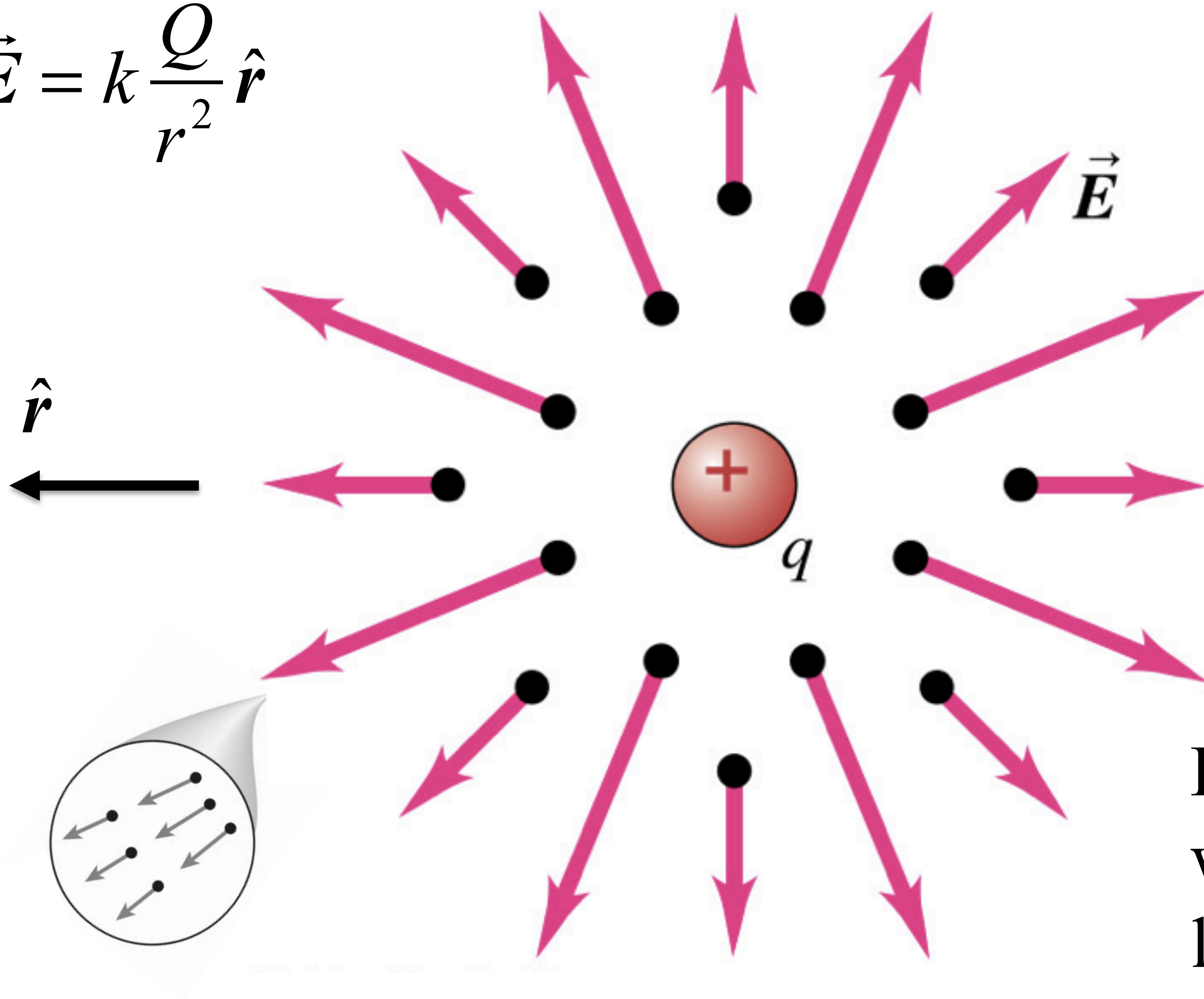
Chapter 20: Electric Charge, Force & Field
Chapter 21: Gauss' law
Tuesday September 6th

- Reminders and Brief Review
  - Coulomb's law
  - Electric fields
- Electric dipoles
  - Electric field due to a dipole
  - Some properties of dipoles
- Continuous charge distributions
  - Electric field due to a line of charge
  - Charge densities
- Intro. to Gauss' law (if time)

Reading: pages 335 – 354 in the text book (Chs. 20/21)

Electric fields

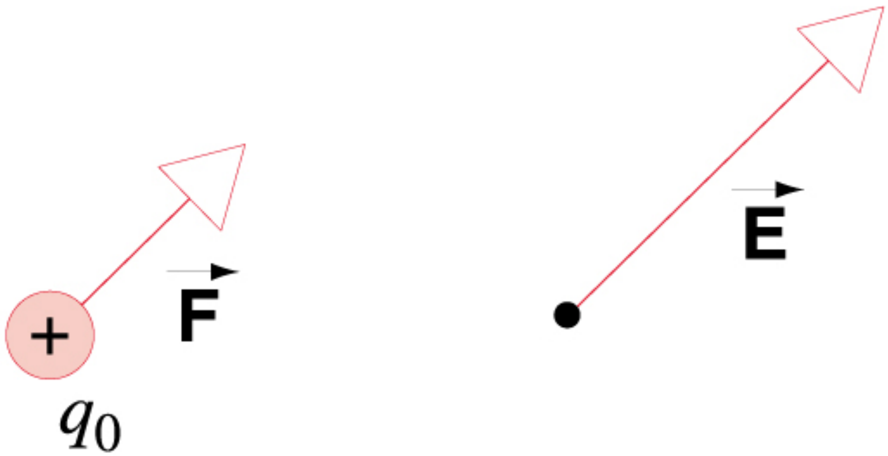
$$\vec{E} = k\frac{Q}{r^2}\hat{r}$$



Field gets weaker at larger distances

Electric fields

Newton's law for electrostatics:



$$\vec{F} = q_0 \vec{E}$$

There's really no need for the "test charge"

$$\vec{F} = q\vec{E}$$

This is the force on a charge q in an electric field $\vec{E}$

Units for E are N/C in this chapter
(later we shall use volts per meter)

Electric fields

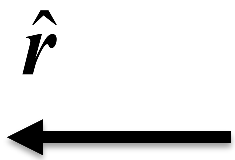
Some Electric Fields

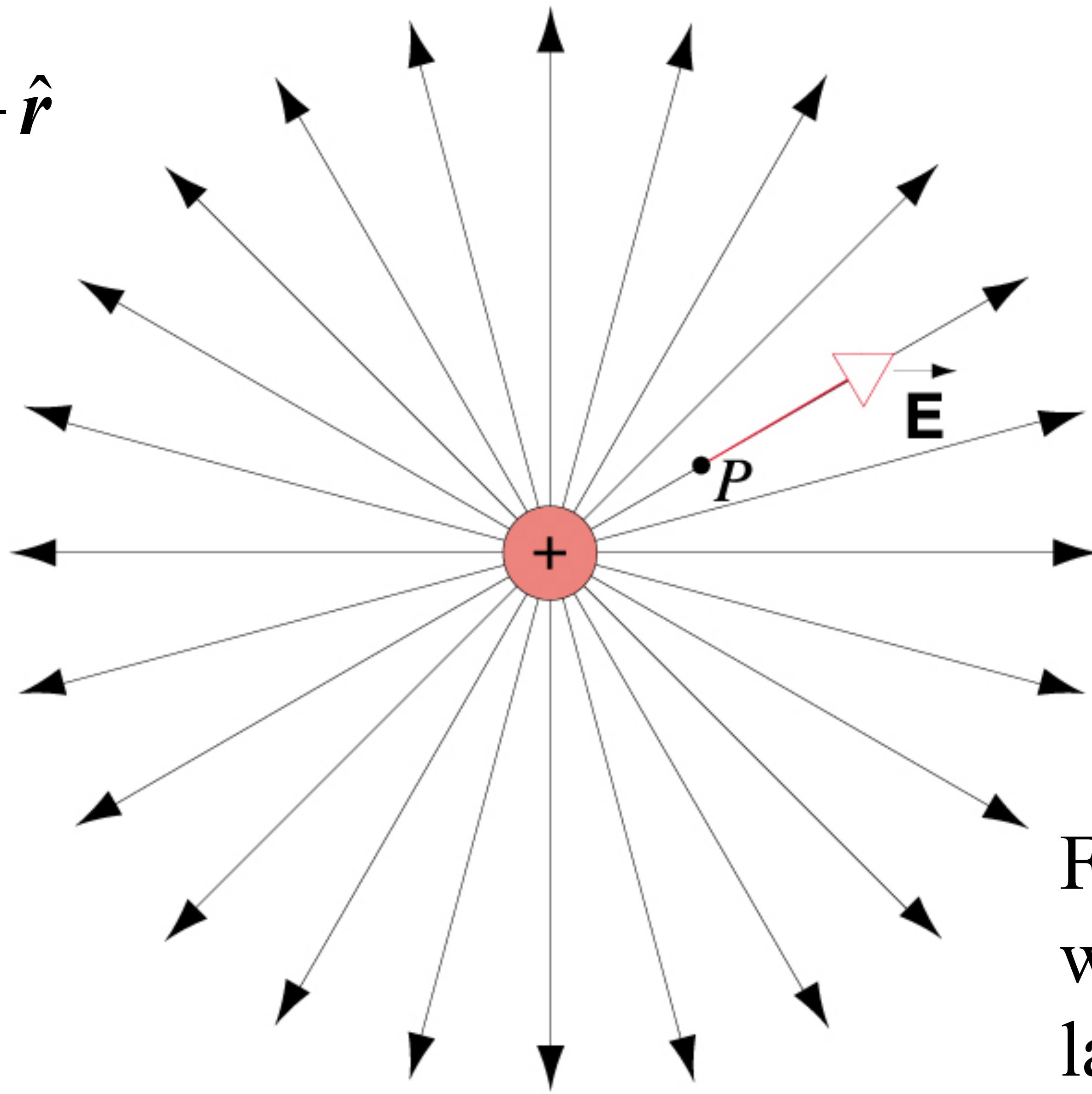
Location	*Electric Field* (N/C) **(V/m)**
At the surface of a uranium nucleus	3×10^{21}
In a hydrogen atom, at the electron's average radius	5×10^{11}
Electric breakdown occurs in air	3×10^{6}
At the charged drum of a photocopier	10^{5}
The electron beam accelerator in a TV set	10^{5}
Near a charged plastic comb	10^{3}
In the lower atmosphere	10^{2}
Inside the copper wire of household circuits	10^{-2}

Units for *E* are N/C in this chapter
(later we shall use volts per meter)

Electric field lines

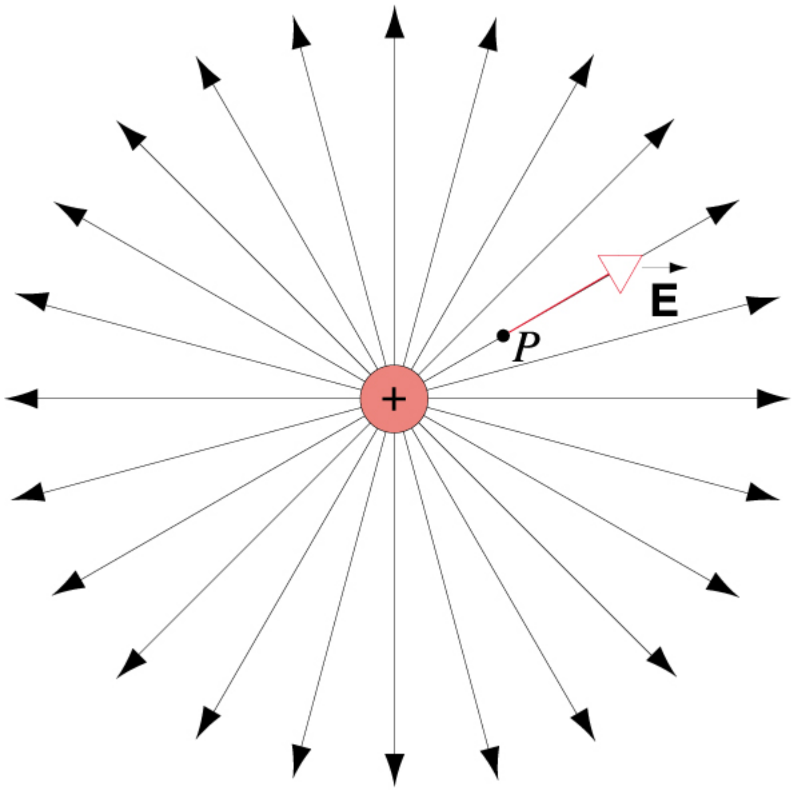
$$\vec{E} = k\frac{Q}{r^2}\hat{r}$$

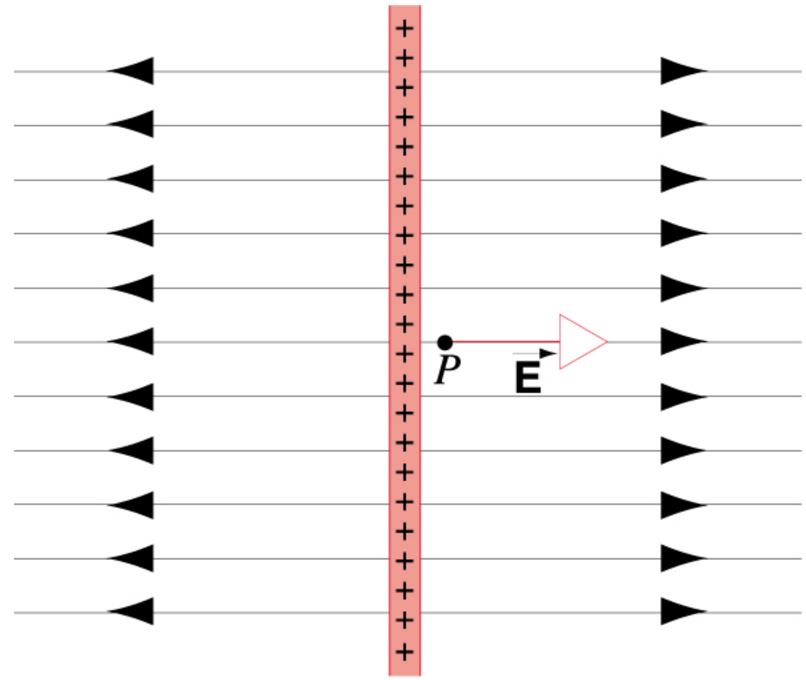




Field gets weaker at larger distances

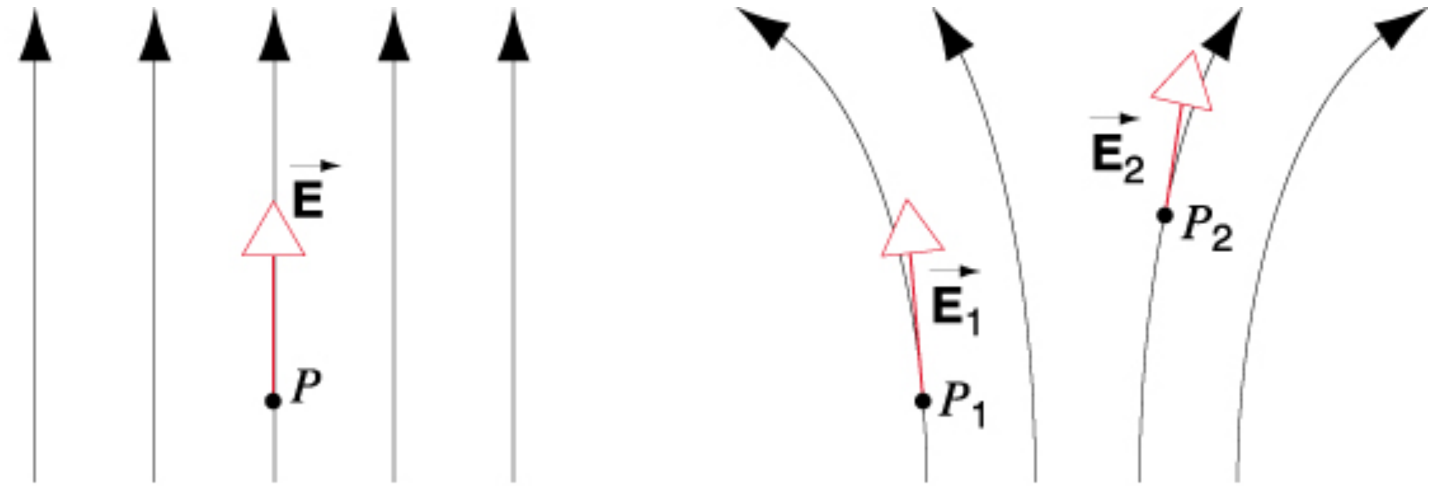
Electric field lines





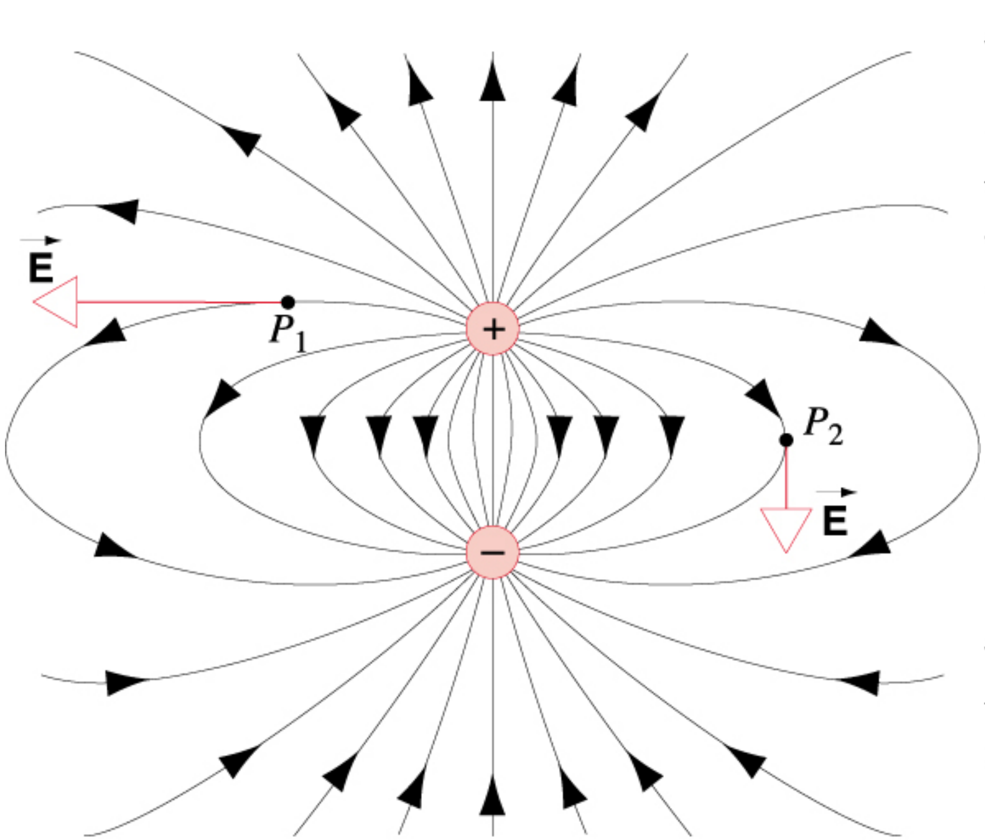
- Electric field lines start on positive charges and end on negative charges (can also start/end at infinity).
- The symmetry of the problem dictates the directions in which field lines radiate from charges.

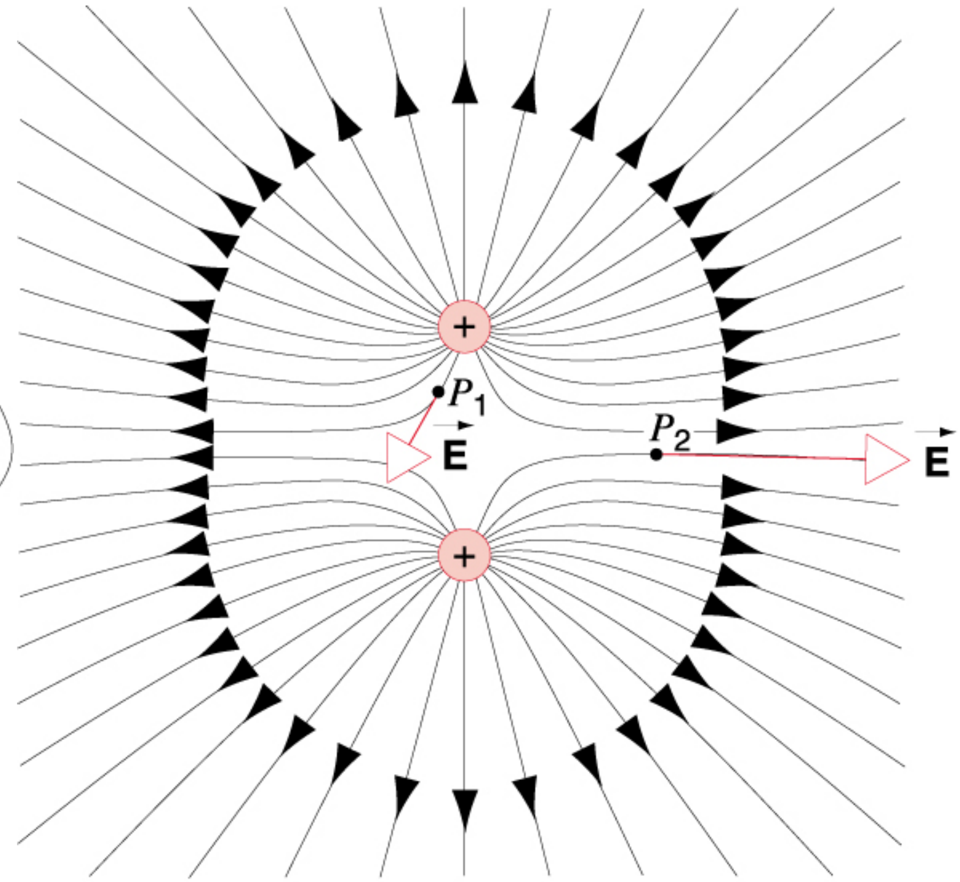
Electric field lines



- The tangent to an electric field line at a point in space gives the direction of the electric field at that point.
- The magnitude of the electric field at any point is proportional to the number of field lines per unit cross-sectional area perpendicular to the lines (tightness of their spacing).
- Plus charges experience a force parallel to the field lines; negative charges in the opposite direction.

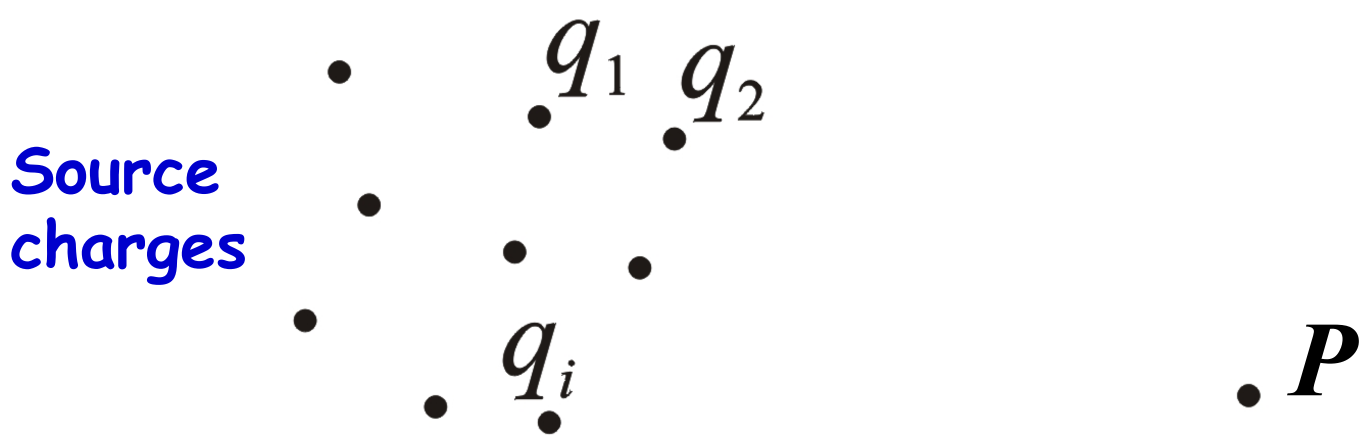
Electric field lines





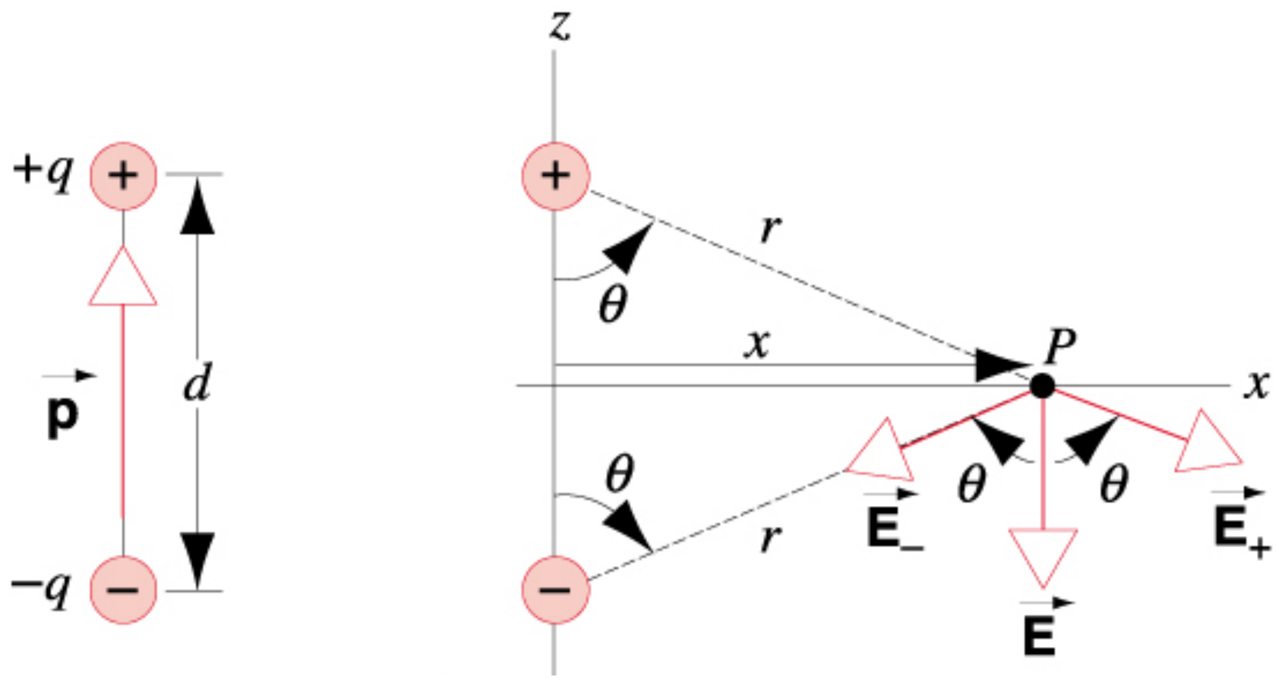
- The number of field lines radiating from a charge is proportional to the charge.
- Field lines cannot cross (why?)

Superposition principle



$$\vec{E}_P = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots \vec{E}_i = \sum_i \vec{E}_i$$

The Electric Dipole

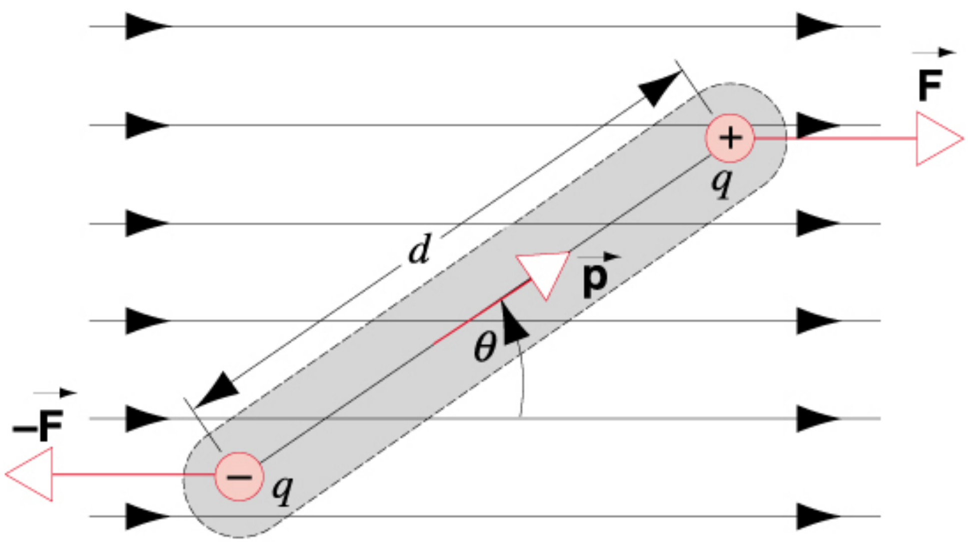


Dipole moment: $p = qd$ *or* $\vec{\mathbf{p}} = q\vec{\mathbf{d}}$

On the median plane (along *x* axis): $E_z = -\dfrac{1}{4\pi\varepsilon_o}\dfrac{p}{x^3}$ $\quad (x >> d)$

On the dipole axis (along *z* axis): $E_z = \dfrac{1}{2\pi\varepsilon_o}\dfrac{p}{z^3}$ $\quad (z >> d)$

A Dipole in an Electric Field

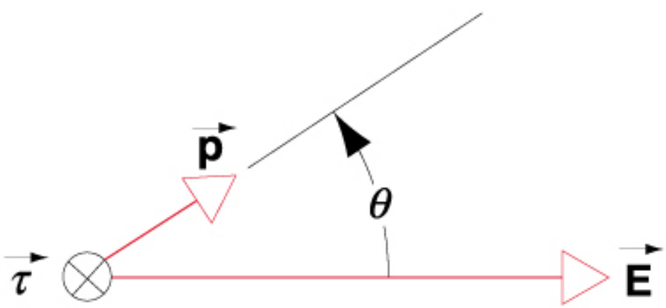


$$\tau = Fd\sin\theta$$

$$= qdE\sin\theta$$

$$= pE\sin\theta$$

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

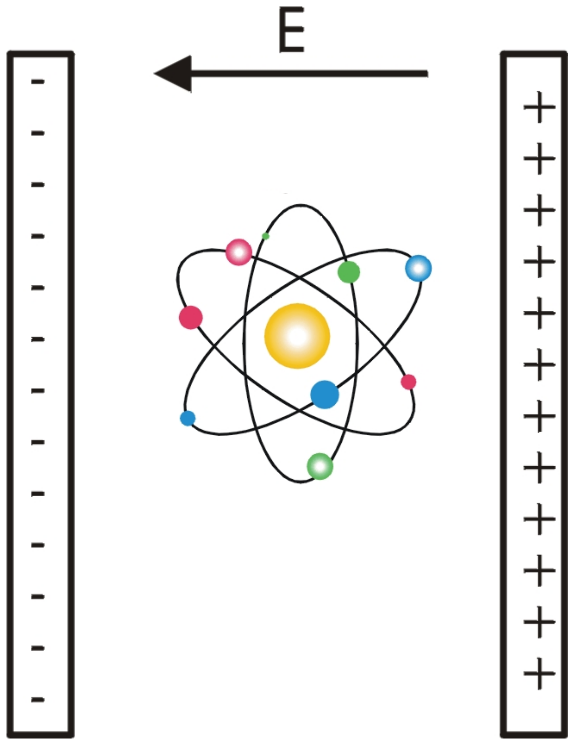


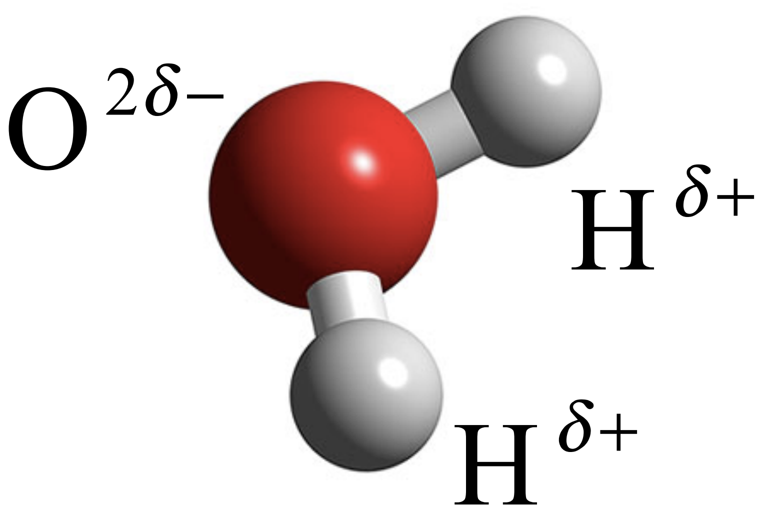
$$U = -pE\cos\theta$$

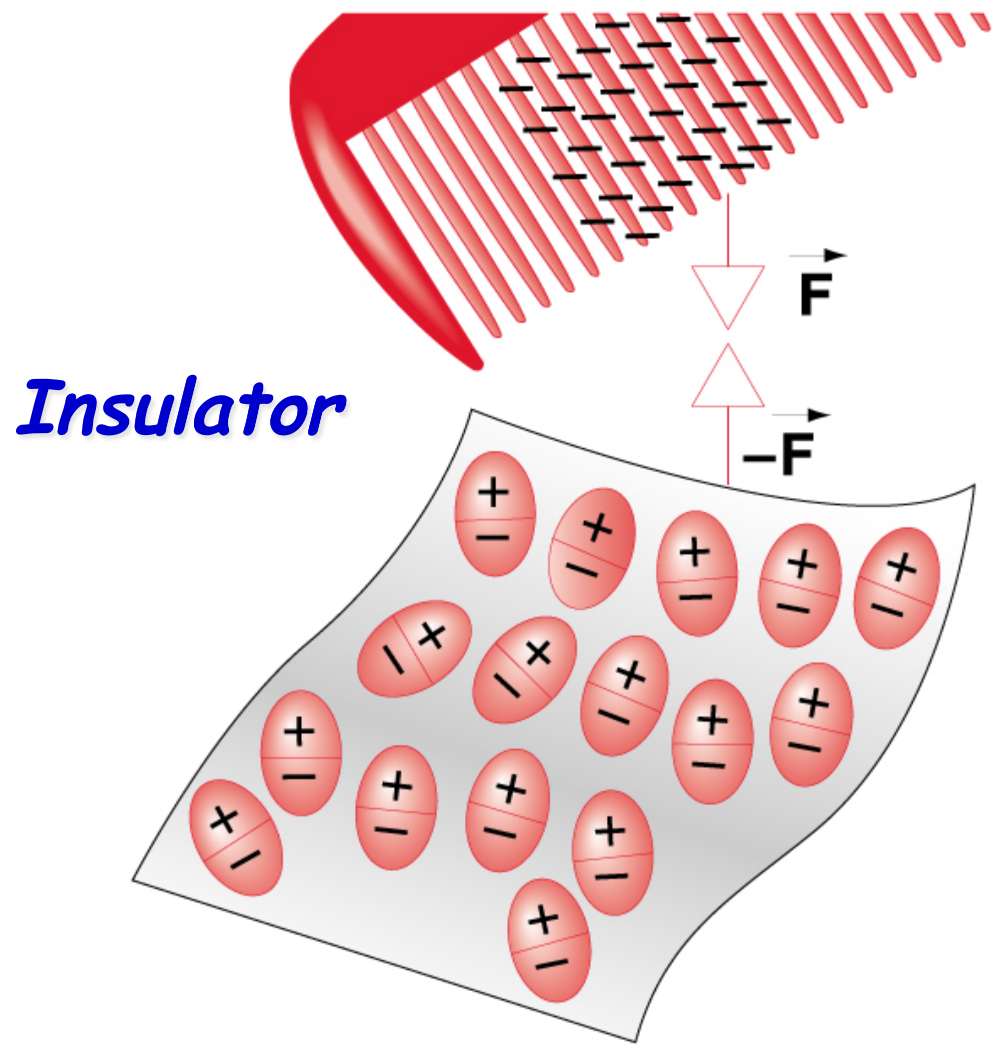
$$= -\vec{\mathbf{p}} \cdot \vec{\mathbf{E}}$$

Force = gradient in the potential energy

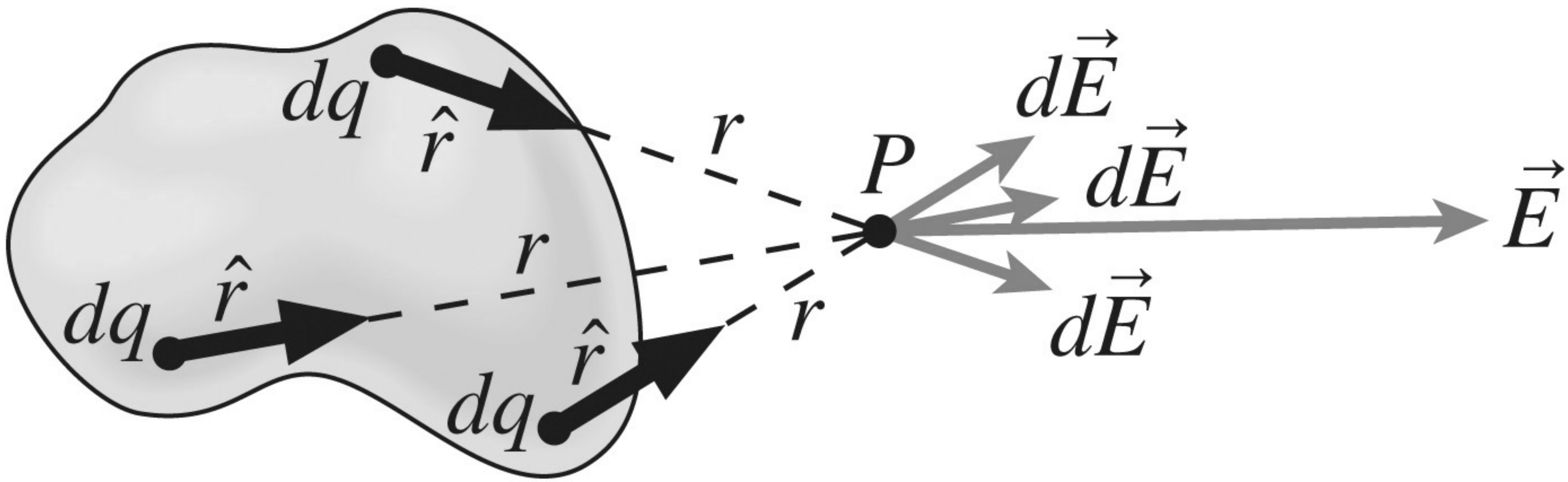
Why do we care about electric dipoles?







Superposition principle
(continuous charge distribution)



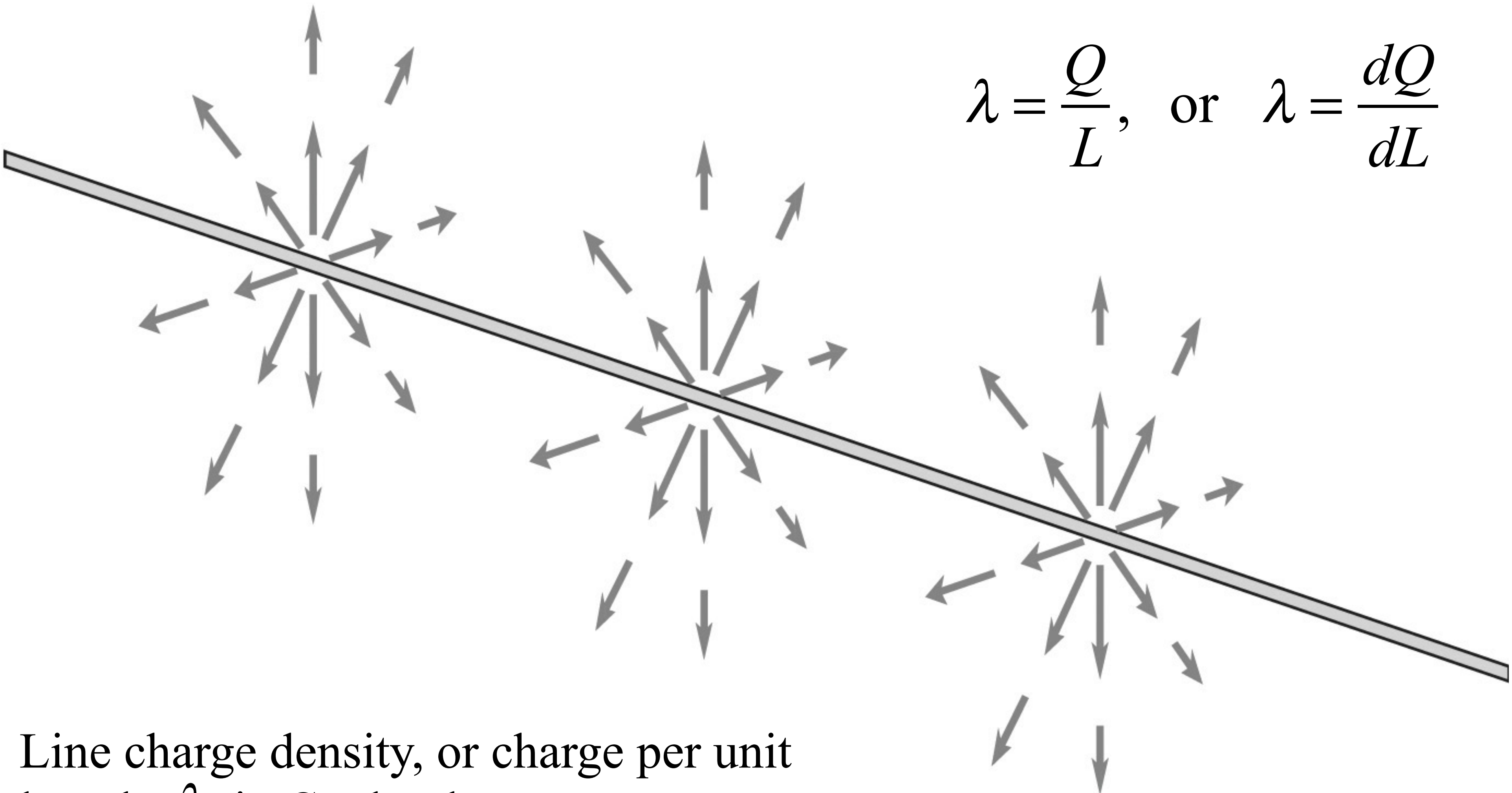
$$\vec{\boldsymbol{E}}_P = \vec{\boldsymbol{E}}_1 + \vec{\boldsymbol{E}}_2 + \vec{\boldsymbol{E}}_3 + \ldots \vec{\boldsymbol{E}}_i = \sum_i \vec{\boldsymbol{E}}_i$$

Superposition principle still holds:

$$\vec{\boldsymbol{E}}_P = \int d\,\vec{\boldsymbol{E}} = \hat{i}\int dE_x + \hat{j}\int dE_y + \hat{k}\int dE_z = \int \frac{kdq}{r^2}\,d\,\hat{\boldsymbol{r}}$$

Line of Charge

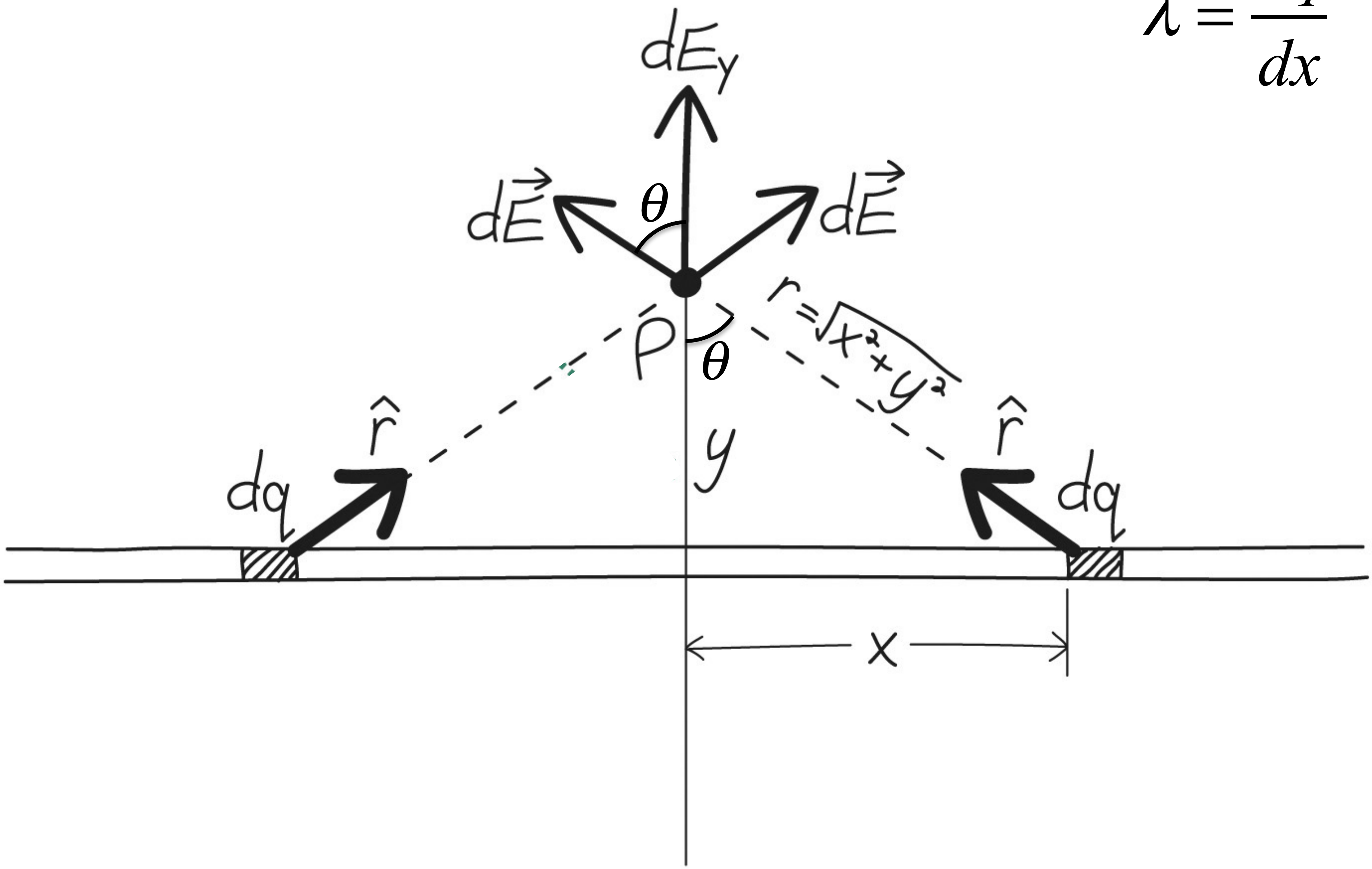
$$\lambda = \frac{Q}{L}, \quad \text{or} \quad \lambda = \frac{dQ}{dL}$$



Line charge density, or charge per unit length, λ, in Coulombs per meter.

Line of Charge

$$\lambda = \frac{dq}{dx}$$



Charge densities

In 1D (a line or wire):

$$\lambda = \frac{Q}{L}, \qquad \text{or} \qquad \lambda = \frac{dQ}{dL}$$

λ is the line charge density, or charge per unit length, in Coulombs per meter. L represents length, and Q is charge.

In 2D (a surface or sheet):

$$\sigma = \frac{Q}{A}, \qquad \text{or} \qquad \sigma = \frac{dQ}{dA}$$

σ is the surface charge density, or charge per unit area in Coulombs per meter^2; A represents area, and Q is charge.

In 3D (a solid object):

$$\rho = \frac{Q}{V}, \qquad \text{or} \qquad \rho = \frac{dQ}{dV}$$

ρ is the volume charge density, or charge per unit volume in Coulombs per meter^3. V represents volume, and Q is charge.