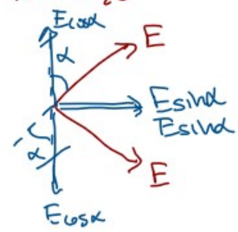
$$\sum \vec{E}_b = (6.80 - 0.55)\times 10^4 \,N/C\, -\hat{i} = \underline{-6.25 \times 10^{-4}}\,\hat{i}\ N/C$$



$$E_{1c} = \frac{9\times10^9\ (12\times10^{-9})}{(0.13)^2}\ N/C = E_{2c} \quad ; r = 0.13m$$

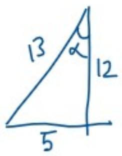
$$E_{1c} = E_{2c} = 6.39 \times 10^{-4}\ N/C = E$$

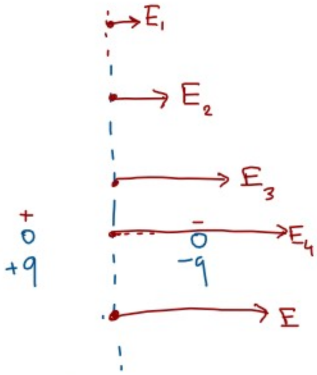
$\sum \vec{E}_c =$



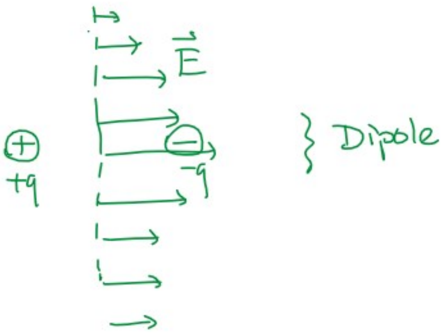
$$\sum \vec{E}_c = 2E\sin\alpha = 2\left(6.39\times10^{4}\right)\frac{5}{13}$$

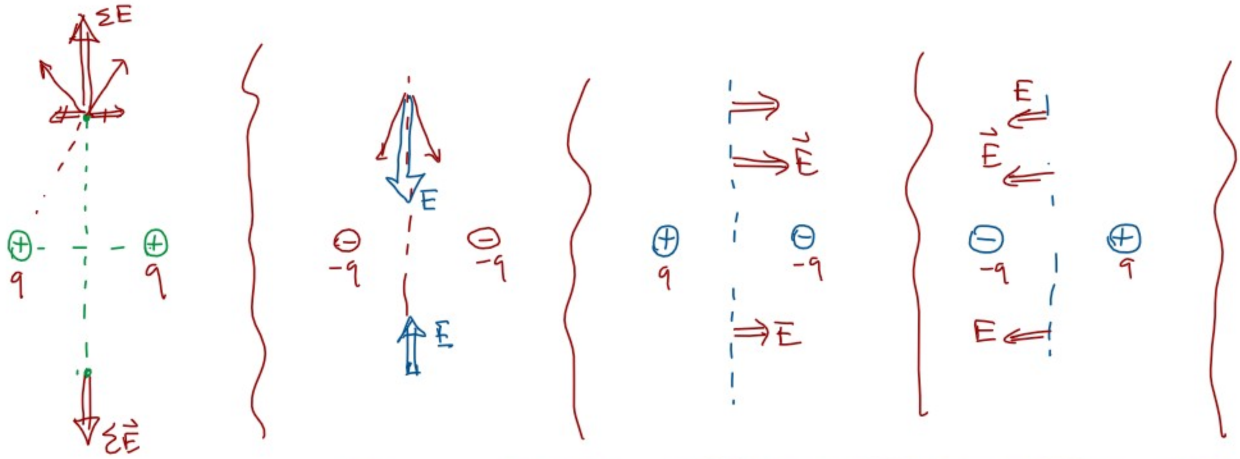
$$\sum \vec{E}_c = 4.9\times10^{-4}\ N/C\ \hat{j}$$





$E_4 > E_3 > E_2 > E_1$

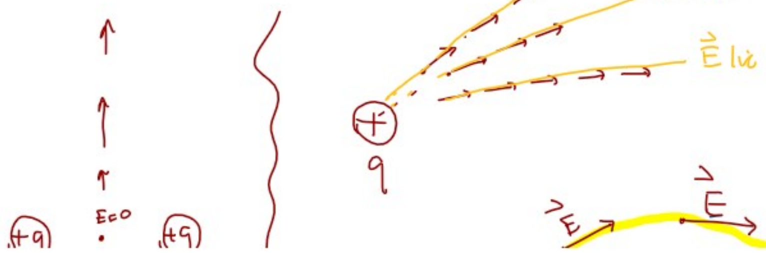




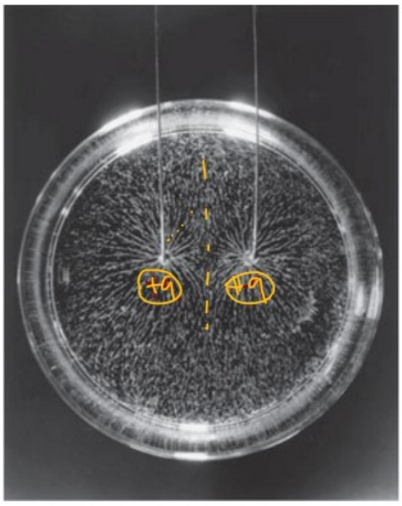
21.29 (a) Electric field lines produced by two equal point charges. The pattern is formed by grass seeds floating on a liquid above two charged wires. Compare this pattern with Fig. 21.28c. (b) The electric field causes polarization of the grass seeds, which in turn causes the seeds to align with the field.

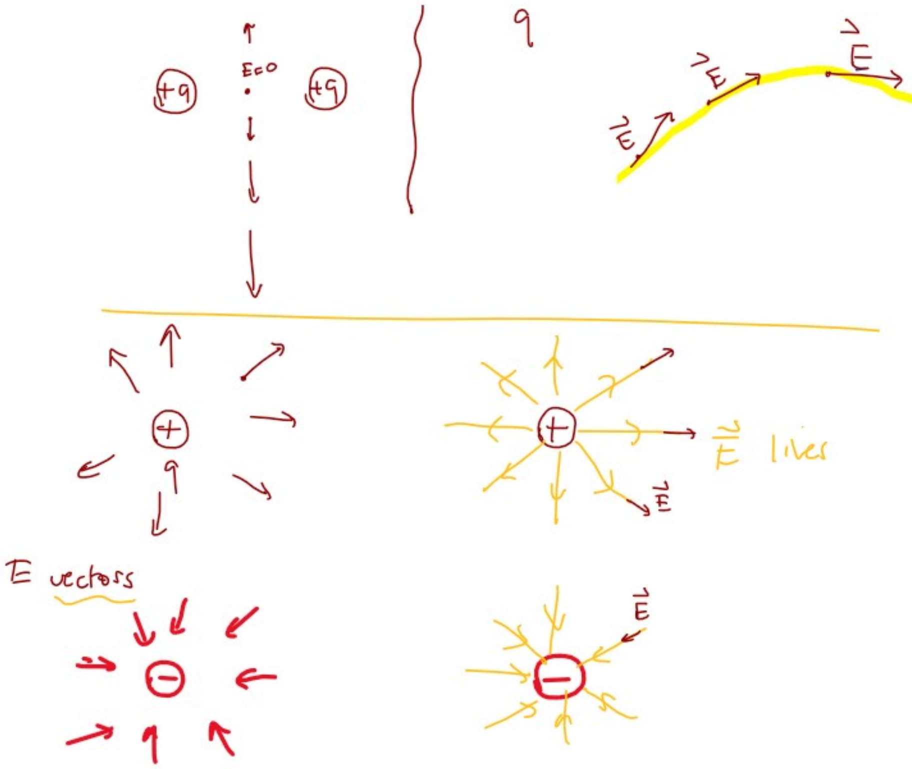
(a)

ELECTRIC FIELD LINES ≡ imaginary lines / curves where $\vec{E}$ vector is tangent to the $\vec{E}$ lines.

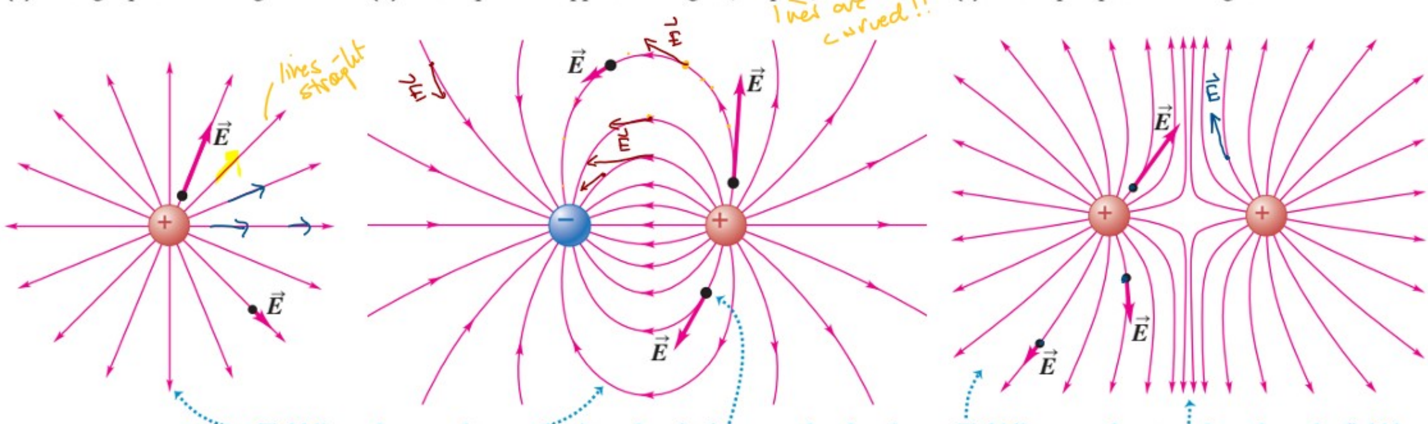


(a)





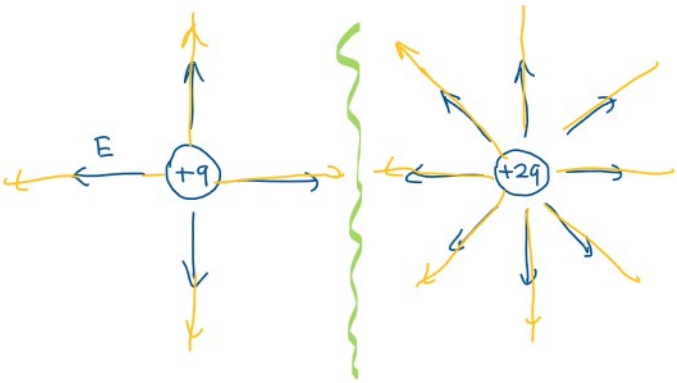
(a) A single positive charge **(b)** Two equal and opposite charges (a dipole) **(c)** Two equal positive charges



Field lines always point *away from* (+) charges and *toward* (−) charges.

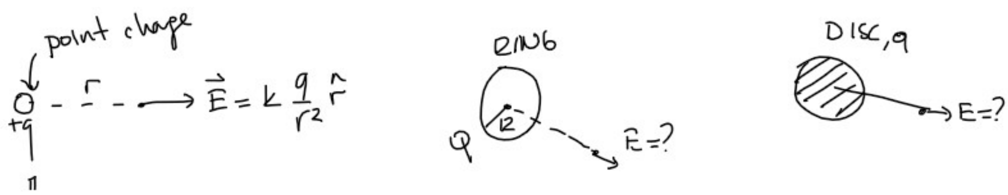
At each point in space, the electric field vector is *tangent* to the field line passing through that point.

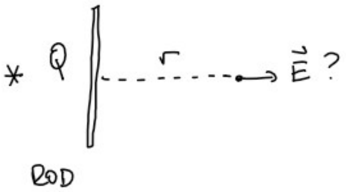
Field lines are close together where the field is strong, farther apart where it is weaker.



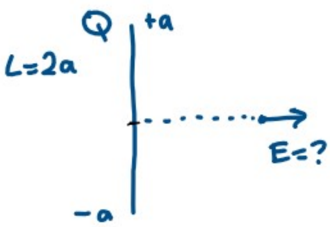
q↑ ; # of $\vec{E}$ vector ↑

of $\vec{E}$ vectors or $\vec{E}$ lines is proportional to the magnitude of charge.





charge is distrubuted on a geometric shape.
integration.

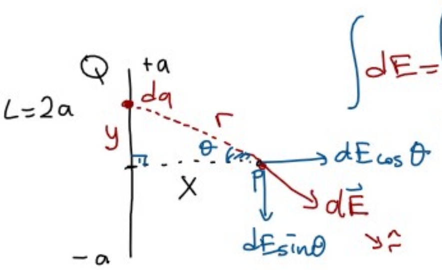


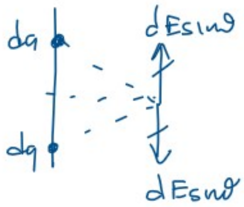
$\vec{E}$ x distance away from its center?

$dq \dashrightarrow \frac{k\,dq}{r^2}$
↳ small

$Q_{total} = \int dq$
Q may depend on space

$$\int dE = \int k \frac{dq}{r^2} = E_p$$





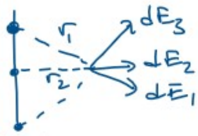
$$\vec{E}_p = \int dE\cos\theta\,\hat{i} + \underbrace{\int dE\sin\theta\,\hat{j}}_{\text{ZERO}}$$

$$E_p = \int dE\cos\theta = \int \frac{k\,dq}{(x^2+y^2)} \frac{x}{(x^2+y^2)^{1/2}}$$

$$= kx \int \frac{dq}{(x^2+y^2)^{3/2}} \;;$$

if you change the location dq on the object will the magnitude / direction of dE change?

YES!

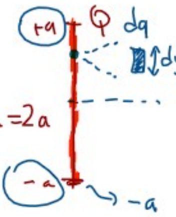


$dE_1 \neq dE_2 \neq dE_3$
q, r are related
$(x^2+y^2)^{1/2}$
q, y related.

$* \quad dq = f(y)$

CHARGE DENSITY = $\frac{\text{charge}}{\text{length}}$ (1D), $\frac{\text{charge}}{\text{area}}$ (2D), $\frac{\text{charge}}{\text{volume}}$ (3D)

ROD → 1 Dim. object



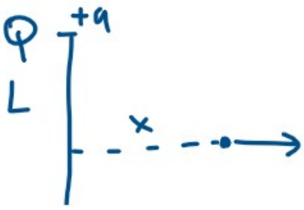
$$\frac{Q}{L} = \frac{Q}{2a} = \frac{dq}{dy} = \lambda \text{ (charge density)} \Rightarrow \begin{array}{l} dq = \lambda\,dy = f(y) \checkmark \\ dq = \left(\frac{Q}{2a}\right) dy \checkmark \end{array}$$

integ. table

$$E_p = \int dE_x = kx \int_{-a}^{+a} \frac{\lambda\,dy}{(x^2+y^2)^{3/2}} = kx\lambda \int \frac{dy}{(x^2+y^2)^{3/2}} = kx\lambda \left[\frac{1}{x^2} \frac{y}{(x^2+y^2)^{1/2}}\right]_{-a}^{+a}$$

$$= kx\lambda \frac{1}{x^2(x^2+a^2)^{1/2}} \left[a - (-a)\right] = \frac{k\cancel{x}\lambda\, 2a}{x\cancel{^2}(x^2+a^2)^{1/2}} = k\cancel{x} \frac{Q}{\cancel{2a}} \frac{\cancel{2a}}{x\cancel{^2}(x^2+a^2)^{1/2}}$$

$$E = \frac{kQ}{x(x^2+a^2)^{1/2}}$$



$$E = \frac{kQ}{x\sqrt{x^2+a^2}} = \frac{kQ}{x\sqrt{x^2+\frac{L^2}{4}}}$$

$x(x^2+a^2)^{1/2}$

$$E = \frac{kQ}{x\sqrt{x^2+a^2}} = \frac{kQ}{x\sqrt{x^2+\frac{L^2}{4}}}$$

unit analysis:

$$E = \frac{kQ}{r^2} \sim \frac{kq}{(\text{distance})^2} \checkmark \qquad \frac{kq}{x\sqrt{x^2}} \checkmark$$

ROD $\Rightarrow$ point charge

$x \gg \frac{L}{2}$, $x \gg a$

$x \gg L$

L, Q

$L \to 0$

$\Rightarrow \frac{kQ}{r^2}$ (expect) $= \frac{kQ}{x^2}$

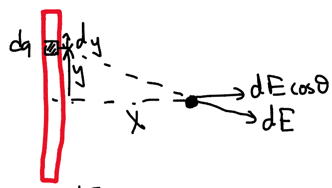
far away

it's a point charge

$$\frac{kQ}{x\sqrt{x^2+L^2/4}} \quad L=0 \quad = \frac{kQ}{x\sqrt{x^2+0}} = \frac{kQ}{x^2} \checkmark$$

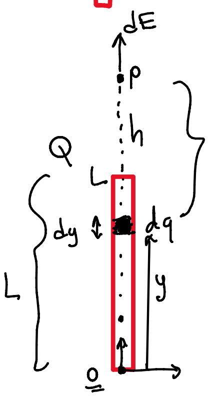
$x \to$ LARGE

$L \to 0$ $\Rightarrow$ point charge.



P, $E = ?$, h

$$\lambda = \frac{Q}{L} = \frac{dq}{dy}$$



$r = L+h-y$

$$\int \frac{k\,dq}{r^2} = \int dE$$

$$\int \frac{k\,dq}{(L+h-y)^2} = \int \frac{k\lambda\,dy}{(L+h-y)^2} = k\lambda \int \frac{-du}{u^2}$$

$$= k\lambda\left[\frac{1}{u}\right]$$

$L+h-y = u$

$-dy = du$

$u^{-1\,\prime} = -1\,u^{-2}$

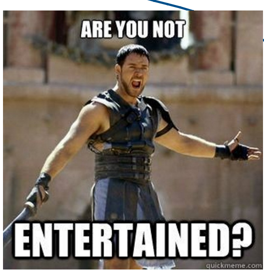
$$= k\lambda\left[\frac{1}{L+h-y}\right]_0^L$$

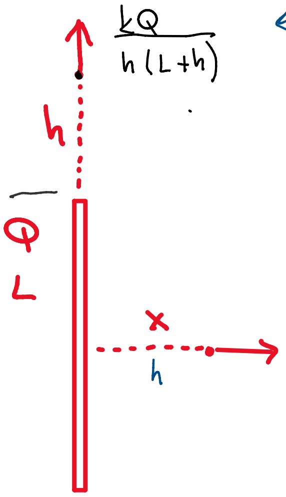
$$= k\lambda\left[\frac{1}{L+h-L} - \frac{1}{L+h-0}\right]$$

$$= k\lambda\left[\frac{1}{h} - \frac{1}{L+h}\right]$$

$$= k\lambda\left[\frac{L}{h(L+h)}\right] = k\frac{Q}{L}\,\frac{L}{h(L+h)}$$

$$\frac{kQ}{h(L+h)}$$





$$\frac{kQ}{x\sqrt{x^2+L^2/4}} = \frac{kQ}{h\sqrt{h^2+L^2/4}}$$

$$E = \frac{kQ}{h(L+h)}$$

RING charge Q, radius R

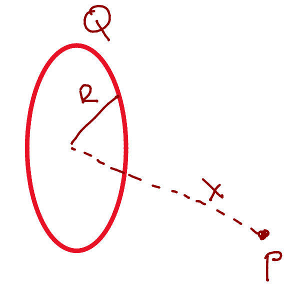
$E_p = ?$

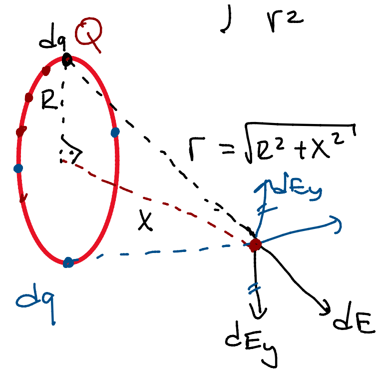
$$\int \frac{k\,dq}{r^2}$$

SIDEVIEW

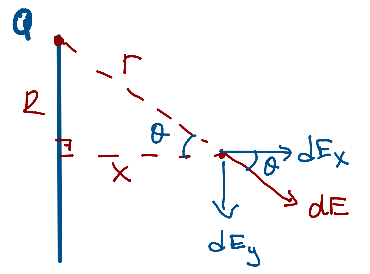
Q

$E_p = ?$





SIDEVIEW



dE_y will cancel each other

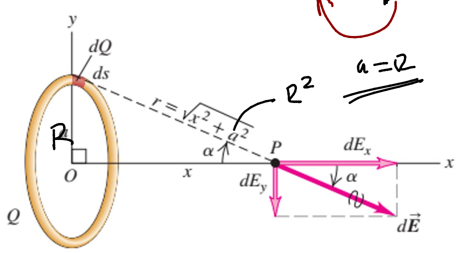
$$\int dE_x = \int dE\cos\theta = \int \frac{k\,dq}{r^2}\,\frac{x}{r}$$

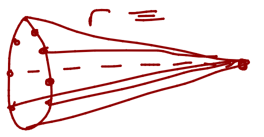
$$= kx \int \frac{dq}{r^3}$$

If we change dq location dE_x change?

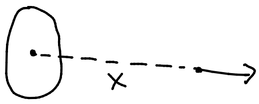
r change?

No! r does NOT change?





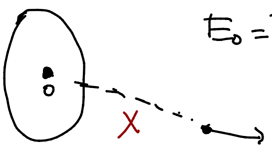
$$\frac{kx}{r^3}\underbrace{\int dq}_{Q} = \frac{kxQ}{r^3} = \frac{kxQ}{(R^2+x^2)^{3/2}}$$



$$\frac{kxQ}{(x^2+R^2)^{3/2}}$$

$$\frac{kQ}{r^2} = E \quad \frac{kQ}{\text{distance}^2} \Rightarrow kQ\,\frac{x}{(x^2+R^2)^{3/2}} \sim \frac{L}{(L^2)^{3/2}} = \frac{L}{L^3} \sim \frac{1}{L^2}$$

What's E at the center of the ring?



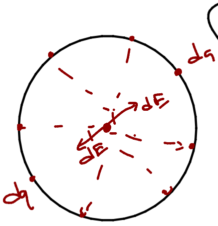
$E_o = ?$

$X = 0$

$$\frac{kQx}{(x^2+R^2)^{3/2}}$$

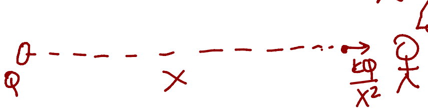
1st case

$$E_o\,(x=0) = \frac{kQ\,0}{(0^2+R^2)^{3/2}} = 0 \quad \text{ZERO} \quad (X=0)$$



2nd case

$X \gg R$ answer $\Rightarrow \dfrac{kQ}{X^2}$ point charge

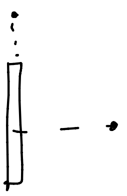


$\dfrac{X}{R} \gg 1 \;;\; \dfrac{R}{X} \sim 0$

$$\frac{kxQ}{(x^2+R^2)^{3/2}}\left(\lim_{\frac{R}{X}\to 0}\right) \Rightarrow \frac{kxQ}{X^3\left[\left(1+\frac{R^2}{X^2}\right)\right]^{3/2}} \sim \frac{kxQ}{X^3} \sim \frac{kQ}{X^2}$$

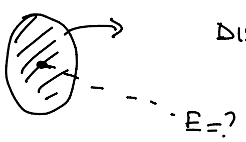
$\frac{R^2}{X^2} \to 0$

$$\int \frac{k\,dq}{r^2} \;;$$



RING

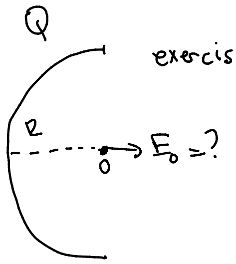
DISC

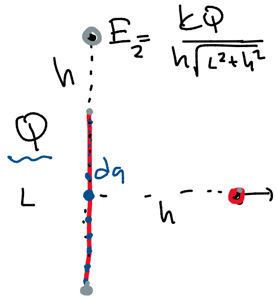


DISC = $\int$ RING

$\cdot + 0 + 0 + 0 + \cdots$

exercise?

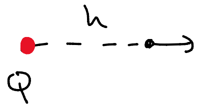




$E_2 = \frac{kQ}{h\sqrt{L^2+h^2}}$

$\frac{kQ}{h\sqrt{h^2+L^2/4}} = E_1$

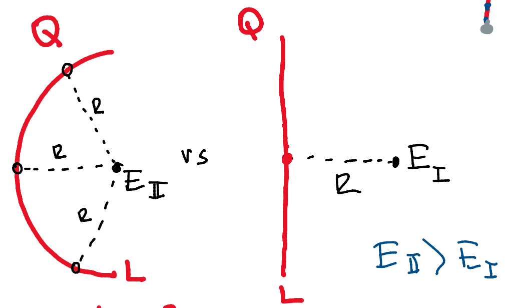
$E_1 \quad E_2 \quad E_3$ highest lowest.



$E_3 = \frac{kQ}{h^2}$

$E_3 = \frac{kQ}{h\sqrt{h^2+0}}$

$$E_3 > E_1 > E_2$$

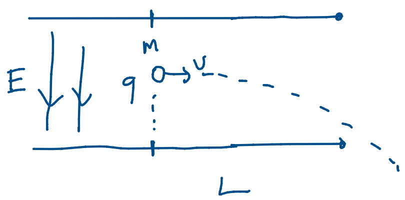


$L = 2\pi R$

$E_{II} > E_{I}$

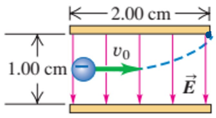
$E_{II} = \frac{kQ}{R^2}$??

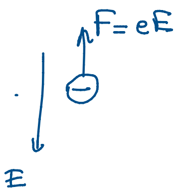
#21-78



21.33 •• **CP** An electron is projected with an initial speed $v_0 = 1.60 \times 10^6$ m/s into the uniform field between the parallel plates in Fig. E21.33. Assume that the field between the plates is uniform and directed vertically downward, and that the field outside the plates is zero. The electron enters the field at a point

Figure **E21.33**



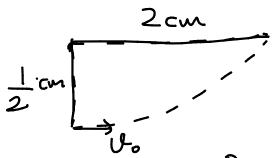


$e = 1.6\times10^{-19}$ C

$m = 9\times10^{-31}$ kg

$E = ?$

$F = ma = eE \qquad a = \frac{eE}{m}$



$X = v_0 t$

$(2\times10^{-2}) = (1.6\times10^{6})\, t$

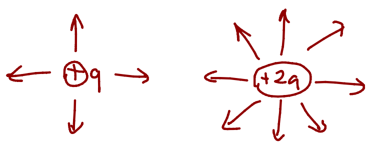
$y_f = \cancel{y_i}^{\,0} + \cancel{v_{yi} t}^{\,0} + \frac{1}{2} a t^2$

$(0.5\times10^{-2}) = \frac{1}{2}\,\frac{eE}{m_e}\, t^2$

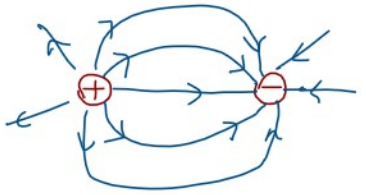
— End of Ch21 —

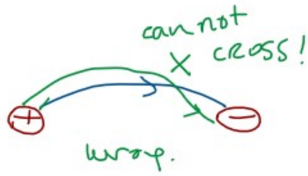
Ch22 Gauss Law: = 1st eqn of Maxwell Eqn.

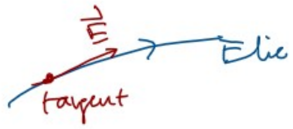
* $\vec{E}$ lines are proportional to amount of charge



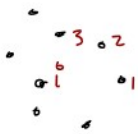
* $\vec{E}$ lines <u>do not</u> cross each other.







can not have two different $\vec{E}$ vector at the point. !



bunch of q

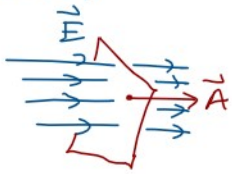
$\vec{E} = \sum_1^N \vec{E}_i$

$\vec{E}$ line

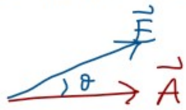
ELECTRIC FLUX (Elektrik Akısı)

$$\Phi = \vec{E}\cdot\underbrace{\vec{A}}_{\text{area}}$$

Φ (phi)



$$\Phi = \vec{E}\cdot\vec{A} = EA\cos\theta$$

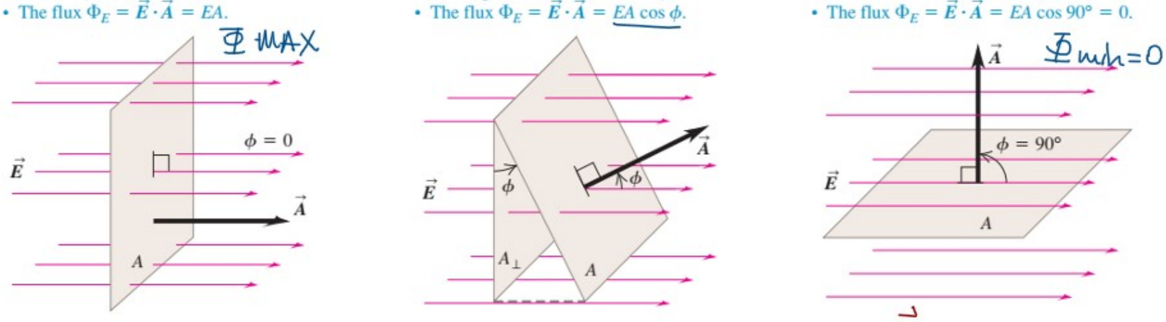


$$\Phi = \left[\frac{N}{C}\, m^2\right]$$

(a) Surface is face-on to electric field:
- $\vec{E}$ and $\vec{A}$ are parallel (the angle between $\vec{E}$ and $\vec{A}$ is $\phi = 0$).
- The flux $\Phi_E = \vec{E}\cdot\vec{A} = EA$.

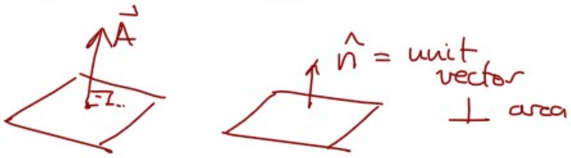
(b) Surface is tilted from a face-on orientation by an angle ϕ:
- The angle between $\vec{E}$ and $\vec{A}$ is ϕ.
- The flux $\Phi_E = \vec{E}\cdot\vec{A} = EA\cos\phi$.

(c) Surface is edge-on to electric field:
- $\vec{E}$ and $\vec{A}$ are perpendicular (the angle between $\vec{E}$ and $\vec{A}$ is $\phi = 90°$).
- The flux $\Phi_E = \vec{E}\cdot\vec{A} = EA\cos 90° = 0$.



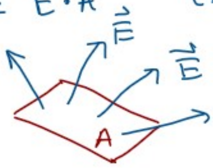
$\vec{A}$ = perpendicular to the physical area

$\vec{A}$ is NORMAL ($\perp$) to the " "



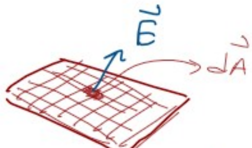
$\vec{A} = A\,\hat{n}$ $\qquad |\hat{n}| = 1$

$\Phi_E = \vec{E}\cdot\vec{A}$ ($\vec{E}$ is uniform; $\vec{E}$ düzgün)



$\vec{E}$ is not const. on the surface

$$\boxed{\Phi_E = \int \vec{E}\cdot d\vec{A}}$$



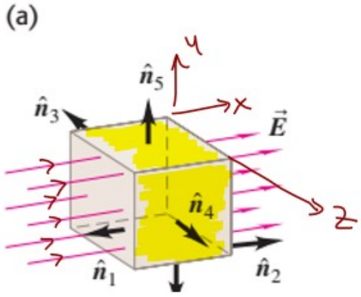
at each $d\vec{A}$ $\quad \vec{E}\cdot d\vec{A} = E\,dA\cos\phi_i$

ϕ = change

ex

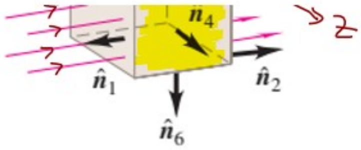
An imaginary cubical surface of side L is in a region of uniform electric field $\vec{E}$. Find the electric flux through each face of the cube and the total flux through the cube when (a) it is oriented with two of its faces perpendicular to $\vec{E}$ (Fig. 22.8a) and (b) the cube is turned by an angle θ about a vertical axis (Fig. 22.8b).

(a)



Φ_{total} on the cube.

Φ_{total} on the cube.



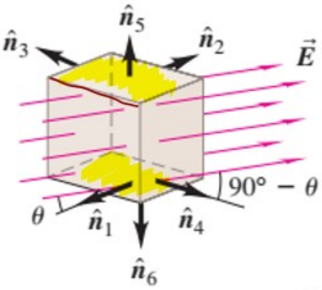
$$\vec{E} = E\hat{\imath}$$

$$\Sigma\Phi = \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4 + \Phi_5 + \Phi_6$$

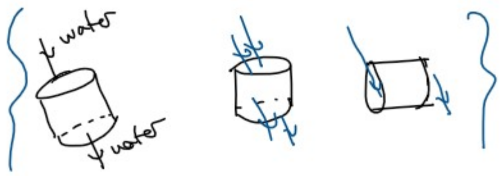
$$E\hat{\imath}\cdot A(-\hat{\imath}) + E\hat{\imath}\cdot A\hat{\imath} + E\hat{\imath}\cdot A\,-\hat{k} + 0 + 0 + 0$$

$$-EA + EA + 0 + 0 + 0 + 0 = -EA + EA = \underline{0} = \Phi$$

(b)



what if we rotate the box? $\Phi = ?$

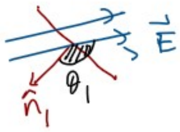


$\vec{E} \perp \hat{n} = \vec{E}\cdot\vec{A} = 0$

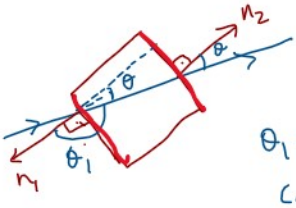
$$\Phi_1 + \Phi_2 + \Phi_3 + \Phi_4 + \Phi_5^{\,0} + \Phi_6^{\,0}$$

$-EA\cos\theta + EA\cos\theta$; Φ_3, Φ_4 cancel

TOP VIEW



$\Phi_1 = \vec{E}\cdot\vec{A} = \vec{E}\cdot A\hat{n}_1 = EA\underbrace{\cos\theta_1}_{(-)}$; $\theta_1 > 90°$



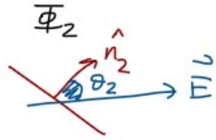
$\cos\theta_1 = -\cos\theta_2$

$\theta_1 + \theta_2 = 180°$

$\cos\theta_1 = -\cos\theta_2$

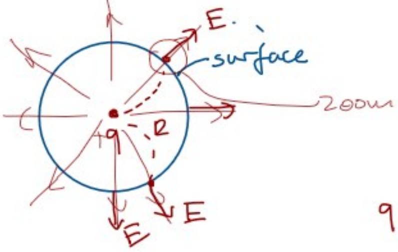
TOP VIEW

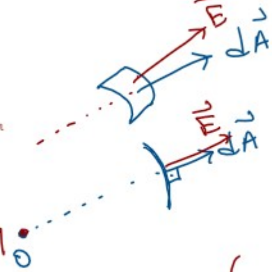
Φ_2



$$\Sigma\Phi = -EA\cos\theta_1 + EA\cos\theta_1 + EA\cos\theta_3 - EA\cos\theta_3 + 0 + 0 = \underline{0} \text{ zero}$$

whats the flux from a spherical surface when there's a point charge at the center





$\vec{E} \parallel d\vec{A}$

$$\Phi = \int \vec{E}\cdot d\vec{A} = \int E\,dA \underbrace{\cos 0°}_{1}$$

$\vec{E}$ at the surface of sphere is SAME

$$\int E\,dA = \Phi = E\underbrace{\int dA}_{\text{total area of sphere}}$$

E → const

surface area $4\pi R^2$

$$\underline{\underline{\Phi = E4\pi R^2}}$$

$q \xrightarrow{R} \frac{kq}{R^2} = E$ $\qquad \Phi = \frac{kq}{R^2}4\pi R^2 = 4\pi kq$; $k = \frac{1}{4\pi\varepsilon_0}$; ε_0 = electric permittivity of space

$$= \frac{q}{\varepsilon_0} = \Phi$$

$$\varepsilon_0 = 8.85\times10^{-12}\ \frac{C^2}{\ldots}$$

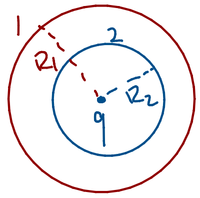
space

$$= \frac{q}{\varepsilon_0} = \Phi$$

$$\varepsilon_0 = 8.85\times10^{-12}\ \frac{C^2}{Nm^2}$$

if $q = 3\mu C$ $\quad \Phi = \frac{q}{\varepsilon_0} = \frac{3\times10^{-6}\ C}{8.85\times10^{-12}\ C^2/Nm^2} = 3.4\times10^{5}\ \frac{Nm^2}{C} = \Phi$

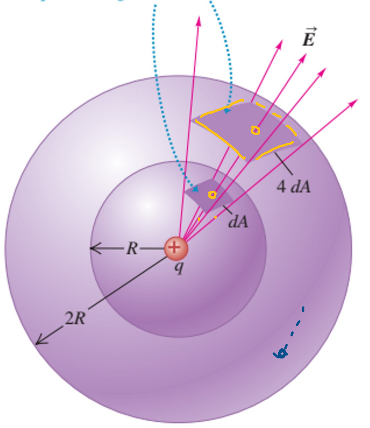
NOTICE THAT in this problem flux does NOT depend on radius of SPHERE $\Phi = \frac{q}{\varepsilon_0}$



$$\Phi_1 = \Phi_2 = \frac{q}{\varepsilon_0}$$

two spheres with two different radius will have the same flux.

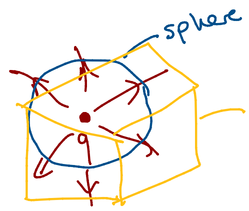
The same number of field lines and the same flux pass through both of these area elements.



GAUSS LAW

$$\boxed{\oint_{\text{closed surface}} \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0} = \Phi}$$

q_{in} = q enclosed in that surface.



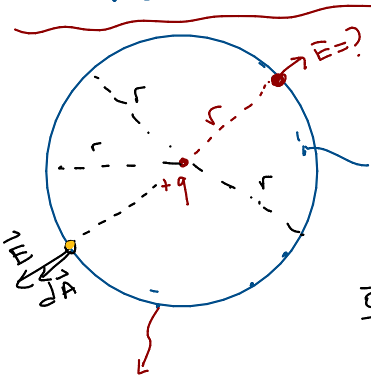
$$\Phi_{sphere} = \Phi_{cube} = \frac{q}{\varepsilon_0}$$

$$\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

$\int_{a=start}^{a=end} \Rightarrow \oint$

Gauss Law to find $\vec{E}$ field of some basic objects.

E
- point charge
- sphere Q
- very long cylinder
- very long ROD
- very big surface ...



$\vec{E}(r) = ?$

1st step draw

gauss surface ≡ sphere with radius r

pick surface such that $\vec{E}$ is const. on that surface.

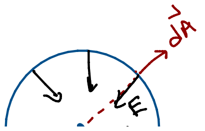
$$\Phi = \oint \vec{E}\cdot d\vec{A} = \oint E\,dA\,\cos\theta = q_{in}/\varepsilon_0$$

when you pick the "correct" surface. easy symetry

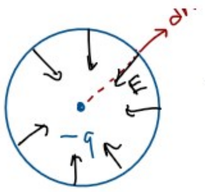
(I) $\oint \vec{E}\cdot d\vec{A} = \int E\,dA\,\underbrace{\cos\theta}_{1}$ $\quad \cos\theta = 1$

(II) E field is const along the surface so that E can be taken out of Integral

$$\int E\,dA = E\underbrace{\int dA}_{\text{area of gauss surface}} = E\,4\pi r^2 = q/\varepsilon_0 \qquad E = \frac{q}{4\pi\varepsilon_0 r^2} = \frac{kq}{r^2}$$



$$\oint \vec{E}\cdot d\vec{A} = \int E\,dA\,\underbrace{\cos 180^\circ}_{-1} = -E\int dA = -E\,4\pi r^2 = \frac{q_{in}}{\varepsilon_0} = \frac{-q}{\varepsilon_0}$$



$$\underbrace{\oint \vec{E}\cdot d\vec{A}}_{(-)} = \int E\,dA \underbrace{\cos 180^\circ}_{-1} = -E\underbrace{\int dA}_{4\pi r^2} = \underbrace{-E4\pi r^2}_{} = \frac{q_{in}}{\varepsilon_0} = \underbrace{\frac{-q}{\varepsilon_0}}_{}$$

$$E = \frac{q}{4\pi\varepsilon_0 r^2}$$

magnitude of $\vec{E}$

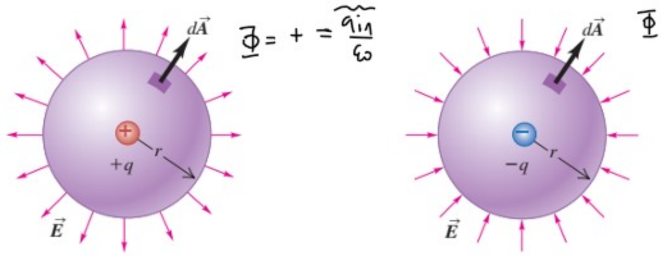
direction of $\vec{E}$; $\oplus$ $\ominus$

(a) Gaussian surface around positive charge: positive (outward) flux

$\Phi = + = \overset{+}{\frac{q_{in}}{\varepsilon_0}}$

(b) Gaussian surface around negative charge: negative (inward) flux

$\Phi = - - = \overset{(-)}{\frac{q_{in}}{\varepsilon_0}}$



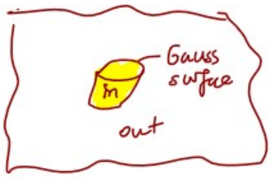
$$\Phi_E = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

electric flux

$\oint dA \Rightarrow$ closed surface area

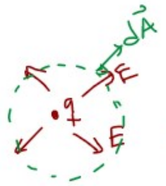
ε_0 = Electric permittivity of space

$\varepsilon_0 = 8.85\times10^{-12}\ C^2/Nm^2$

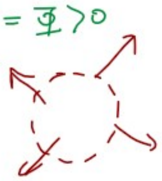


$F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}$

$\varepsilon_0 = \left[\frac{C^2}{Nm^2}\right]$

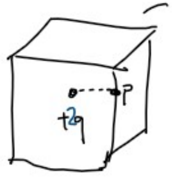


$\underbrace{\oint \vec{E}\cdot d\vec{A}}_{+} = \Phi > 0$



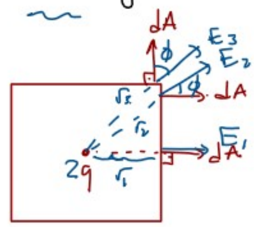
ex)

cube what's the Electric flux at point P? $\rightarrow \phi$



$\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

front view



$\oint \vec{E}\cdot d\vec{A}$

$\oint E\,dA\cos\phi$ = hard to perform

angle change at each point

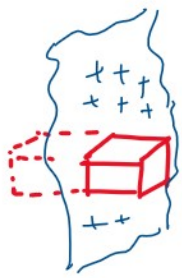
$E_1 \neq E_2 \neq E_3$

$\Phi = \frac{2q}{\varepsilon_0}$ ✓

	gauss surface
q • point charge	sphere
q | ∞ rod	cylinder
q ∞ cylinder	cylinder
q sphere	sphere
∞ sheet	cylinder cube prism ✓

$\oint \vec{E}\cdot d\vec{A}$ EASY

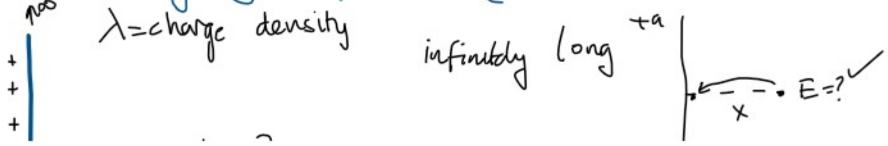
$\int \vec{E}\cdot d\vec{A}$ = easy



ex: infinitely long charged wire (rod)

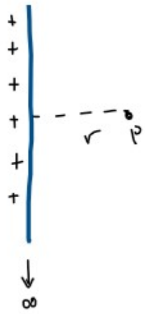
λ = charge density

infinitely long



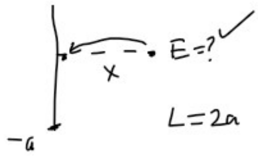
$\int k\frac{dq}{r^2} = E$

Infinitely long



$E_p = ?$

$\lambda = \text{charge density} = \dfrac{\text{charge}}{\text{Length}}$



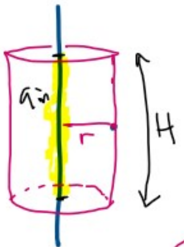
$E = ?$ ✓

$\int k \dfrac{dq}{r^2} = E$

$L = 2a$ $\quad 2a = L \gg x \Rightarrow \infty$ LONG !!

$100 \gg 1$ ✓

gauss surface = cylinder

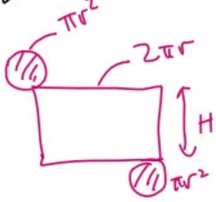


$$\underbrace{\oint \vec{E}\cdot d\vec{A}}_{\text{LHS}} = \underbrace{\frac{q_{in}}{\varepsilon_0}}_{\text{RHS}}$$

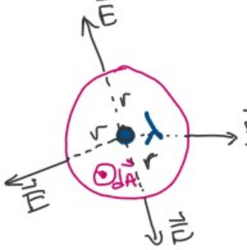
RHS of equ. q_{in}

$$\lambda = \frac{Q \to \infty}{L \to \infty} = \text{const} = \frac{q_{in}}{H}$$

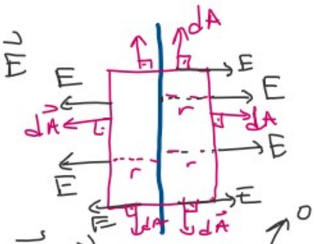
$$\boxed{q_{in} = \lambda H}$$ ✓



TOP VIEW



SIDE VIEW



$$\oint \vec{E}\cdot d\vec{A} = \underbrace{\int \vec{E}\cdot d\vec{A}}_{\text{TOP} \to 0} + \underbrace{\int \vec{E}\cdot d\vec{A}}_{\text{side}} + \underbrace{\int \vec{E}\cdot d\vec{A}}_{\text{BOTTOM} \to 0}$$

$\int E\, dA \cos 0$, $\cos 0 = 1$

E is constant r distance away from the rod.

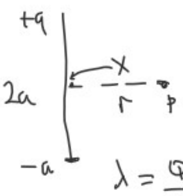
$\vec{E}\cdot d\vec{A} = E\, dA \cos 90 \to 0$

TOP, BOTTOM $= 0$

$$\underbrace{E \int dA}_{\text{SIDE}} = \frac{q_{in}}{\varepsilon_0} = \frac{\lambda H}{\varepsilon_0}$$

$$E\, 2\pi r H = \frac{\lambda H}{\varepsilon_0} \Rightarrow \boxed{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

remember



$$\frac{kQ}{x\sqrt{x^2 + \frac{L^2}{4}}} = E_p$$

$$\lambda = \frac{Q}{2a} = \frac{Q}{L}$$

Same!!

$$\frac{\lambda}{2\pi\varepsilon_0 x} = \frac{\lambda}{2\cancel{4}\pi\varepsilon_0 \frac{x}{\cancel{2}}} = \frac{k\lambda}{\frac{x}{2}} = \frac{kQ}{x\frac{L}{2}\left[1 + \underbrace{\left(\frac{x}{L/2}\right)}_{0}\right]^{1/2}}$$

$x \ll L$

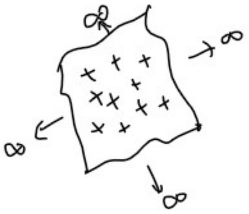
$\frac{x}{L} \ll 1$

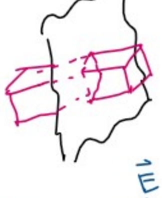
$\frac{x}{L/2} \ll 1$

ex) ~~Infiteln~~ Infinitely large surface.

σ = charge density given

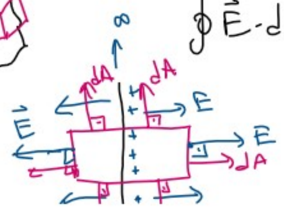
$$\sigma \text{ (sigma)} = \frac{\text{charge}}{\text{area}} = \frac{Q \to \infty}{A \to \infty} = \text{const}$$

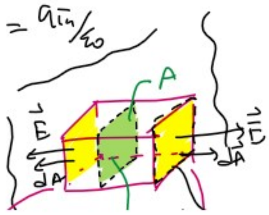




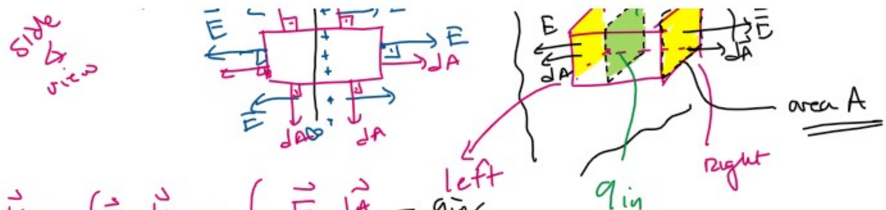
side view

$$\oint \vec{E}\cdot d\vec{A} = q_{in}/\varepsilon_0$$





area A



$$\oint \vec{E}\cdot d\vec{A} = \int_{\text{left}} \vec{E}\cdot d\vec{A} + \int_{\text{Right}} \vec{E}\cdot d\vec{A} + \int_{\text{side}} \vec{E}\cdot d\vec{A} = q_{in}/\varepsilon_0$$

$$\int E\,dA\cos 0 + \int E\,dA \cos 0 + \int E\,dA\cancel{\cos 90}$$

$$\sigma = \frac{q_{in}}{A} \Rightarrow q_{in} = \sigma A$$

$$2E\underbrace{\int dA}_{A} = q_{in}/\varepsilon_0$$

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow \boxed{E = \frac{\sigma}{2\varepsilon_0}}$$ = Electric field of ∞'ly large surface (slab)

$$E = \frac{kq}{r^2} = \frac{q}{4\pi\varepsilon_0 r^2} = \frac{1}{\varepsilon_0}\left[\frac{\text{charge}}{\text{area}}\right]$$

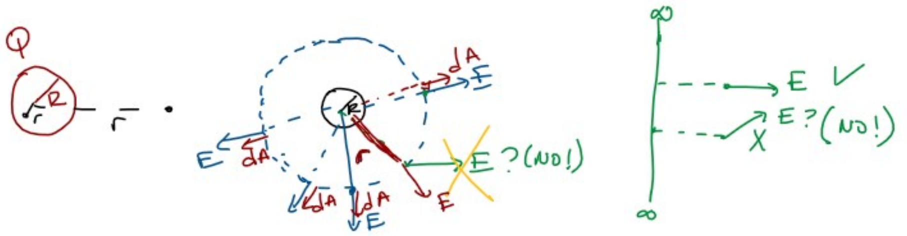
① point charge ② ∞ long rod ③ ∞ large surface.

$$E = \frac{\sigma}{2\varepsilon_0} = \frac{1}{\varepsilon_0}\left[\text{charge/area}\right]$$ checks out ✓

ELECTRIC FIELD of UNIFORMLY CHARGED SPHERE = INSULATOR (Yalıtkan)

charge density constant

$E(r>R) = ?$ $E(r<R) = ?$



$$\oint \vec{E}\cdot d\vec{A} = q_{in}/\varepsilon_0$$

$E(r>R)$

$$E\oint dA = \oint E\,dA\cos 0° = E\oint dA = E4\pi r^2 = \frac{Q}{\varepsilon_0} \Rightarrow E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

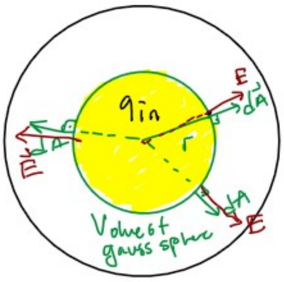
$\oint dA$: area of sphere

E = const at every point on the gaussian surface

area of sphere

$E(r<R) = ?$

q_{in} = charge inside of gaussian surface



$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$ RHS

$$\int E\,dA\cos 0$$

$$E\int dA$$

charge density $= \rho$ (rho) $= \frac{\text{charge}}{\text{volume}} = \frac{q_{in}}{V_{in}}$ vol. of gauss sphere

$$\rho = \frac{q_{in}}{\frac{4}{3}\pi r^3} = \frac{Q}{V}$$

$\frac{4}{3}\pi r^3 \rho$ ① r^3

$$\rho = \frac{q_{in}}{4\ldots} = \frac{Q}{4\ldots}$$

$$E\int dA$$

$$E\,4\pi r^2 = \frac{\frac{4}{3}\pi r^3 \rho}{\varepsilon_0} = \frac{\frac{Q r^3}{R^3}}{\varepsilon_0}$$

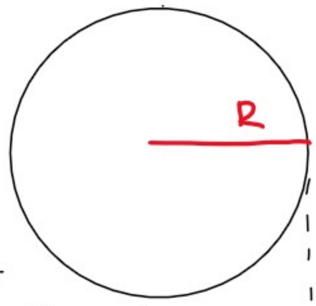
$$\rho = \frac{q_{in}}{\frac{4}{3}\pi r^3} = \frac{Q}{\frac{4}{3}\pi R^3}$$

$$q_{in} = \frac{4}{3}\pi r^3 \rho$$

$$q_{in} = Q\frac{r^3}{R^3}$$

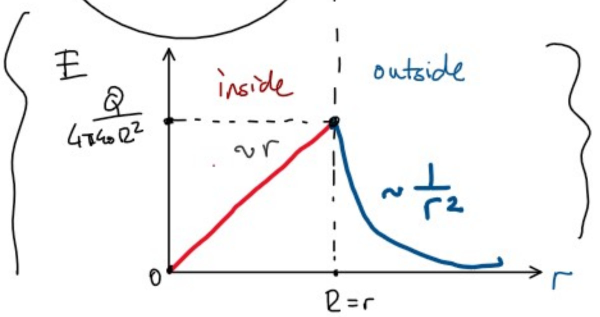
$$E(r<R) = E = \frac{\rho r}{3\varepsilon_0} = \frac{Q r}{4\pi\varepsilon_0 R^3} \checkmark$$

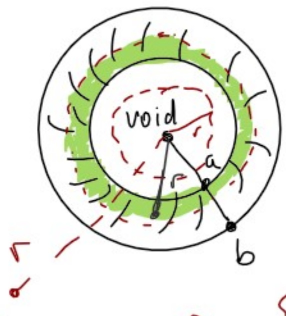
$$E = \frac{Q}{4\pi\varepsilon_0 R^3} r \sim r \qquad E = \frac{Q}{4\pi\varepsilon_0 r^2} \sim \frac{1}{r^2}$$



@ $r=R$ $\quad$ @ $r=R$

$$E_{out} = \frac{Q}{4\pi\varepsilon_0 R^2} = E_{in} = \frac{Q}{4\pi\varepsilon_0 R^{\cancel{3}2}}\cancel{R} \checkmark$$





Q

$b = R$

$a =$ inner radius

$E(r>b) = ?$

$E(r<a) = ?$

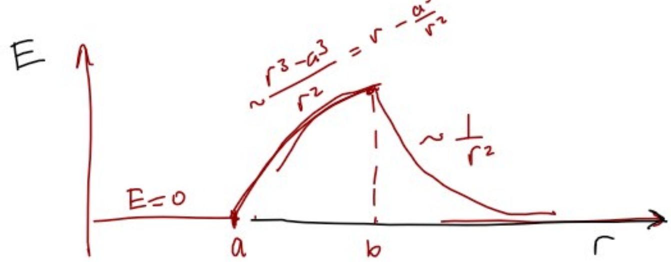
$E(b>r>a) = ?$

$$E\int dA = E\,4\pi r^2 = \frac{Q}{\varepsilon_0}$$

$$\frac{Q}{4\pi\varepsilon_0 r^2} \checkmark$$

?

$q_{in} = 0 \quad E = 0$



LHS

$$\oint \vec{E}\cdot d\vec{A} = E\,4\pi r^2 = \frac{q_{in}}{\varepsilon_0} = \frac{Q}{V}\frac{V_{in}}{\varepsilon_0}$$

$$V_{in} = \left(\frac{4}{3}\pi r^3 - \frac{4}{3}\pi a^3\right)$$

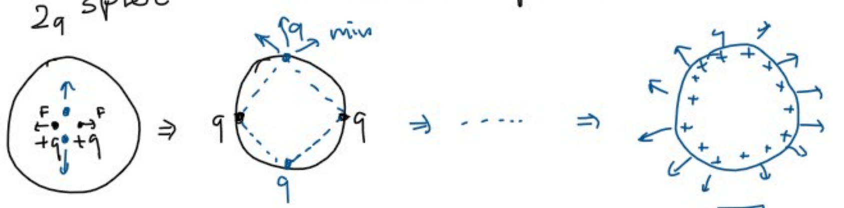
$$E = \frac{Q\,(r^3 - a^3)}{\varepsilon_0 4\pi r^2 (b^3 - a^3)} \sim \frac{(x^3-1)}{x^2} \longleftarrow E\,4\pi r^2 = \frac{Q \quad \frac{4}{3}\pi\,(r^3 - a^3)}{\left(\frac{4}{3}\pi b^3 - \frac{4}{3}\pi a^3\right)}$$

$$E(r=b) \overset{?}{=} \frac{Q}{4\pi\varepsilon_0 b^2} = \frac{Q\,\cancel{(b^3-a^3)}}{\varepsilon_0 4\pi b^2\,\cancel{(b^3-a^3)}} \checkmark$$

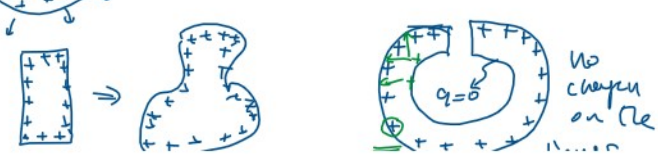
Electrostatic situation

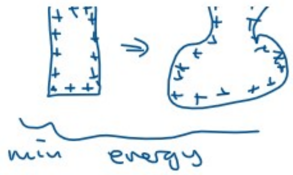
Charges in metal : is distributed such that they have the least energy.

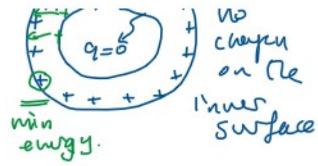
Forces on charges are minimum $\qquad$?!



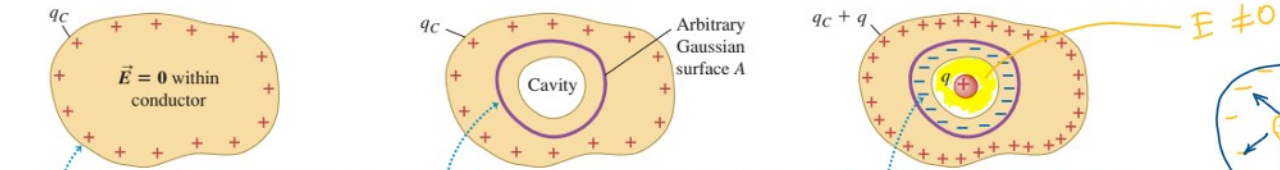
charges are always on the surface of metal object







(a) Solid conductor with charge q_C (b) The same conductor with an internal cavity (c) An isolated charge q placed in the cavity

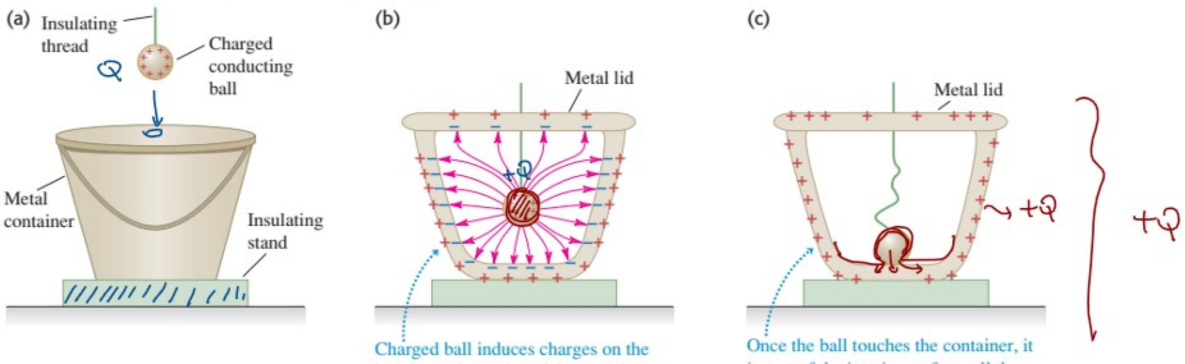


The charge q_C resides entirely on the surface of the conductor. The situation is electrostatic, so $\vec{E} = 0$ within the conductor.

Because $\vec{E} = 0$ at all points within the conductor, the electric field at all points on the Gaussian surface must be zero.

For $\vec{E}$ to be zero at all points on the Gaussian surface, the surface of the cavity must have a total charge $-q$.

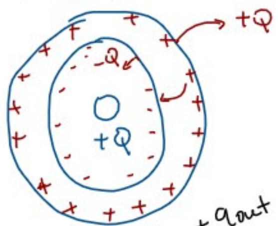
22.25 (a) A charged conducting ball suspended by an insulating thread outside a conducting container on an insulating stand. (b) The ball is lowered into the container, and the lid is put on. (c) The ball is touched to the inner surface of the container.



Charged ball induces charges on the interior and exterior of the container.

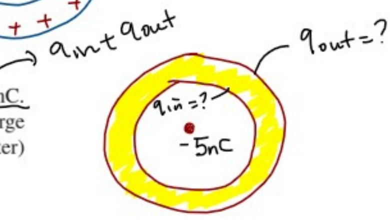
Once the ball touches the container, it is part of the interior surface; all the charge moves to the container's exterior.

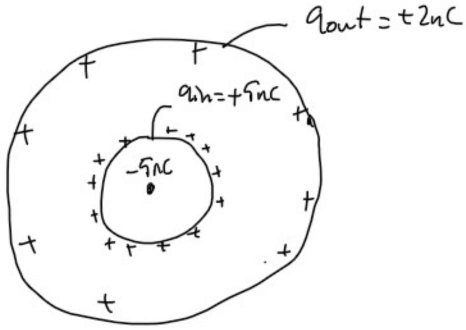
$+Q - Q + Q = Q$



ex

A solid conductor with a cavity carries a total charge of +7 nC. Within the cavity, insulated from the conductor, is a point charge of −5 nC. How much charge is on each surface (inner and outer) of the conductor?





$q_{Net} = +7nC$

$q_{conductor} = \underline{+7nC}$

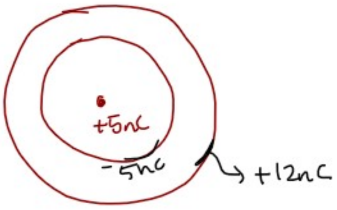
$7nC = q_{in} + q_{out}$
$+5nC$
$q_{out} = +2nC$

$\Sigma Q = q_{cond} + q_{center}$

$= 7nC + -5nC = +2nC$

$= \underbrace{2nC}_{q_{out}} + \underbrace{5nC}_{q_{in}} \underbrace{-5nC}_{center} = +2nC$

ex) $q_{cond} = +7nC$
$q_{center} = +5nC$



$-5nC$ $\to +12nC$

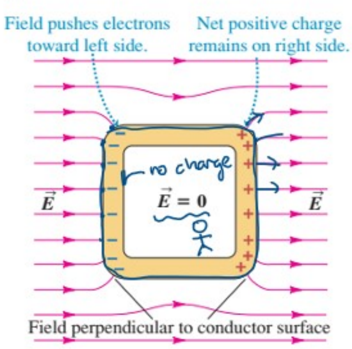
$-5nC + 12nC = 7nC$

22.27 (a) A conducting box (a Faraday cage) immersed in a uniform electric field. The field of the induced charges on the box combines with the uniform field to give zero total field inside the box. (b) This person is inside a Faraday cage, and so is protected from the powerful electric discharge.

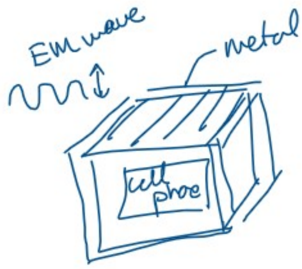
$\vec{E} \to \ominus$

$\oplus \to$

(a)

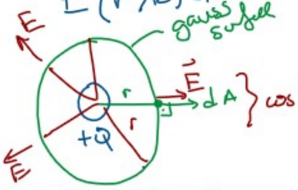


(b)

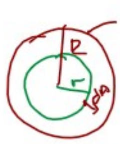


E field of a conductor sphere, Q, R
metal

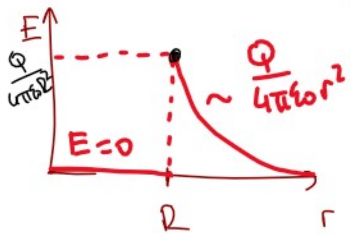
$E(r>R) = ?$ $\quad E(r<R) = ?$



$\cos\theta = \cos 0$



$\oint \vec{E} \cdot d\vec{A} = q_{in}/\varepsilon_0 \to \underline{\underline{0}}$



$\oint \vec{E} \cdot d\vec{A} = Q/\varepsilon_0$

$\oint E\, dA \underbrace{\cos 0}_{1}$

$E \underbrace{\oint dA} = Q/\varepsilon_0$

$E 4\pi r^2 = Q/\varepsilon_0$

$E(r>R) = \frac{Q}{4\pi\varepsilon_0 r^2}$

$\oint \vec{E} \cdot d\vec{A} = 0$

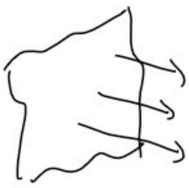
$\Downarrow$

$dA \neq 0$

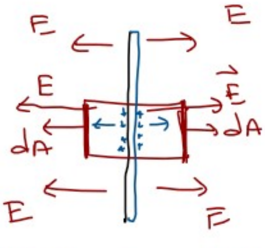
$E = 0$ (must be)

$E(r=R) = \frac{Q}{4\pi\varepsilon_0 R^2}$ ✓

∞ large insulating surface



$E = \frac{\sigma}{2\varepsilon_0}$



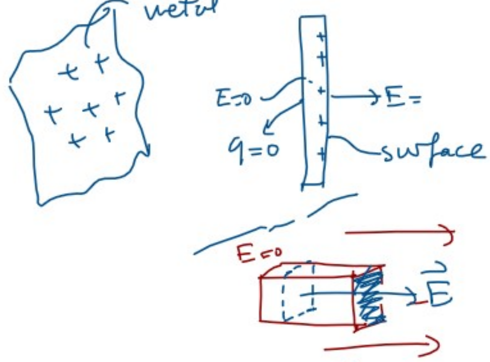
σ = charge density = $\frac{\text{charge}}{\text{area}}$

$EA + EA + 0 = 2EA = \frac{q_{in}}{\varepsilon_0} = \frac{\sigma A}{\varepsilon_0}$

$E = \frac{\sigma}{2\varepsilon_0}$

∞ large conducting surface.

metal



$\frac{q_{in}}{\varepsilon_0} = \frac{\sigma A}{\varepsilon_0} = \oint \vec{E} \cdot d\vec{A} = EA + 0 + \underline{0 + 0 + 0 + 0}$

right, left, side surface

$$= 2EA = \frac{\quad}{\varepsilon_0}$$

$$E = \frac{\sigma}{2\varepsilon_0}$$

insulator

$$\frac{q_{in}}{\varepsilon_0} = \frac{\sigma}{\varepsilon_0} = \oint E \cdot dA = \underbrace{\;}_{\text{right surface}} + \underbrace{\;}_{\text{left surface}} + \underbrace{\;}_{\text{side surface}}$$

$$E\cancel{A} = \frac{\sigma \cancel{A}}{\varepsilon_0}$$

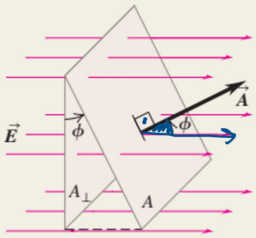
$$\boxed{E = \frac{\sigma}{\varepsilon_0}}$$

metal

Electric flux: (akı) Electric flux is a measure of the "flow" of electric field through a surface. It is equal to the product of an area element and the perpendicular component of $\vec{E}$, integrated over a surface. (See Examples 22.1–22.3.)

$$\Phi_E = \int E\cos\phi \, dA$$ (phi)

$$= \int E_\perp \, dA = \int \vec{E} \cdot d\vec{A} \qquad (22.5)$$



Gauss's law: Gauss's law states that the total electric flux through a closed surface, which can be written as the surface integral of the component of $\vec{E}$ normal to the surface, equals a constant times the total charge Q_{encl} enclosed by the surface. Gauss's law is logically equivalent to Coulomb's law, but its use greatly simplifies problems with a high degree of symmetry. (See Examples 22.4–22.10.)

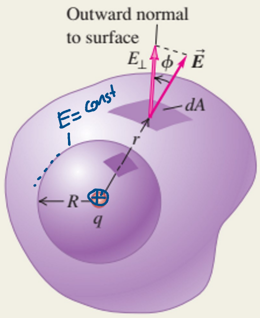
When excess charge is placed on a conductor and is at rest, it resides entirely on the surface, and $\vec{E} = \mathbf{0}$ everywhere in the material of the conductor. (See Examples 22.11–22.13.)

flux akı

$$\Phi_E = \oint E\cos\phi \, dA \qquad E$$

$$= \oint E_\perp \, dA = \oint \vec{E} \cdot d\vec{A}$$

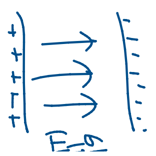
$$= \frac{Q_{encl}}{\epsilon_0} = \frac{q_{in}}{\varepsilon_0} \qquad (22.8), (22.9)$$

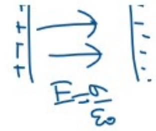


Charge Distribution	Point in Electric Field	Electric Field Magnitude
Single point charge q	Distance r from q	$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$
Charge q on surface of conducting sphere with radius R	Outside sphere, $r > R$	$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$
	Inside sphere, $r < R$	$E = 0$
Infinite wire, charge per unit length λ ; ∞ ROD	Distance r from wire	$E = \frac{1}{2\pi\epsilon_0}\frac{\lambda}{r}$
Infinite conducting cylinder with radius R, charge per unit length λ	Outside cylinder, $r > R$	$E = \frac{1}{2\pi\epsilon_0}\frac{\lambda}{r}$
	Inside cylinder, $r < R$	$E = 0$
Solid insulating sphere with radius R, charge Q distributed uniformly throughout volume (Yalıtkan küre)	Outside sphere, $r > R$	$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$ ⇒ dışarıda yalıtkan = iletken
	Inside sphere, $r < R$	$E = \frac{1}{4\pi\epsilon_0}\frac{Qr}{R^3}$ } yalıtkan, insulator
Infinite sheet of charge with uniform charge per unit area σ	Any point	$E = \frac{\sigma}{2\epsilon_0}$ } insulating
Two oppositely charged conducting plates with surface charge densities $+\sigma$ and $-\sigma$	Any point between plates	$E = \frac{\sigma}{\epsilon_0}$ } same
Charged conductor	Just outside the conductor	$E = \frac{\sigma}{\epsilon_0}$ → conducting

$$E_{conductor} > E_{insulator}$$

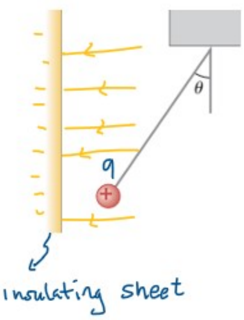
$$\frac{\sigma}{\varepsilon_0} > \frac{\sigma}{2\varepsilon_0}$$





$\frac{\sigma}{\varepsilon_0} > \frac{\sigma}{2\varepsilon_0}$

22.43



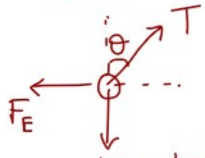
$m = 4\times10^{-6}\,kg$

$q = 5\times10^{-8}\,C$

$\sigma = -2.5\times10^{-9}\,\frac{C}{m^2}$

$\theta = ?$

FBD

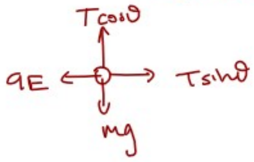


$mg = 4\times10^{-6}\times9.8$

$= 3.92\times10^{-5}\,N$

$F_E = qE = q\,\frac{\sigma}{2\varepsilon_0}$

$\frac{(5\times10^{-8})\,(2.5\times10^{-9})}{2\,(8.85\times10^{-12})} = 0.7\times10^{-5}\,N$



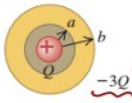
$\frac{T\sin\theta}{T\cos\theta} = \frac{qE}{mg} = \tan\theta$

$\tan\theta = \frac{0.7\times10^{-5}}{3.92\times10^{-5}} = 0.178$

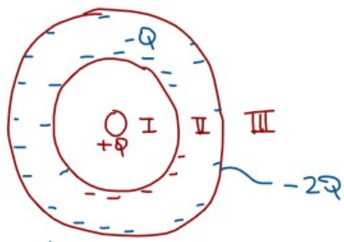
$\theta = \tan^{-1}(0.178) = 10^\circ$

22.46 • A conducting spherical shell with inner radius a and outer radius b has a positive point charge Q located at its center. The total charge on the shell is $-3Q$, and it is insulated from its surroundings (Fig. P22.46). (a) Derive expressions for the electric-field magnitude in terms of the distance r from the center for the regions $r < a$, $a < r < b$, and $r > b$. (b) What is the surface charge density on the inner surface of the conducting shell? (c) What is the surface charge density on the outer surface of the conducting shell? (d) Sketch the electric field lines and the location of all charges. (e) Graph the electric-field magnitude as a function of r.

Figure
P22.46



⇒ total

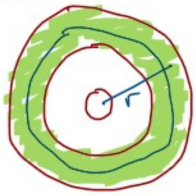


$r < a$

$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

$E\,4\pi r^2 = \frac{+Q}{\varepsilon_0}$

$\left\{ E_I = \frac{Q}{4\pi\varepsilon_0 r^2} \quad (r<a) \right\}$

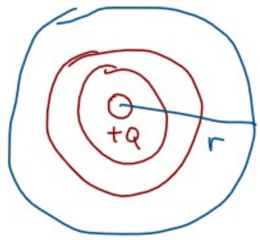


$a < r < b$

$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

$E\,4\pi r^2 = \frac{+Q-Q}{\varepsilon_0} = 0$

$\left\{ E_{II} = 0 \quad a<r<b \right\}$



$r > b$

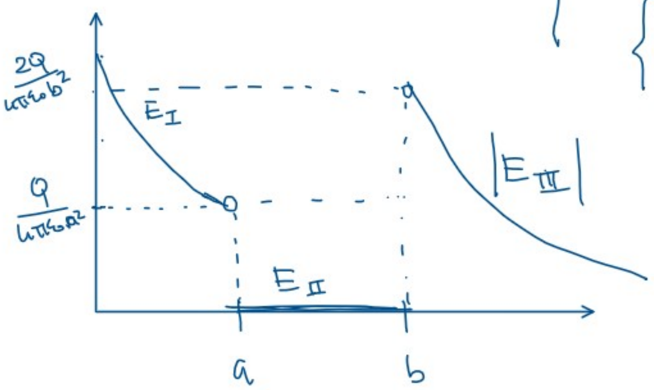
$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

$E\,4\pi r^2 = \frac{+Q-3Q}{\varepsilon_0}$

$= \frac{+Q-Q-2Q}{\varepsilon_0}$

$E\,4\pi r^2 = \frac{-2Q}{\varepsilon_0}$

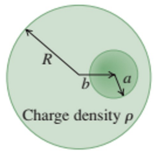
$E_{III} = \frac{-Q}{2\varepsilon_0\pi r^2}$



$|E_{III}| = \frac{2Q}{4\pi\varepsilon_0 r^2}$

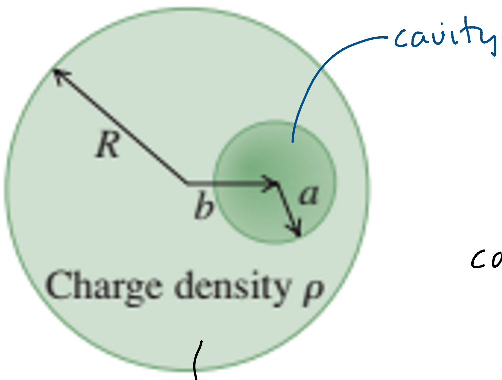
22.61 • (a) An insulating sphere with radius a has a uniform charge density ρ. The sphere is not centered at the origin but at $\vec{r} = \vec{b}$. Show that the electric field inside the sphere is given by $\vec{E} = \rho(\vec{r} - \vec{b})/3\epsilon_0$. (b) An insulating sphere of radius R has a spherical hole of radius a located within its volume and centered a distance b from the center of the sphere, where $a < b < R$ (a cross section of the sphere is shown in Fig. P22.61). The solid part of the sphere has a uniform volume charge density ρ. Find the magnitude and direction of the electric field $\vec{E}$ inside the hole, and show that $\vec{E}$ is uniform over the entire hole. [*Hint:* Use the principle of superposition and the result of part (a).]

Figure **P22.61**



22.61'

insulating charged sphere

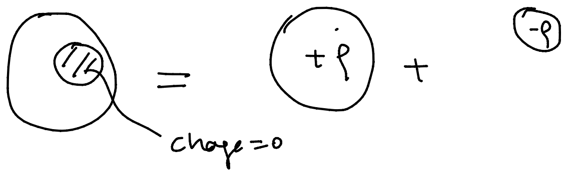


$+\rho$ = charge density

$\vec{E}$ inside the cavity $= \rho(\vec{r}-\vec{b})/3\varepsilon_0$

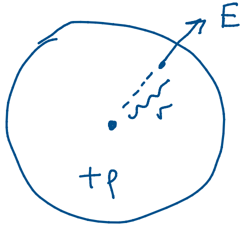
Show this!

cavity $= +\rho + (-\rho) =$ zero charge.



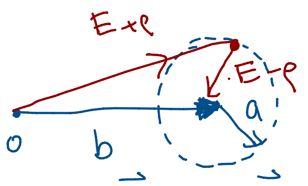
inside a insulating sphere

$$\vec{E} = \frac{\rho \vec{r}}{3\varepsilon_0}$$



within the cavity

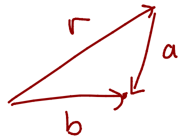
$$\vec{E}_{+\rho} + \vec{E}_{-\rho}$$



$\vec{E}_{+\rho} + \vec{E}_{-\rho}$

$$E_{+\rho} = \frac{\rho \vec{r}}{3\varepsilon_0}$$

$$E_{-\rho} = \frac{-\rho \vec{a}}{3\varepsilon_0}$$



$$\frac{\rho}{3\varepsilon_0}\underbrace{(\vec{r}-\vec{a})}_{\vec{b}} = \left\{\frac{\rho}{3\varepsilon_0}\vec{b}\right\}$$ E field within the cavity

Ch 21–22

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r} \Rightarrow \vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r} \longrightarrow \Phi_E = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

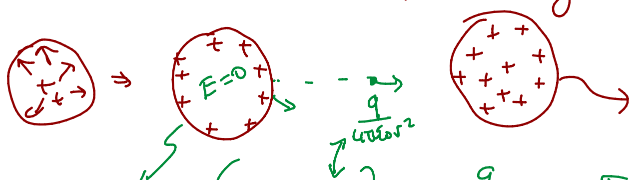
symmetric situations {point charge, sphere, ∞ ROD, ∞ area, cylinder}

$\frac{\sigma}{2\varepsilon_0}$

$$\varepsilon_0 = 8.85\times10^{-12}\ \frac{C^2}{Nm^2} \quad ; \quad k = \frac{1}{4\pi\varepsilon_0} = 8.99\times10^{9}\ \frac{Nm^2}{C^2}$$

$$F = qE \Rightarrow E = \left[\frac{N}{C}\right] \quad ; \quad \Phi_E = \left[\frac{N}{C}m^2\right] = \left[\frac{C}{C^2/Nm^2}\right] \equiv \text{Electric flux.}$$

metal (conductor) ; plastics, glass (insulators)



charge density $\left\{\lambda = \frac{Q}{L} \ ; \ \sigma = \frac{Q}{A} \ ; \ \rho = \frac{Q}{V}\right\}$

∞ Large surfaces or you get close to the surface $\left\{E = \frac{\sigma}{\varepsilon_0}\right\}$

$$\frac{q}{4\pi r^2 \varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

∞ Large surfaces $\left\{ E = \frac{\sigma}{\varepsilon_0} \right\}$ $\qquad \frac{\quad}{4\pi r^2 \varepsilon_0} \rightarrow \frac{\quad}{\varepsilon_0}$

or you get close to the surface so that it looks ∞-big for you