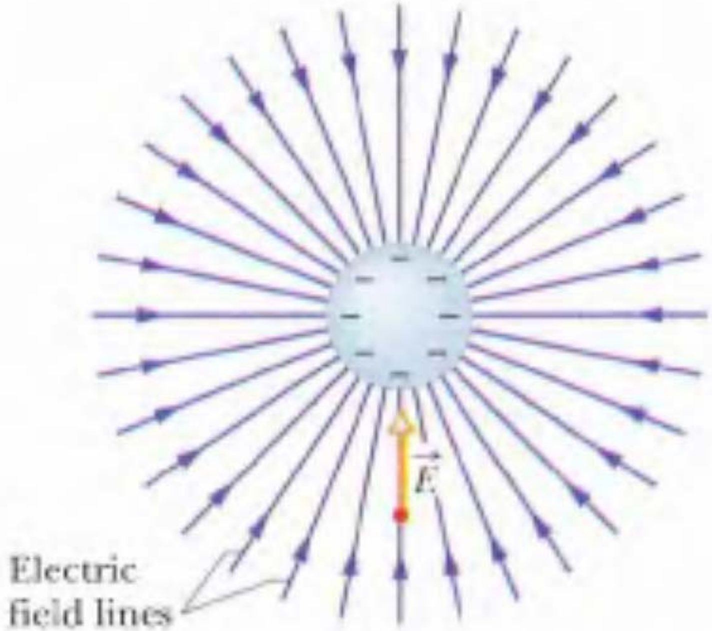
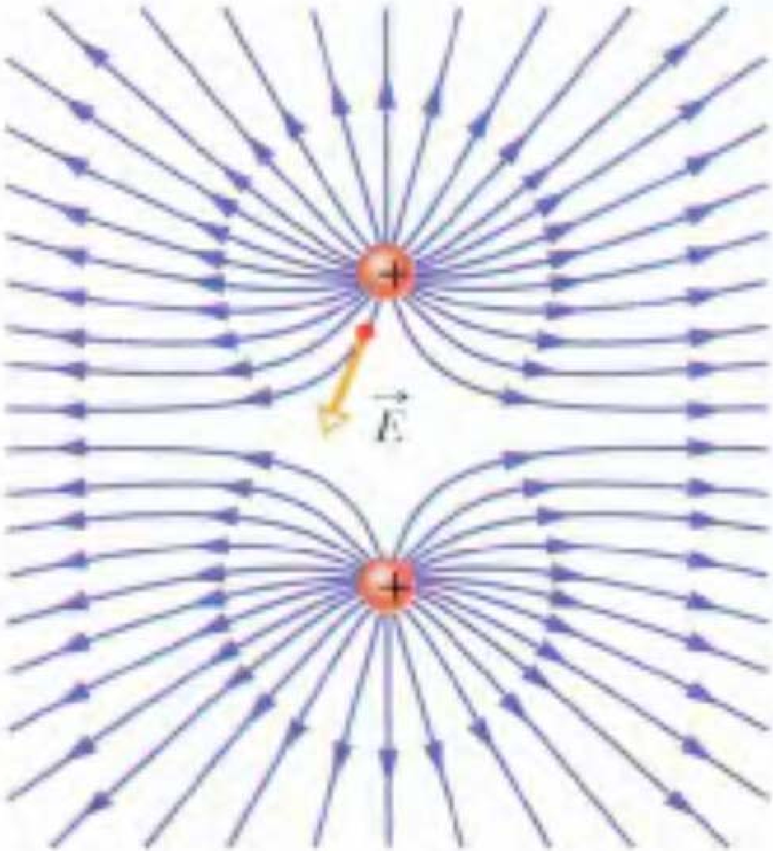
$$\vec{E} = \frac{\vec{F}}{q_0} \qquad \text{(electric field).}$$

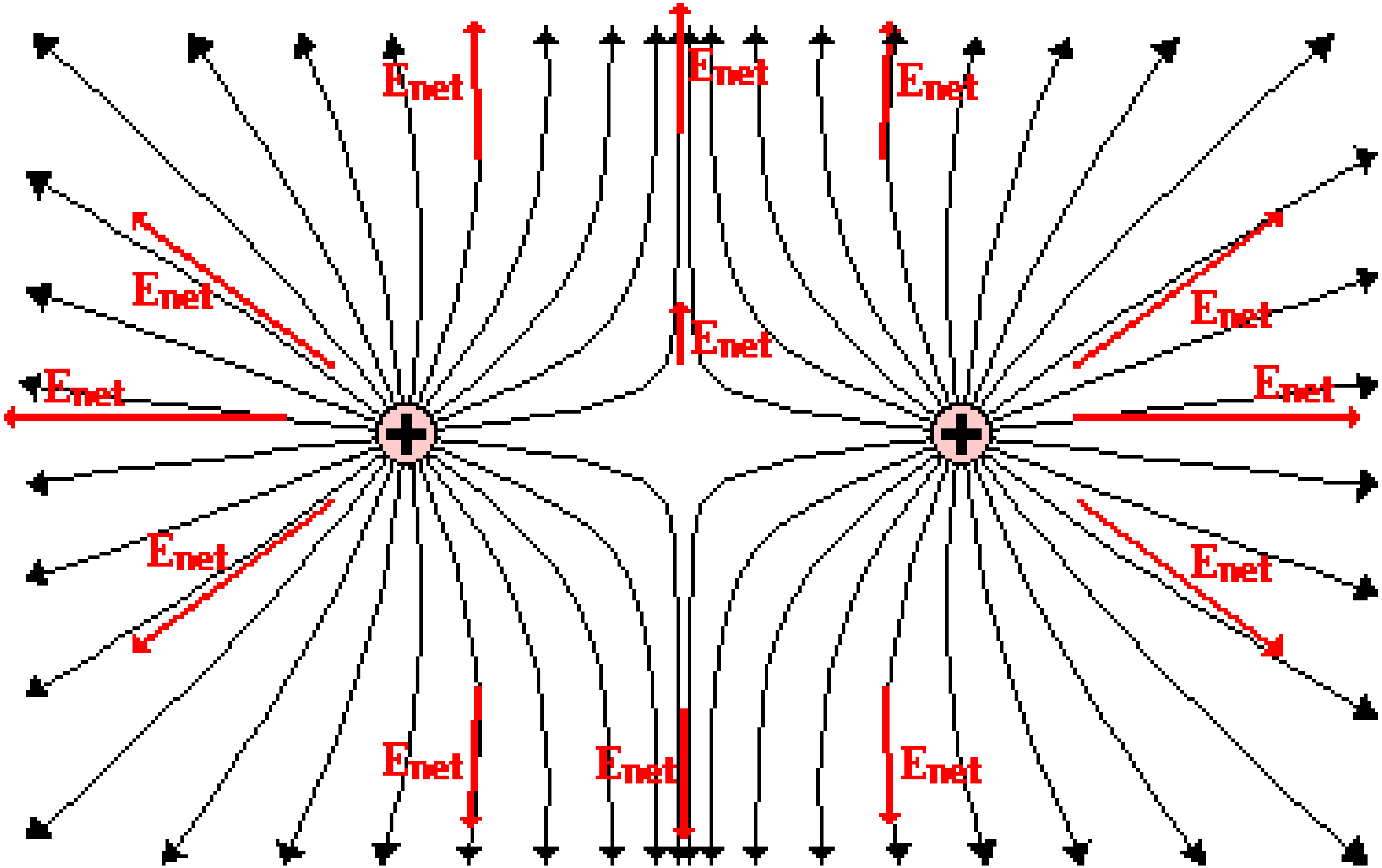
(*a*)



(*b*)



$\vec{E}$



Enet
Enet
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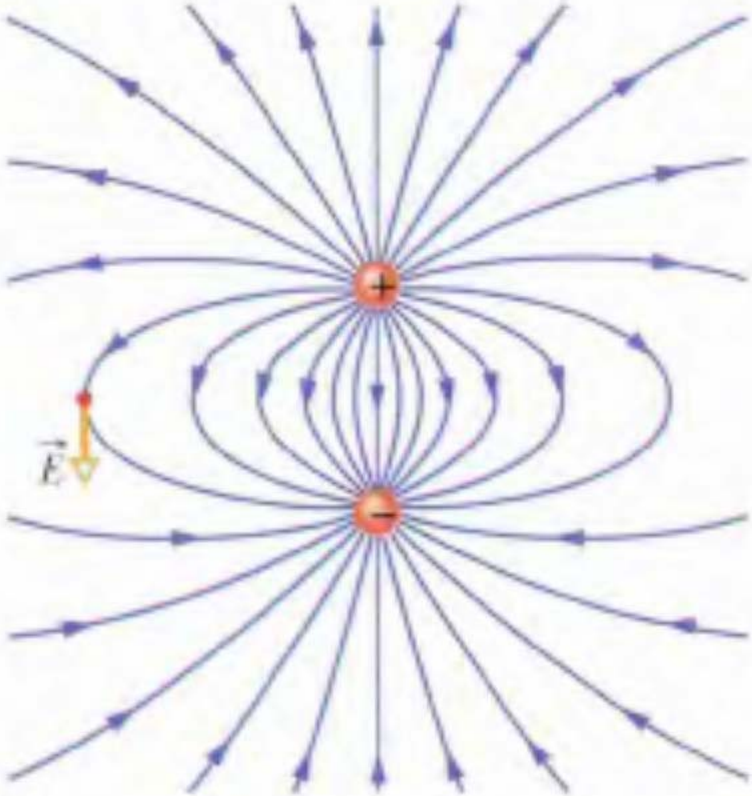
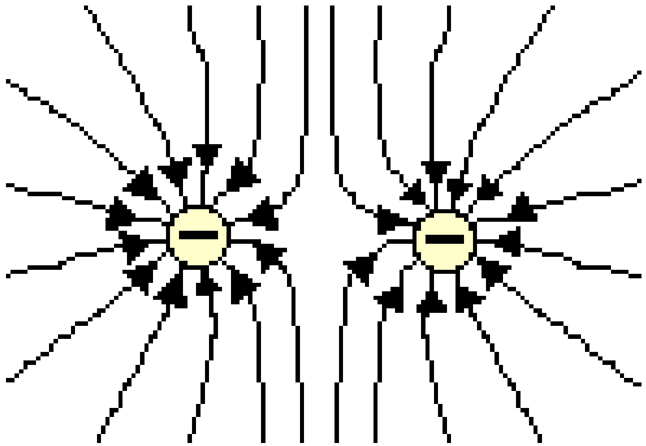
Enet

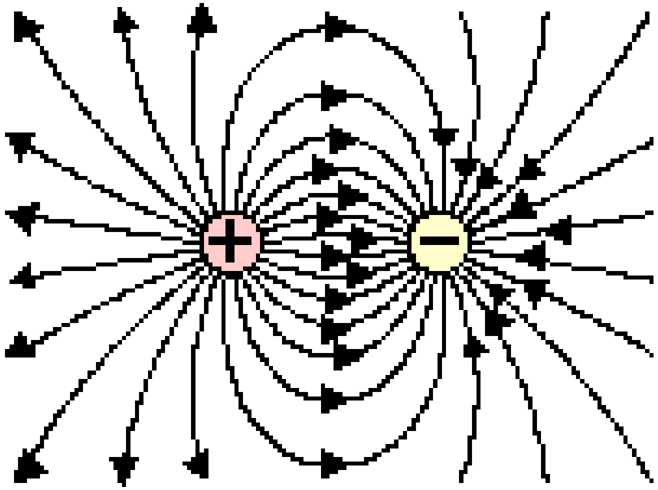


+
−
$\vec{E}$

Other Charge Configurations

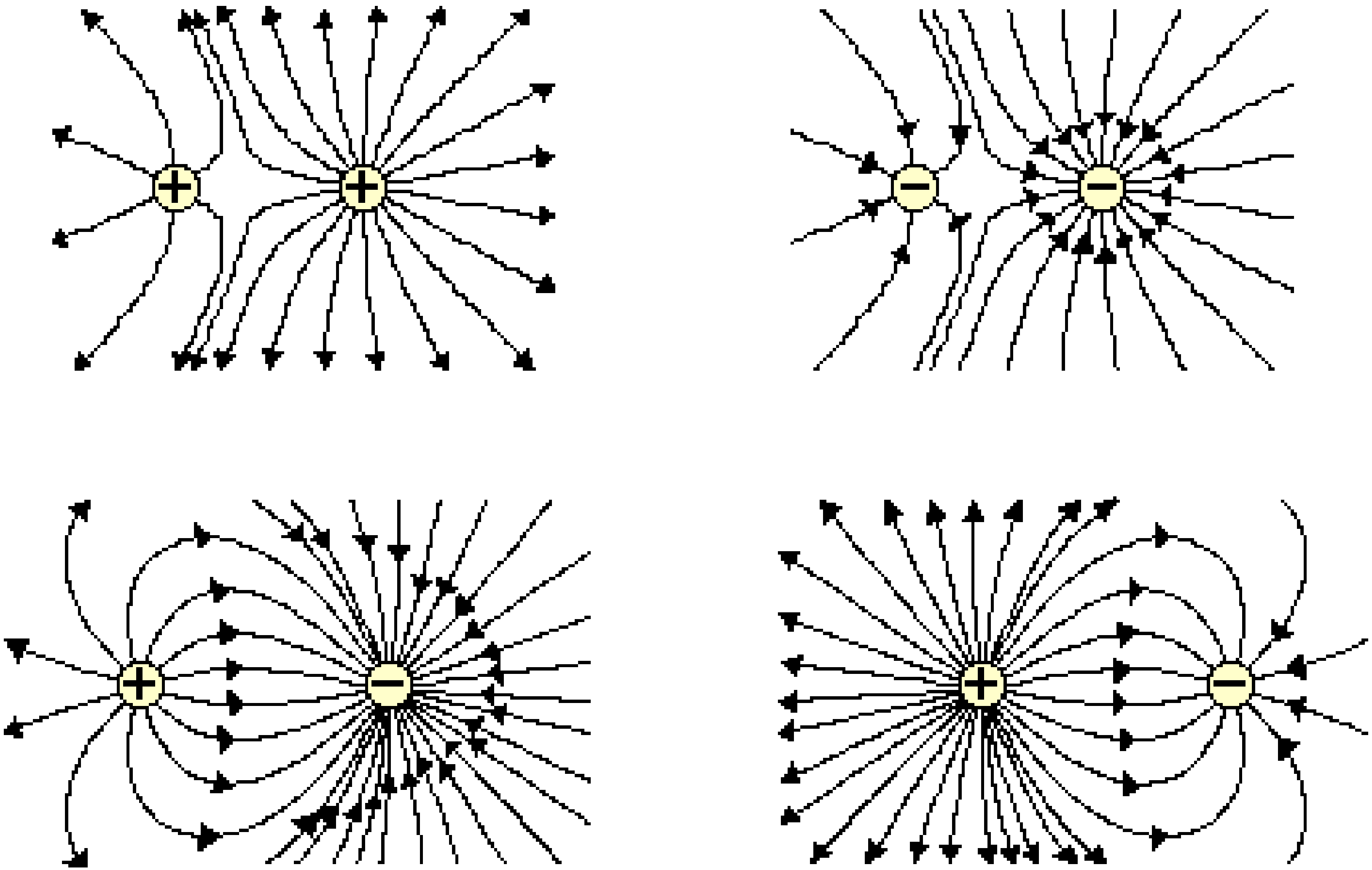


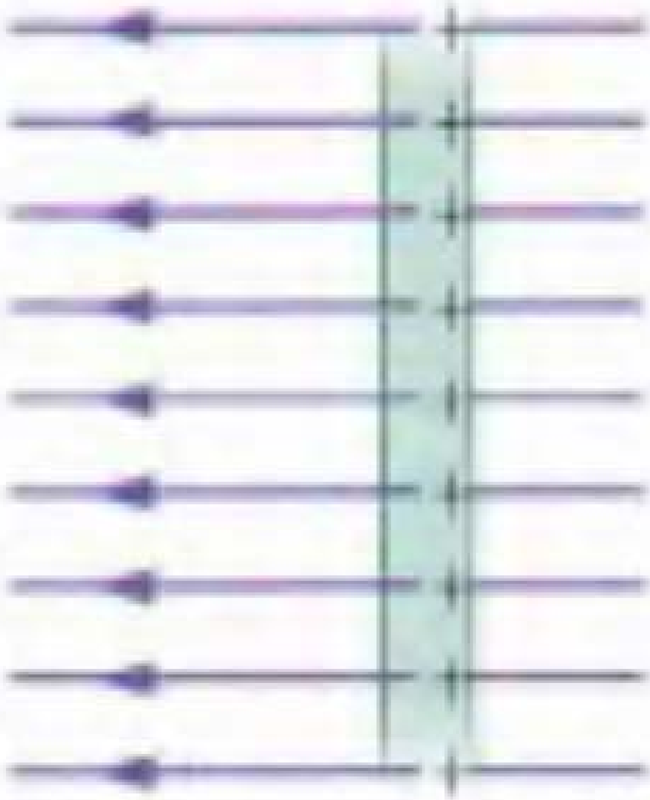
Two Negatively Charged Objects



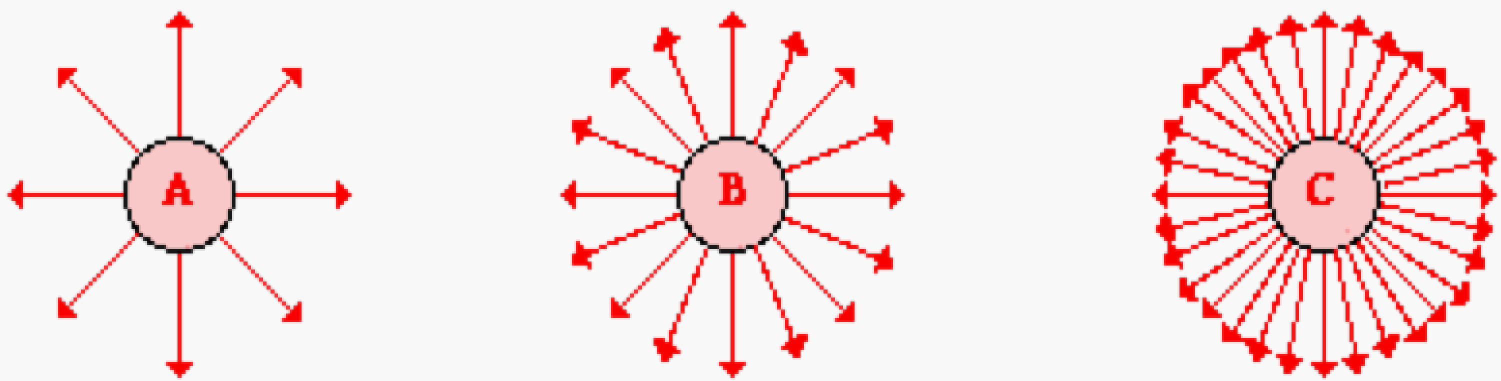
A Positively and a Negatively Charged Object

Electric Field Line Patterns for Objects with Unequal Amounts of Charge

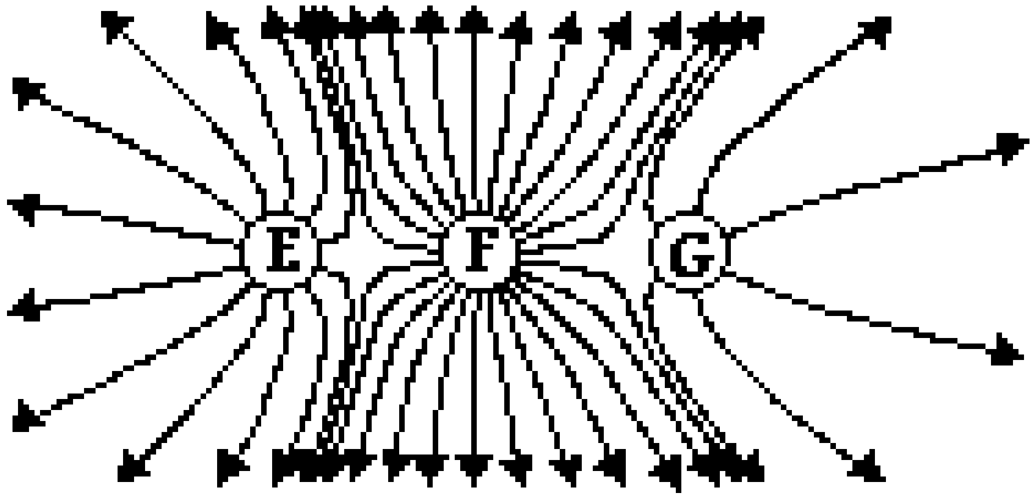


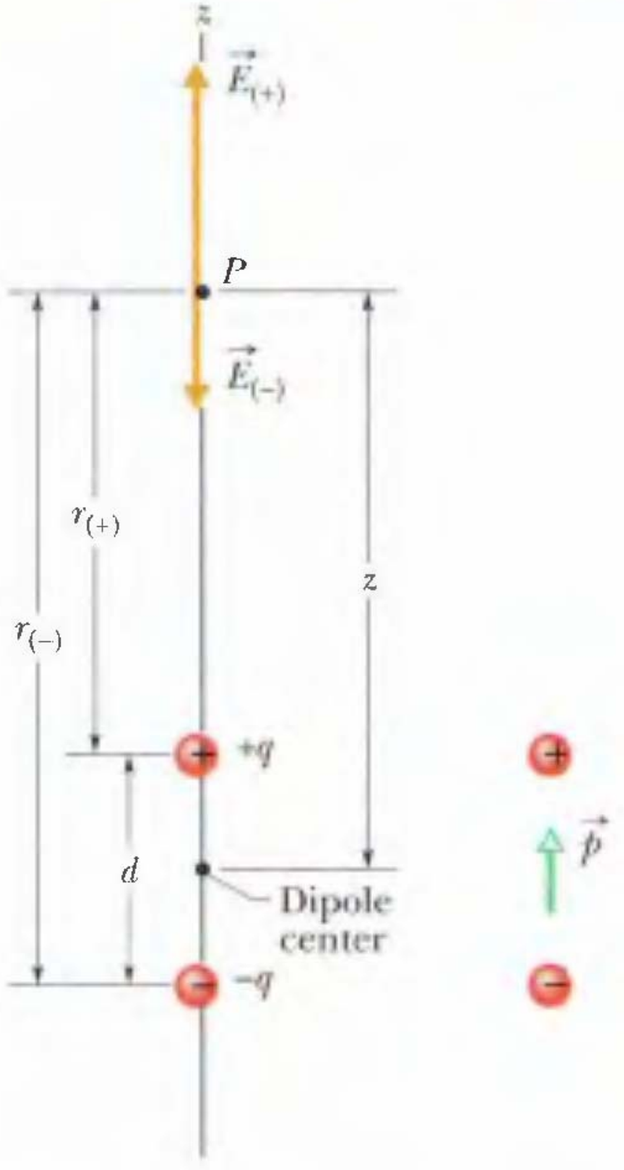


Density of Lines in Patterns

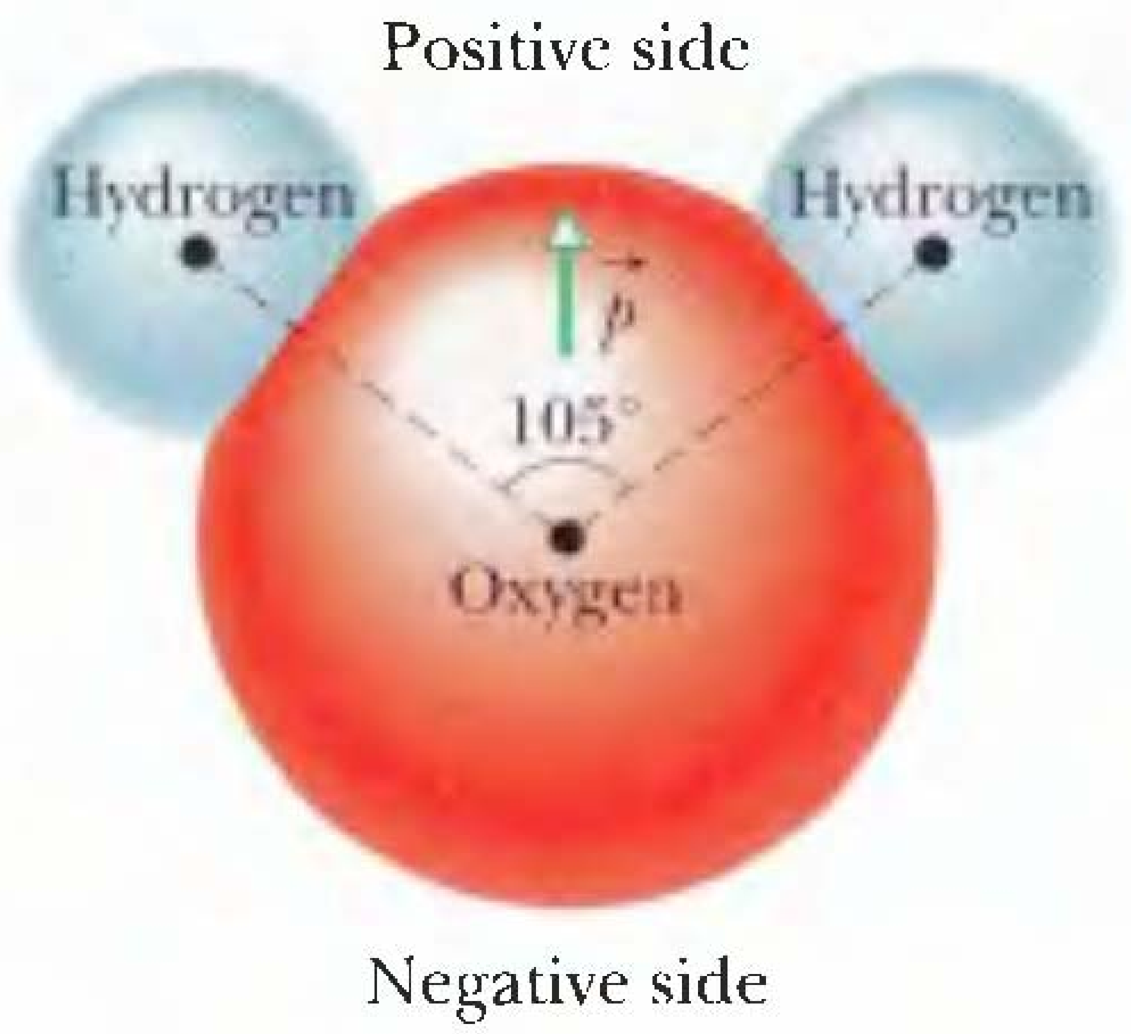


The density of electric field lines around these three objects reveals that the quantity of charge on C is greater than that on B which is greater than that on A.


E
F
G



(a) (b)

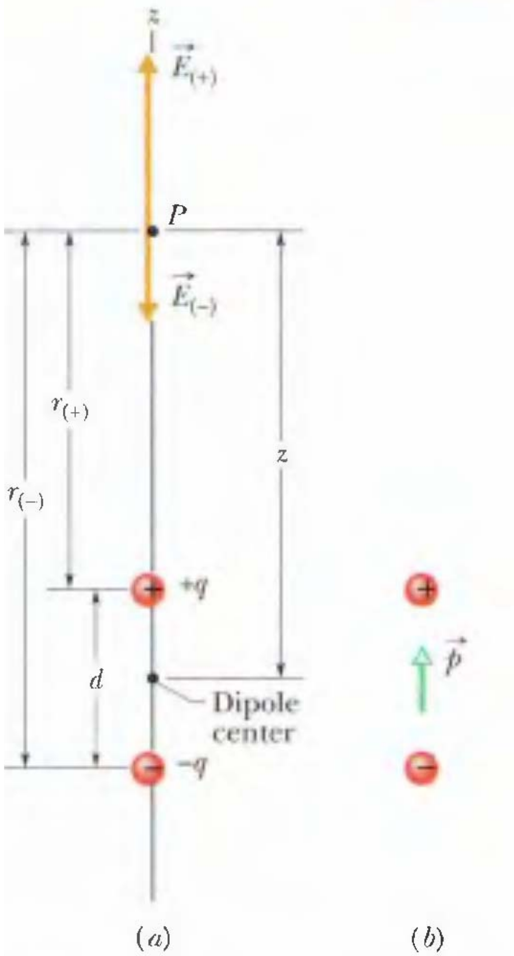


Positive side
Hydrogen
Hydrogen
$\vec{p}$
105°
Oxygen
Negative side

$$E = E_{(+)} - E_{(-)}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(+)}^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(-)}^2}$$

$$= \frac{q}{4\pi\varepsilon_0(z - \frac{1}{2}d)^2} - \frac{q}{4\pi\varepsilon_0(z + \frac{1}{2}d)^2}.$$



ttle algebra, we can rewrite this equation as

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{1}{\left(1 - \frac{d}{2z}\right)^2} - \frac{1}{\left(1 + \frac{d}{2z}\right)^2}\right).$$

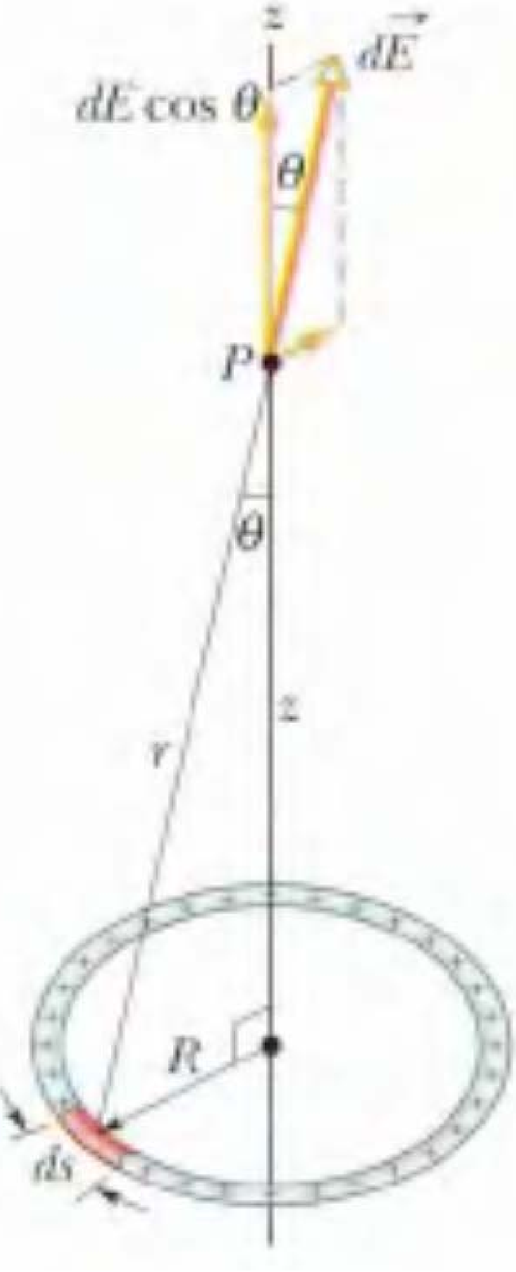
ming a common denominator and multiplying its terms, we come

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\frac{2d/z}{\left(1 - \left(\frac{d}{2z}\right)^2\right)^2} = \frac{q}{2\pi\varepsilon_0 z^3}\frac{d}{\left(1 - \left(\frac{d}{2z}\right)^2\right)^2}.$$

re usually interested in the electrical effect of a dipole only at di
ırge compared with the dimensions of the dipole—that is, at distanc
d. At such large distances, we have $d/2z \ll 1$ in Eq. 22-7. Thus, in
proximation, we can neglect the $d/2z$ term in the denominator, which leaves

$$E = \frac{1}{2\pi\varepsilon_0}\frac{qd}{z^3}.$$

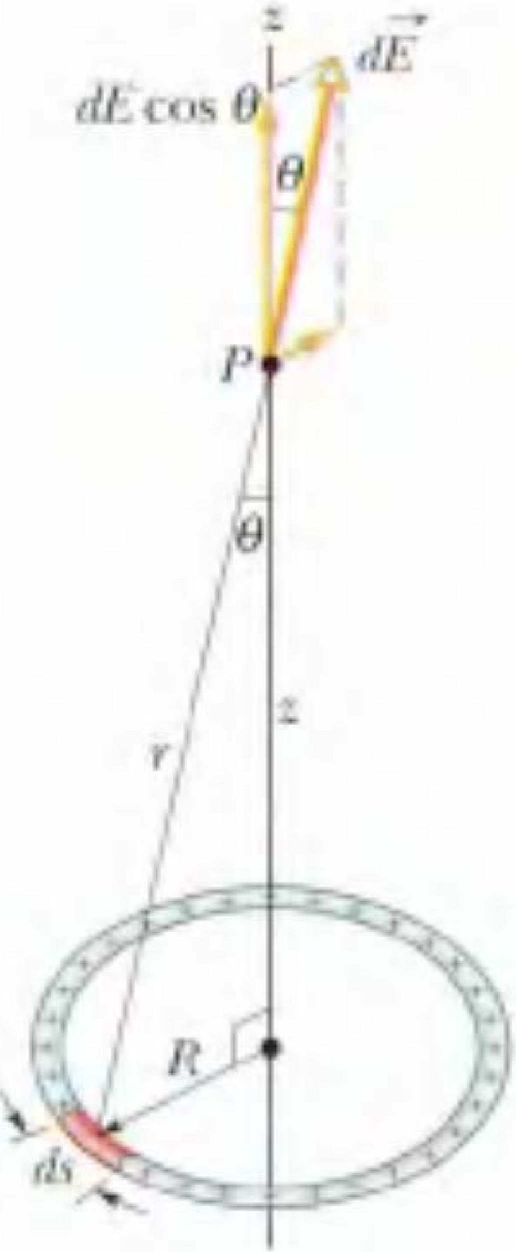
$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3} \qquad \text{(electric dipole).}$$



z
$d\vec{E}$
$dE \cos\theta$
θ
P
θ
z
r
R
ds

Some Measures of Electric Charge

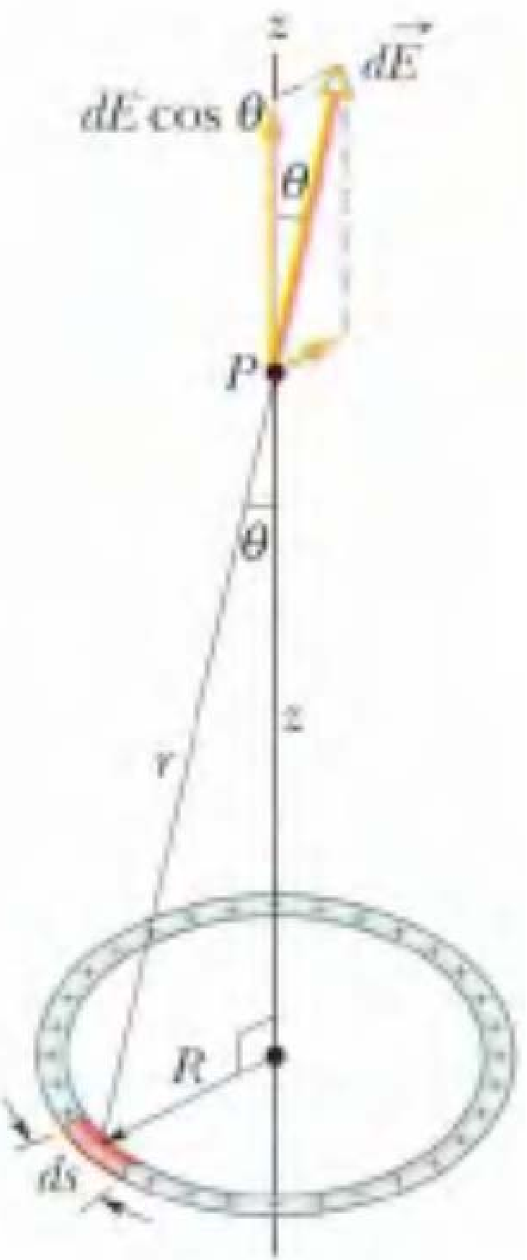
Name	Symbol	SI Unit
Charge	q	C
Linear charge density	λ	C/m
Surface charge density	σ	C/m^2
Volume charge density	ρ	C/m^3



$$dq = \lambda \, ds.$$

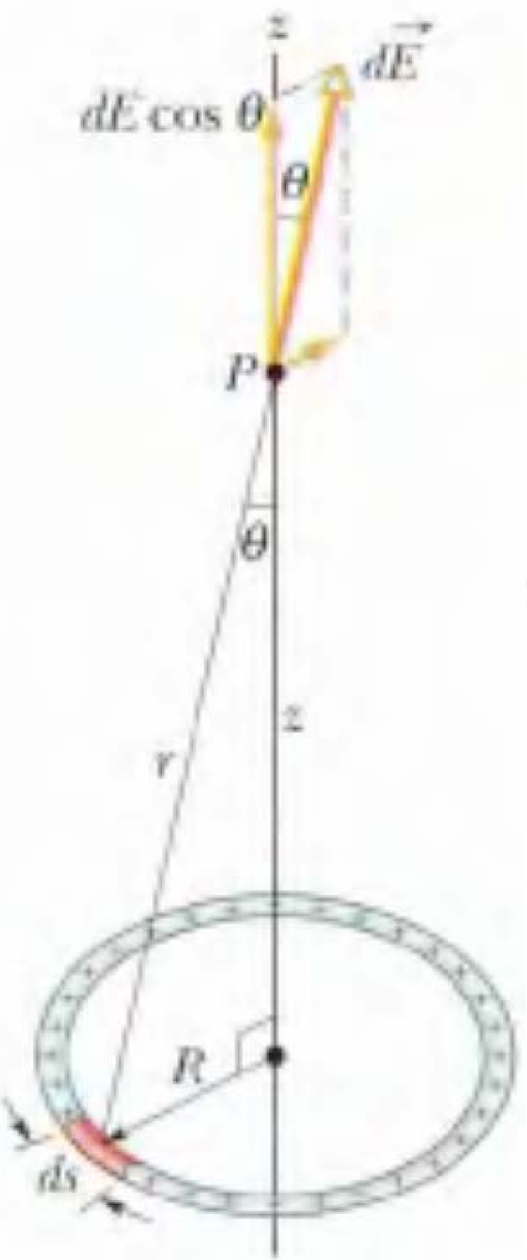
$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{\lambda \, ds}{r^2}.$$

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{\lambda \, ds}{(z^2 + R^2)}.$$



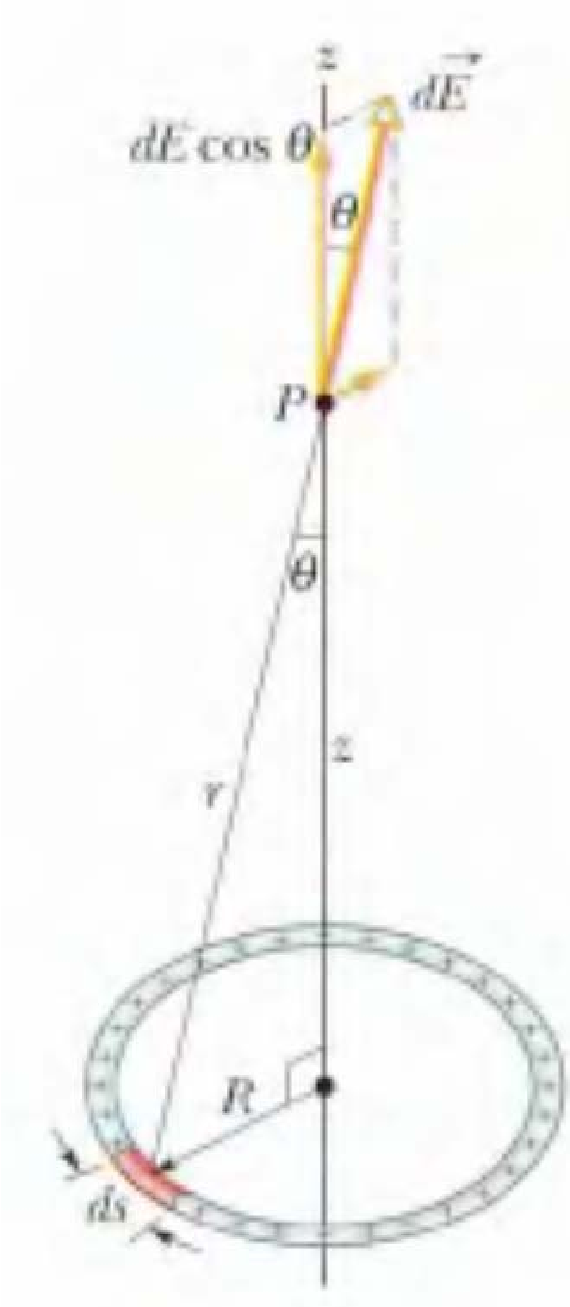
$$\cos\theta = \frac{z}{r} = \frac{z}{(z^2 + R^2)^{1/2}}.$$

$$dE\cos\theta = \frac{z\lambda}{4\pi\varepsilon_0(z^2 + R^2)^{3/2}}\,ds.$$

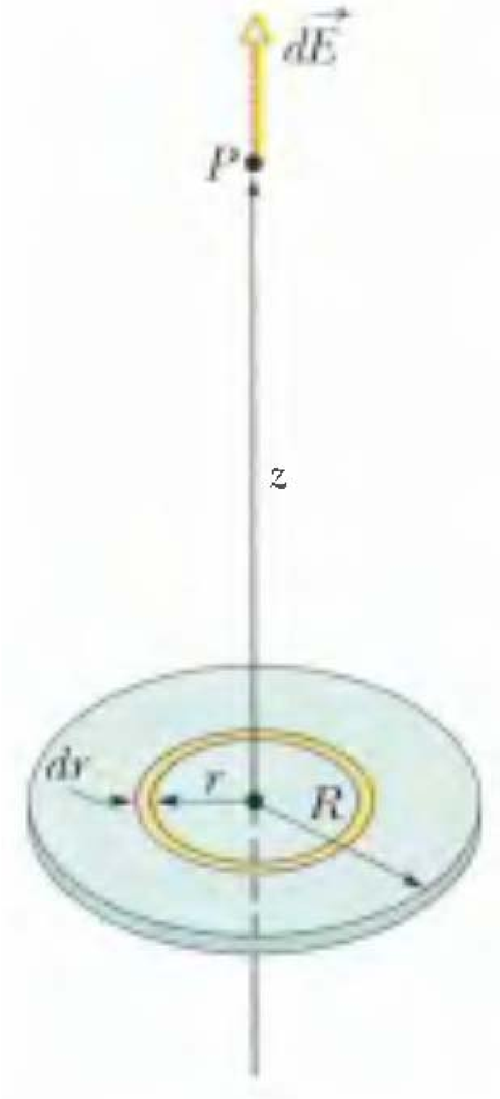


$$= \int dE\cos\theta = \frac{z\lambda}{4\pi\varepsilon_0(z^2 + R^2)^{3/2}} \int_0^{2\pi R} ds$$

$$= \frac{z\lambda(2\pi R)}{4\pi\varepsilon_0(z^2 + R^2)^{3/2}}.$$



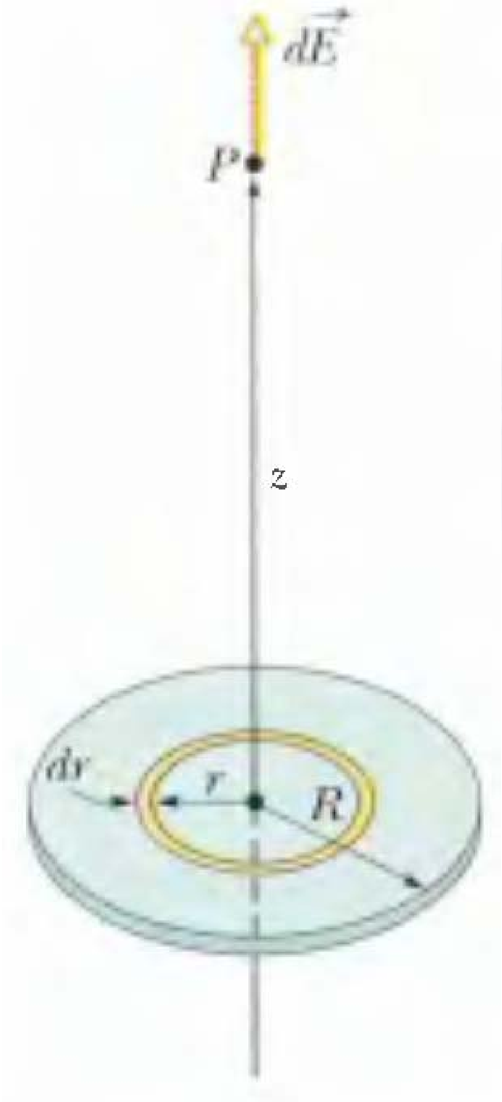
$$E = \frac{qz}{4\pi\varepsilon_0(z^2 + R^2)^{3/2}} \qquad \text{(charged ring)}$$



$$dq = \sigma\, dA = \sigma\,(2\pi r\, dr),$$

$$dE = \frac{z\sigma 2\pi r\, dr}{4\pi\varepsilon_0(z^2 + r^2)^{3/2}},$$

$$dE = \frac{\sigma z}{4\varepsilon_0}\frac{2r\, dr}{(z^2 + r^2)^{3/2}}.$$



$$E = \frac{\sigma}{2\varepsilon_0}\left(1 - \frac{z}{\sqrt{z^2 + R^2}}\right) \qquad \text{(charged disk)}$$

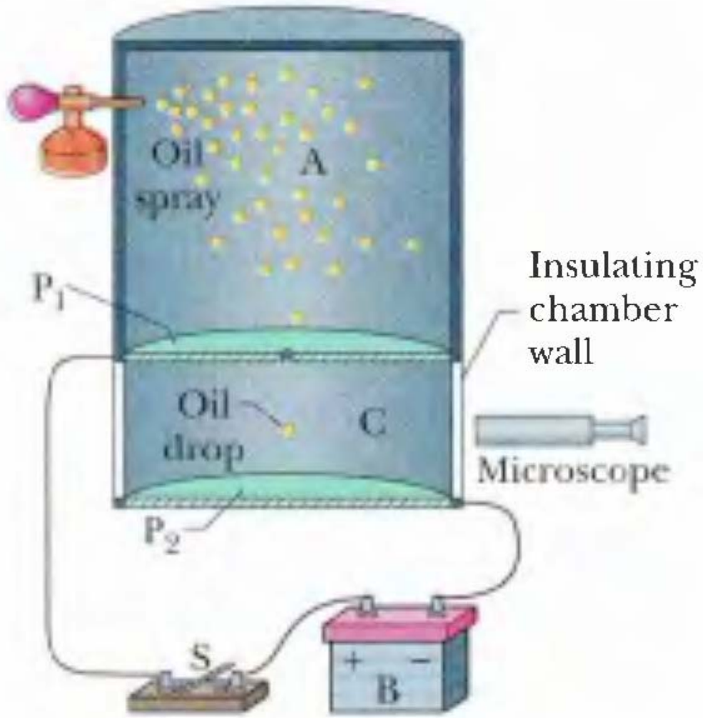


FIG. 22-14 The Millikan oil-drop apparatus for measuring the elementary charge e. When a charged oil drop drifted into chamber C through the hole in plate P_1, its motion could be controlled by closing and opening switch S and thereby setting up or eliminating an electric field in chamber C. The microscope was used to view the drop, to permit timing of its motion.

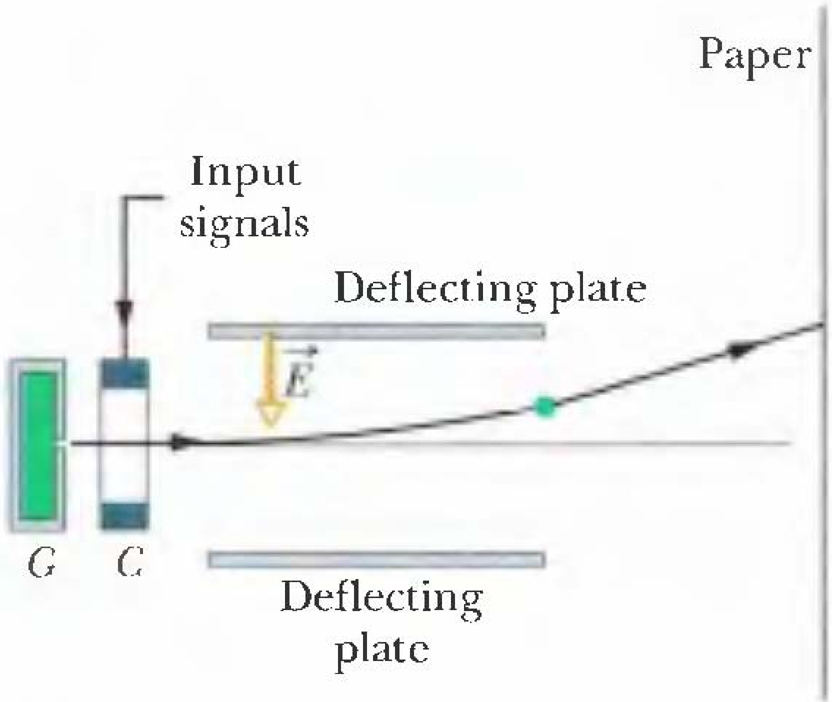
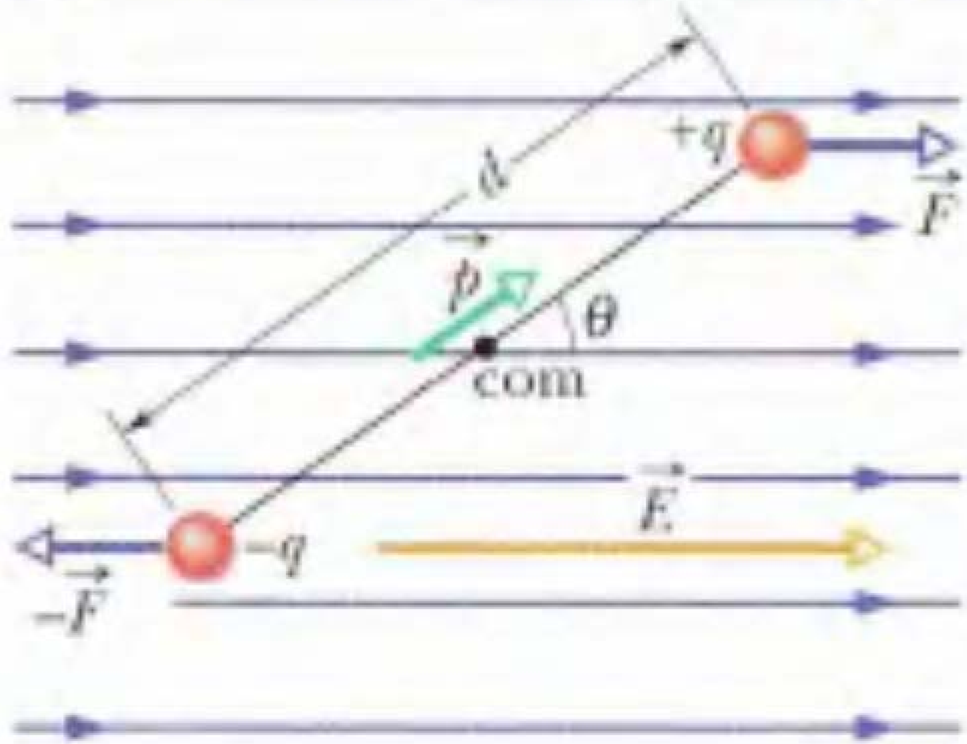
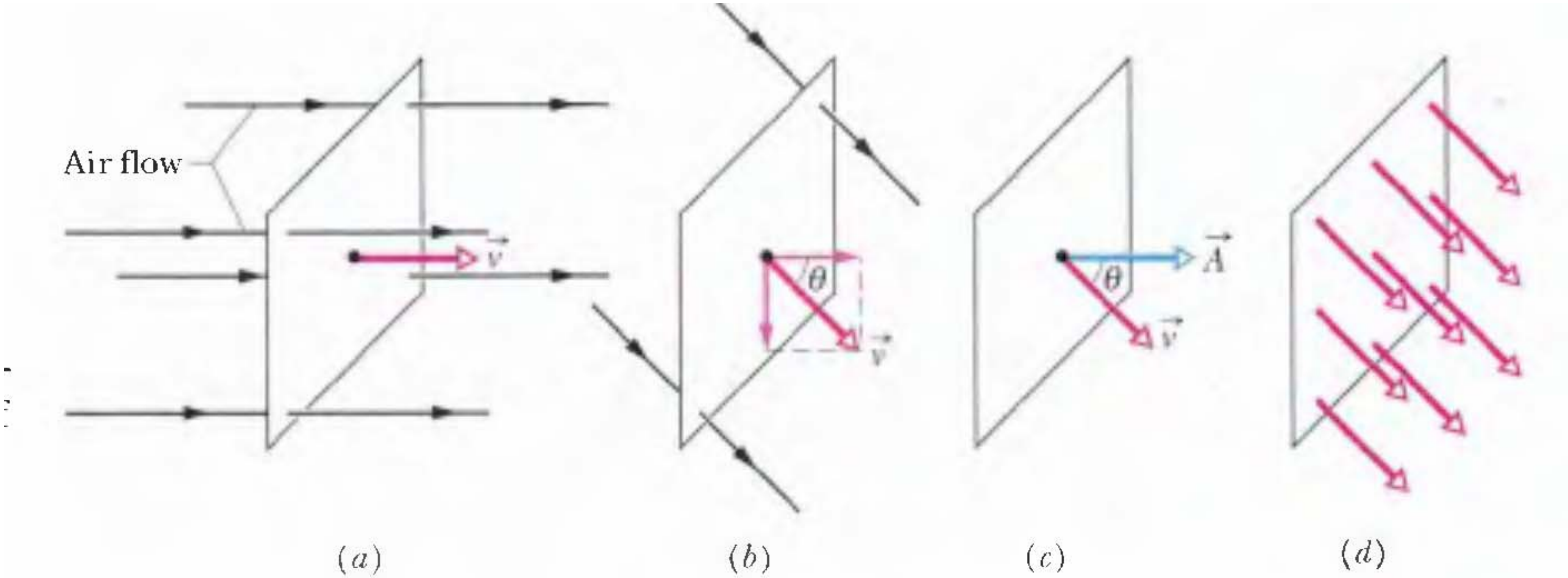


FIG. 22-15 The essential features of an ink-jet printer. Drops are shot out from generator G and receive a charge in charging unit C. An input signal from a computer controls the charge given to each drop and thus the effect of field $\vec{E}$ on the drop and the position on the paper at which the drop lands. About 100 tiny drops are needed to form a single character.



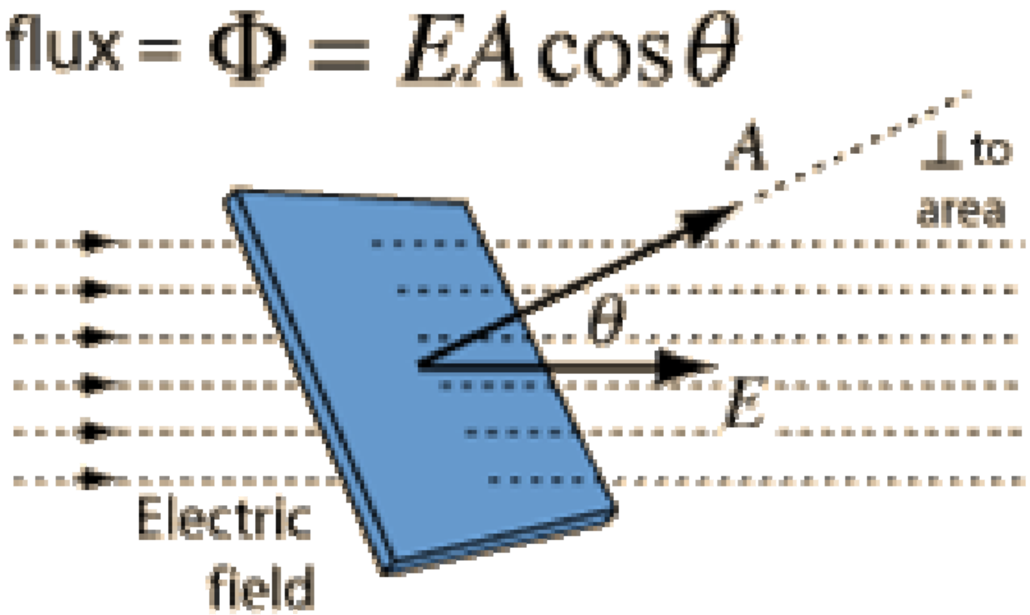
(a)

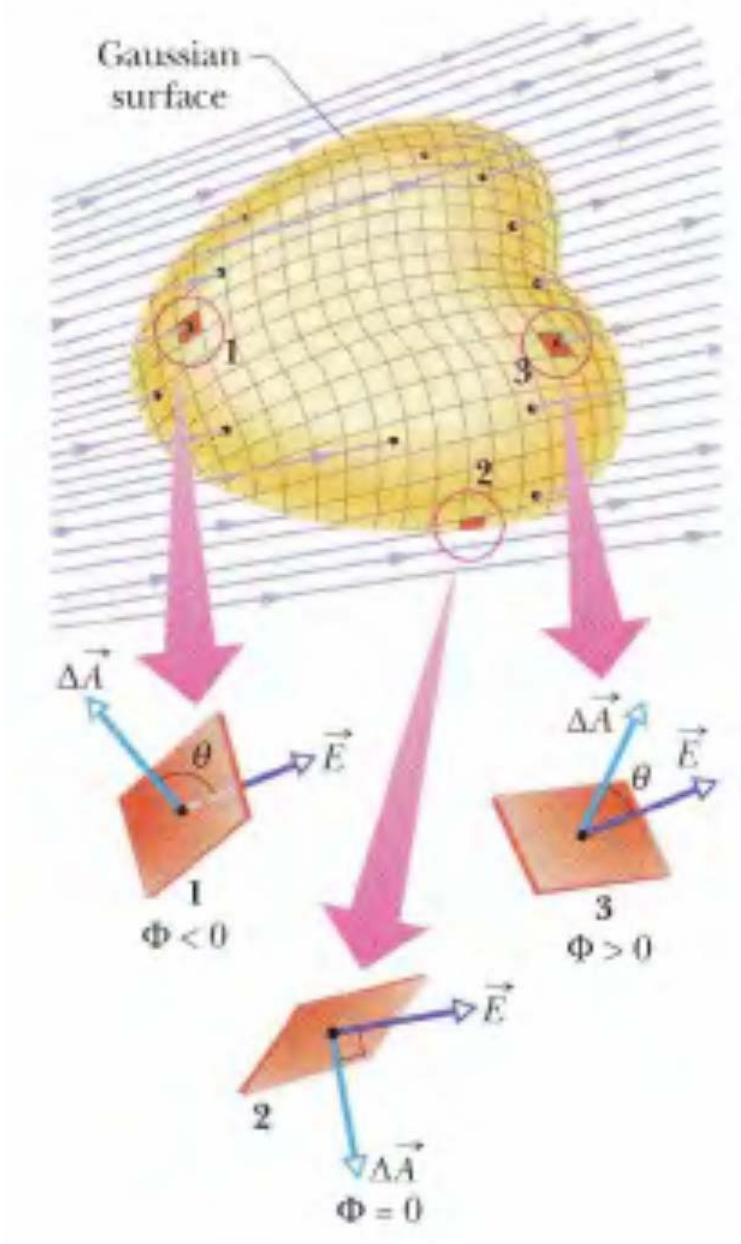
flux



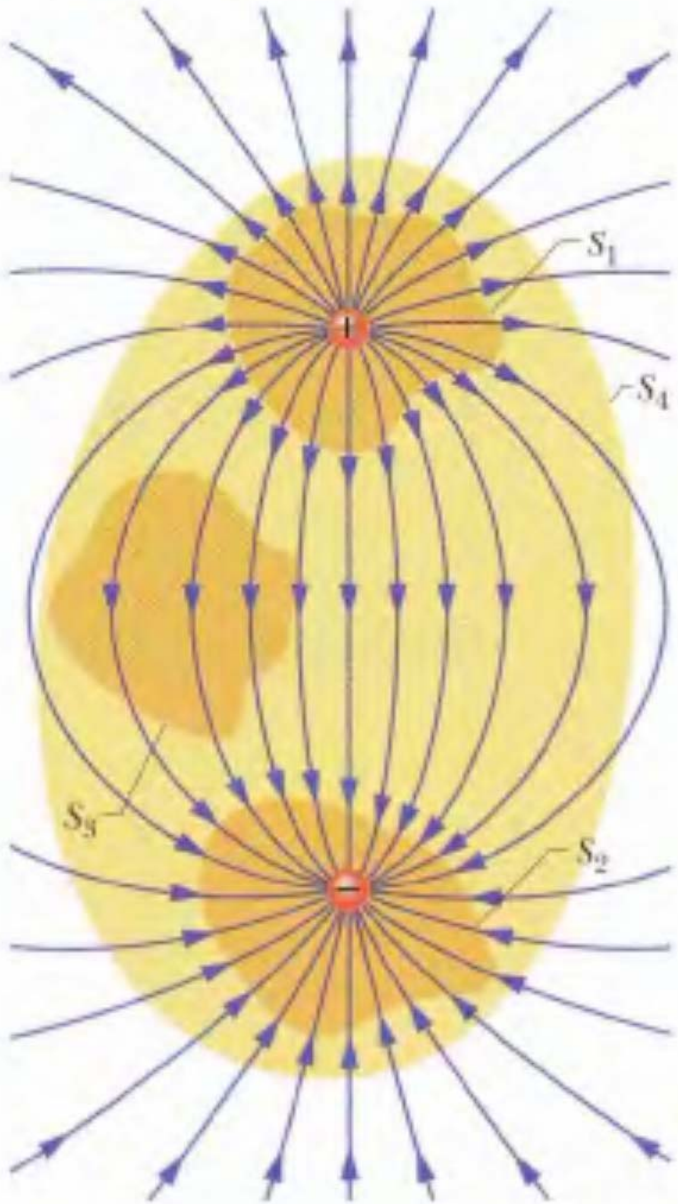
$$\Phi = vA\cos\theta = \vec{v}\cdot\vec{A},$$

electric flux





Gaussian surface
1
2
3
$\Delta\vec{A}$
θ
$\vec{E}$
1
$\Phi < 0$
$\Delta\vec{A}$
θ
$\vec{E}$
3
$\Phi > 0$
$\vec{E}$
2
$\Delta\vec{A}$
$\Phi = 0$



S1
S4
S3
S2

The total of the electric flux out of a closed surface is equal to the charge enclosed divided by the permittivity.

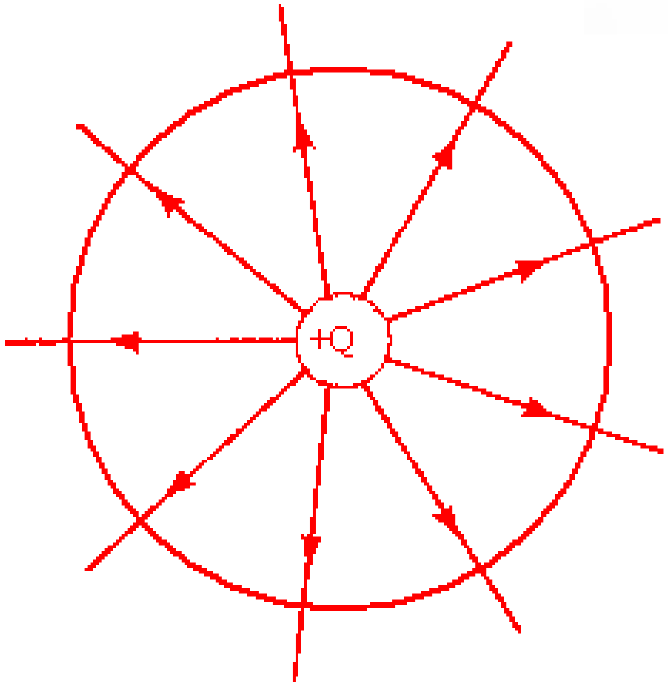
$$\Phi = \oint \vec{E} \cdot d\vec{A} \qquad \text{(electric flux through a Gaussian surface).}$$

$$\varepsilon_0 \Phi = q_{enc} \qquad \text{(Gauss' law).}$$

$$\varepsilon_0 \oint \vec{E} \cdot d\vec{A} = q_{enc} \qquad \text{(Gauss' law).}$$

Gauss' Law and Coulomb's Law

$$\varepsilon_0 \oint \vec{E} \cdot d\vec{A} = \varepsilon_0 \oint E\, dA = q_{\text{enc}}.$$



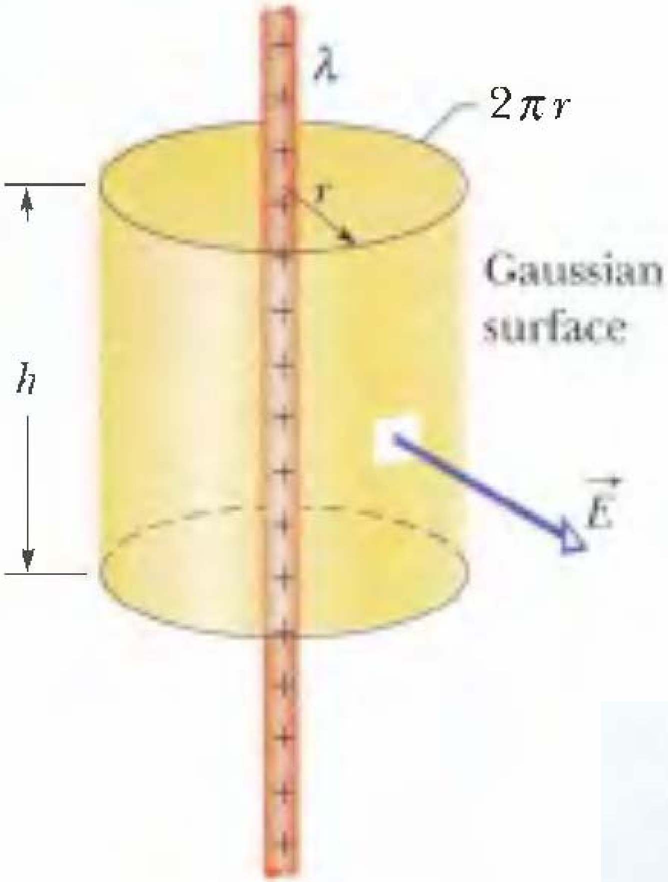
$$\varepsilon_0 E \oint dA = q.$$

$$\varepsilon_0 E(4\pi r^2) = q$$

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

Applying Gauss' Law: Cylindrical Symmetry

$$\Phi = EA\cos\theta = E(2\pi rh)\cos 0 = E(2\pi rh).$$



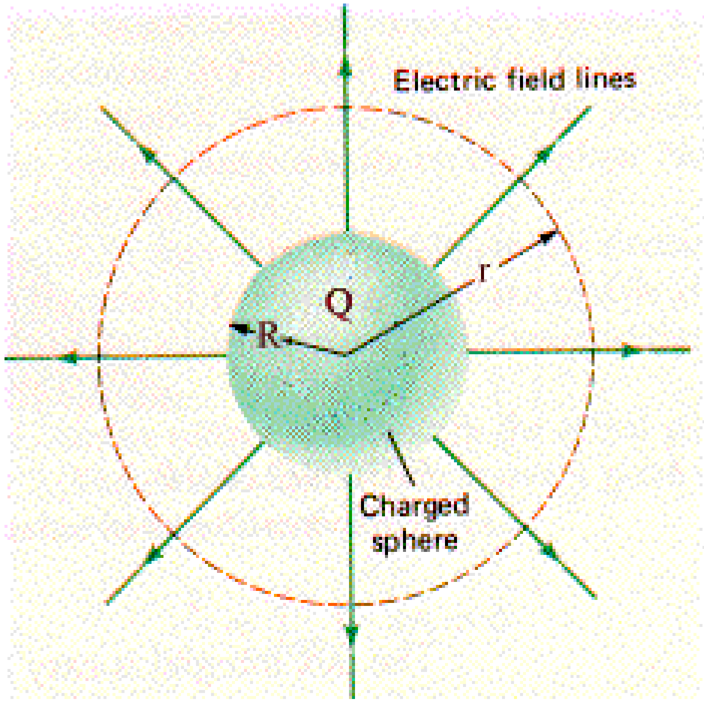
$$\varepsilon_0 \Phi = q_{enc},$$

$$\varepsilon_0 E(2\pi rh) = \lambda h,$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} \quad \text{(line of charge).}$$

Electric field for a uniform sphere of charge

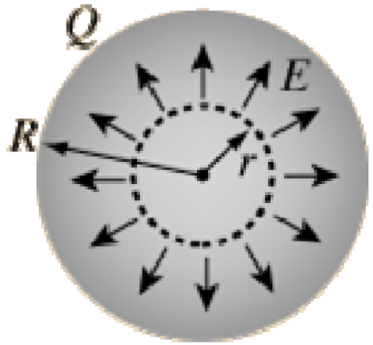
r > R



$$\Phi = EA = E4\pi r^2 = \frac{Q}{\varepsilon_0}$$

For $r > R$

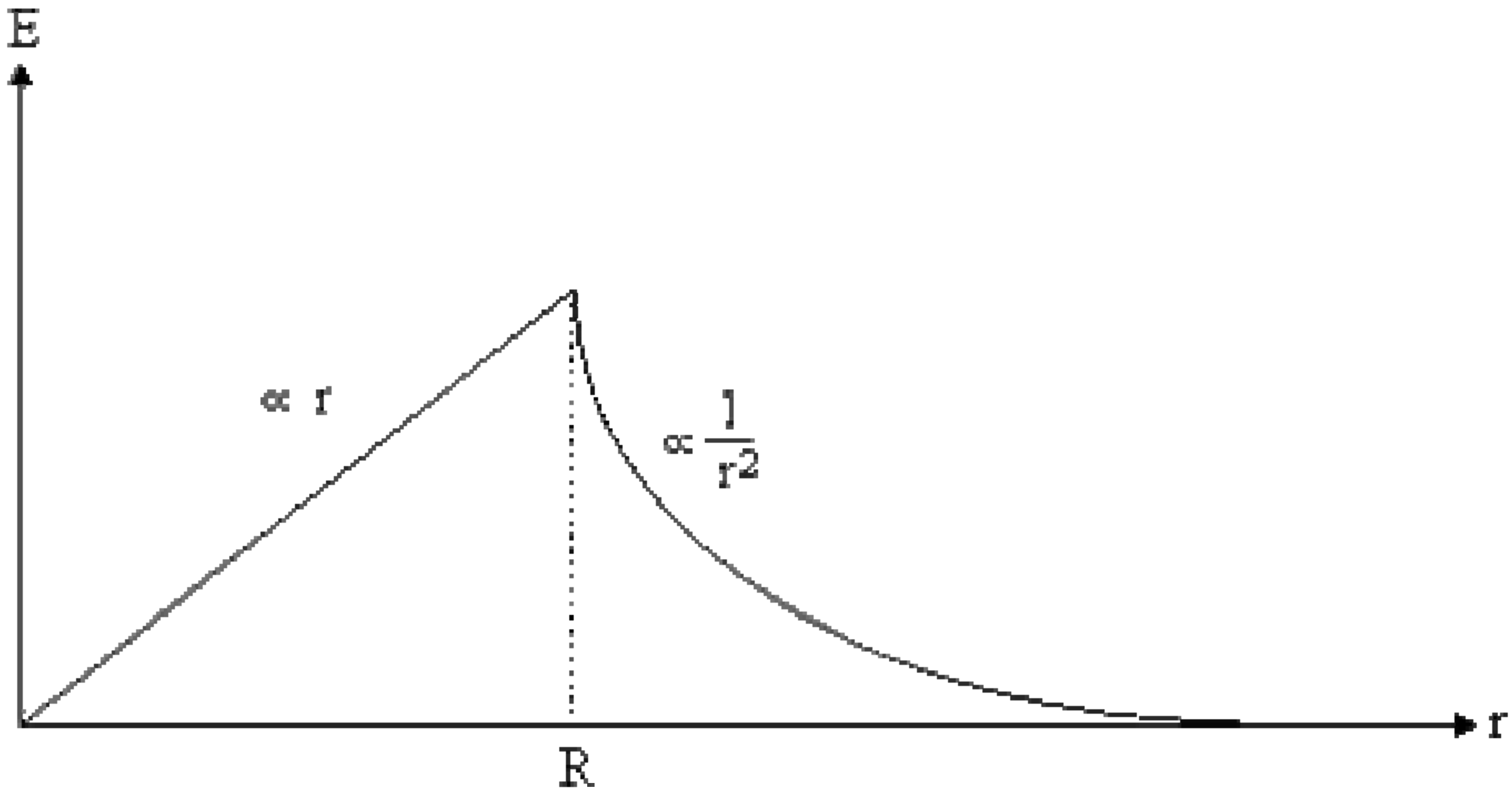
$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$



$$\frac{Q'}{Q} = \frac{\frac{4}{3}\pi r^3}{\frac{4}{3}\pi R^3} \quad \text{or} \quad Q' = Q\frac{r^3}{R^3}$$

$$\Phi = E4\pi r^2 = \frac{Qr^3}{\varepsilon_0 R^3}$$

$$E = \frac{Qr}{4\pi\varepsilon_0 R^3}$$


E
∝ r
∝ 1/r²
R
r