

Lecture 26

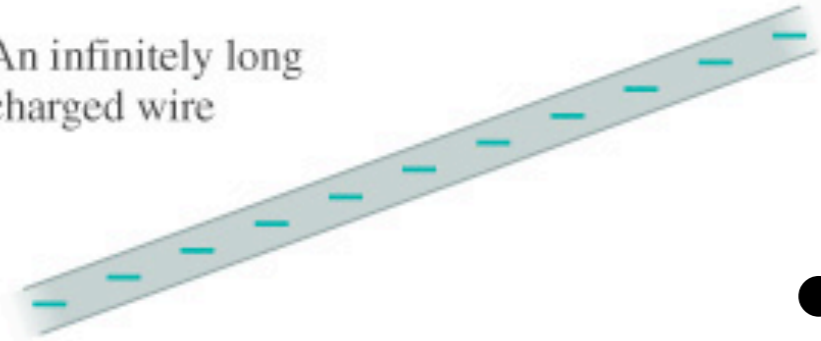
- Chapter 26 (The Electric Field)
 - \vec{E} due to configuration of (source) charges (today)
 - parallel plate capacitor (uniform \vec{E})
 - motion of (other) charges in \vec{E}

Electric Field Models

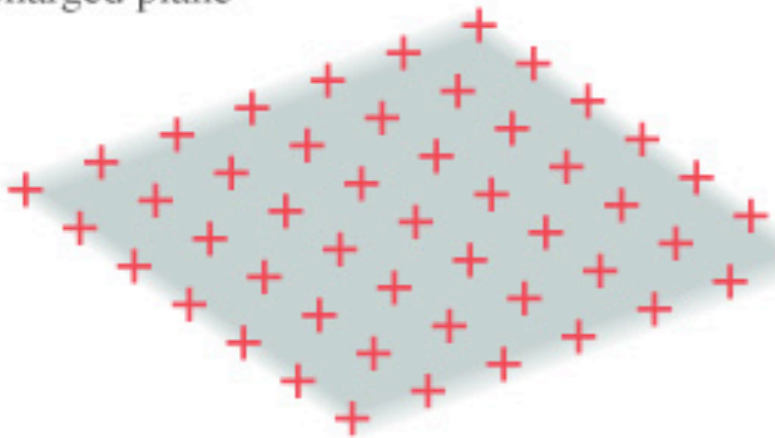
A point charge



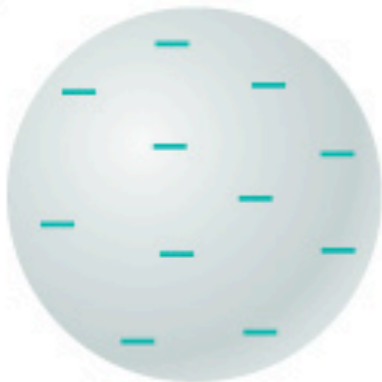
An infinitely long charged wire



An infinitely wide charged plane



A charged sphere



- good approx. for small charged object, real wire

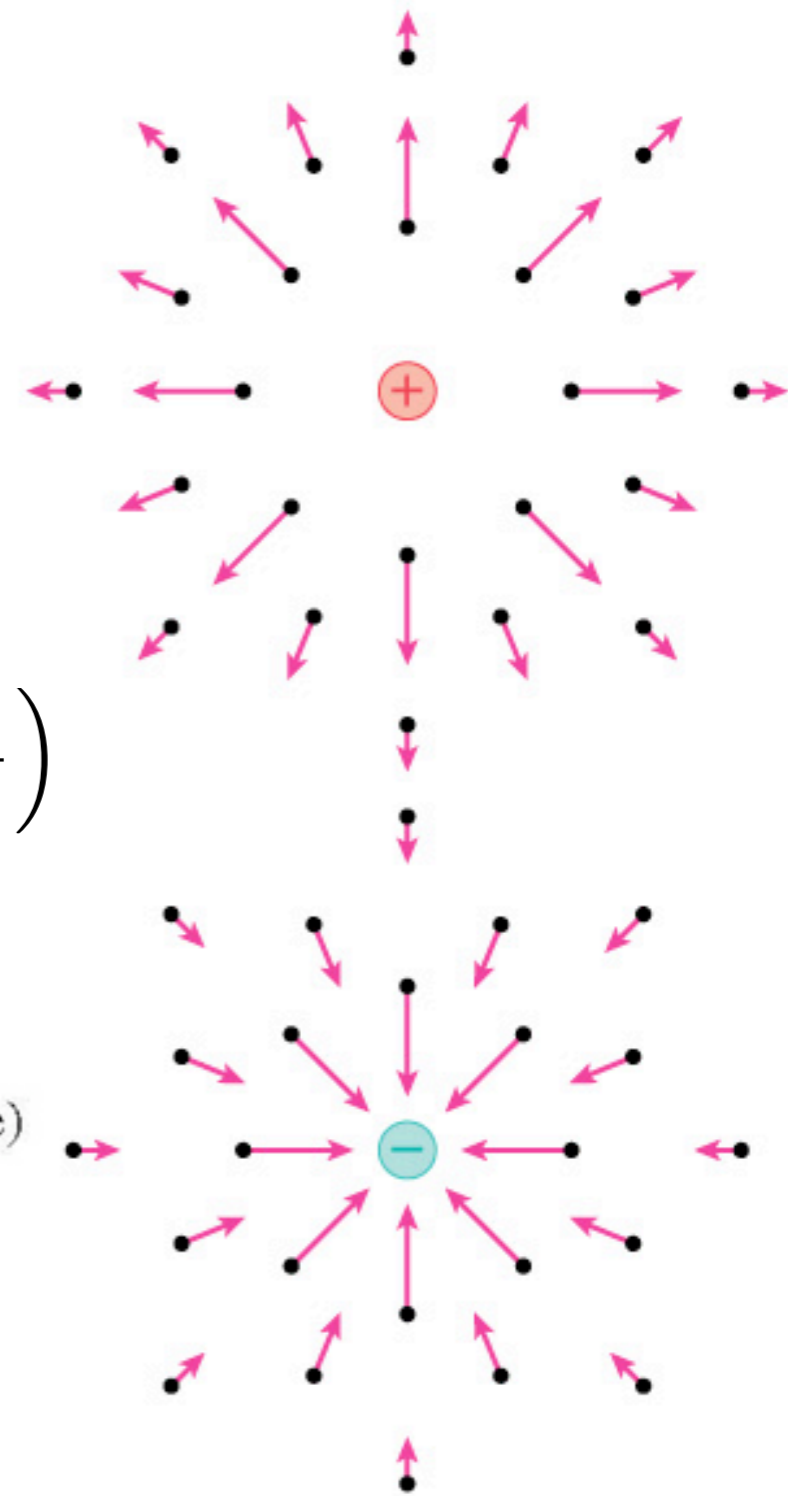
- Coulomb's law

$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2} \left(K = \frac{1}{4\pi\epsilon_0} \right)$$

- \vec{E} due to point charge

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r} \quad (\text{electric field of a point charge})$$

- limiting cases (check + simpler formula): like \vec{E} point charge very far (\gg size)



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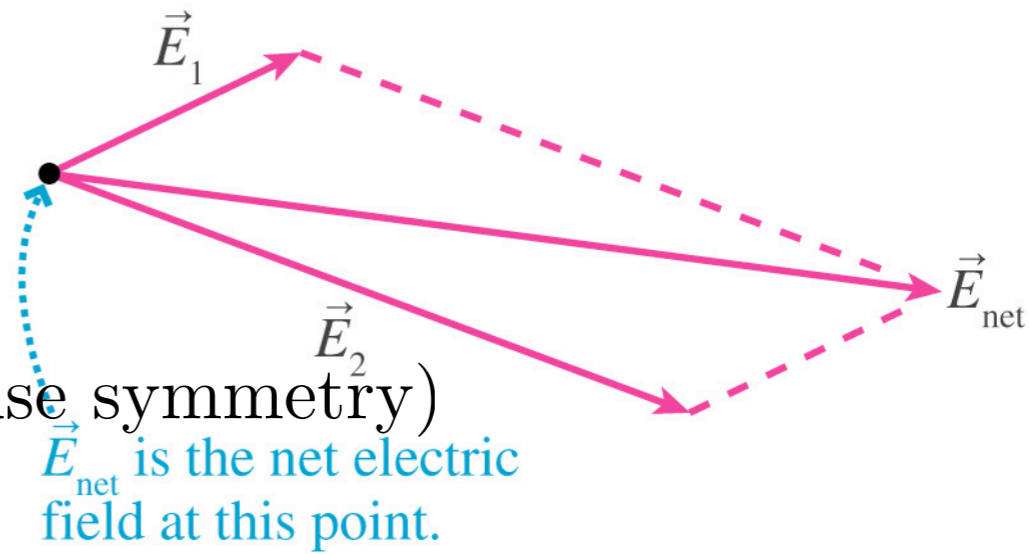
Electric Field of Multiple Charges

- Principle of superposition

$$\vec{E}(x, y, z) = \frac{\vec{F}_{\text{on } q} \text{ at } (x, y, z)}{q}$$

$$+\vec{F}_{\text{on } q} = \vec{F}_{1 \text{ on } q} + \vec{F}_{2 \text{ on } q} \Rightarrow \vec{E}_{\text{net}} = \sum_i \vec{E}_i$$

Strategy: picture..., identify P, find \vec{E}_i , $\sum_i \vec{E}_i$ (use symmetry)

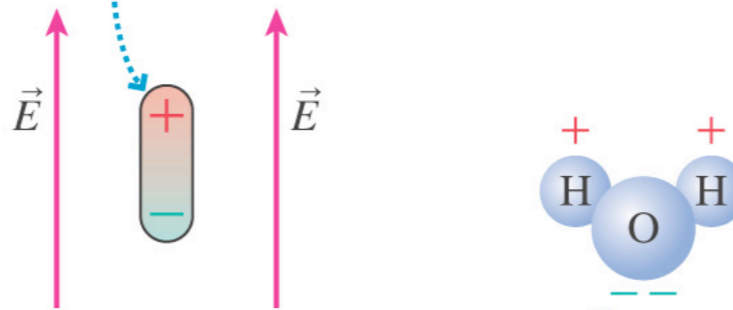


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- Electric field of a dipole (two opposite charges separated by small distance s): no net charge, but does have a net \vec{E}

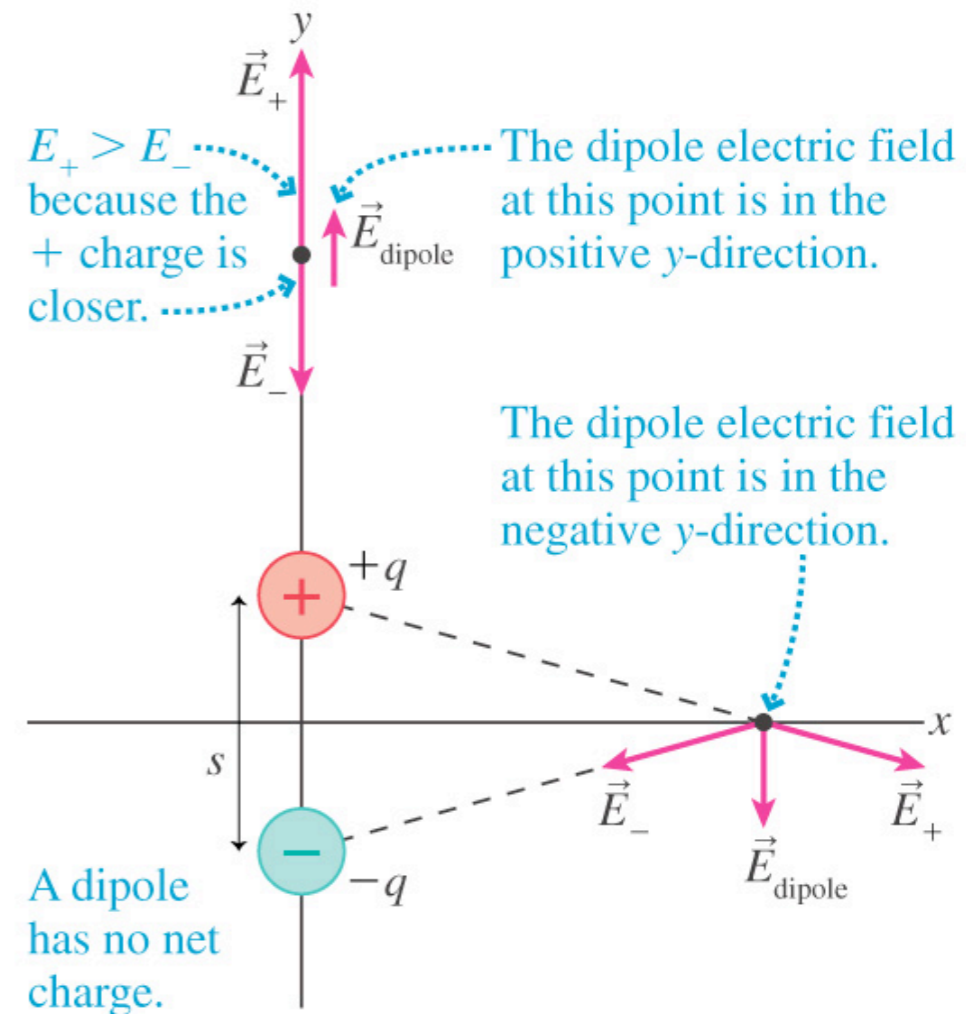
$$\begin{aligned} & (E_{\text{dipole}})_y \\ = & (E_+)_y + (E_-)_y \\ = & \frac{1}{4\pi\epsilon_0} \frac{q}{(y - 1/2s)^2} + \frac{1}{4\pi\epsilon_0} \frac{-q}{(y + 1/2s)^2} \\ = & \frac{q}{4\pi\epsilon_0} \frac{2ys}{(y - 1/2s)^2 (y + 1/2s)^2} \end{aligned}$$

This dipole is *induced*, or stretched, by the electric field acting on the + and - charges.



A water molecule is a *permanent* dipole because the negative electrons spend more time with the oxygen atom.

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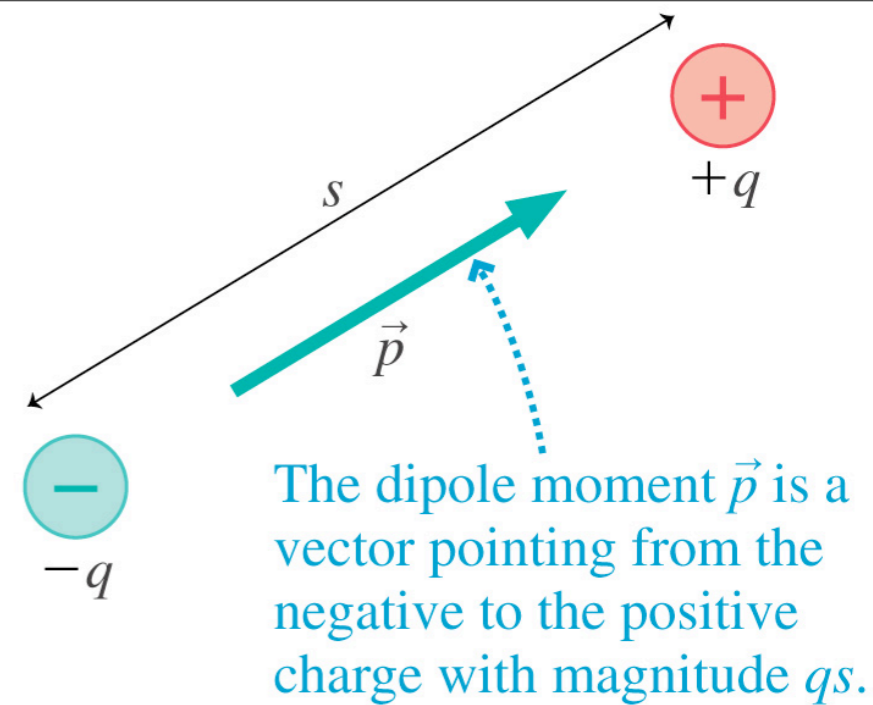
Electric Field of a Dipole

- For $y \gg s$: $(E_{dipole})_y \approx \frac{1}{4\pi\epsilon_0} \frac{2qs}{y^3}$

$$\vec{E}_{dipole} \approx \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}}{r^3} \quad (\text{on the axis of an electric dipole})$$

- dipole moment: $\vec{p} = (qs, \text{ from negative to positive})$

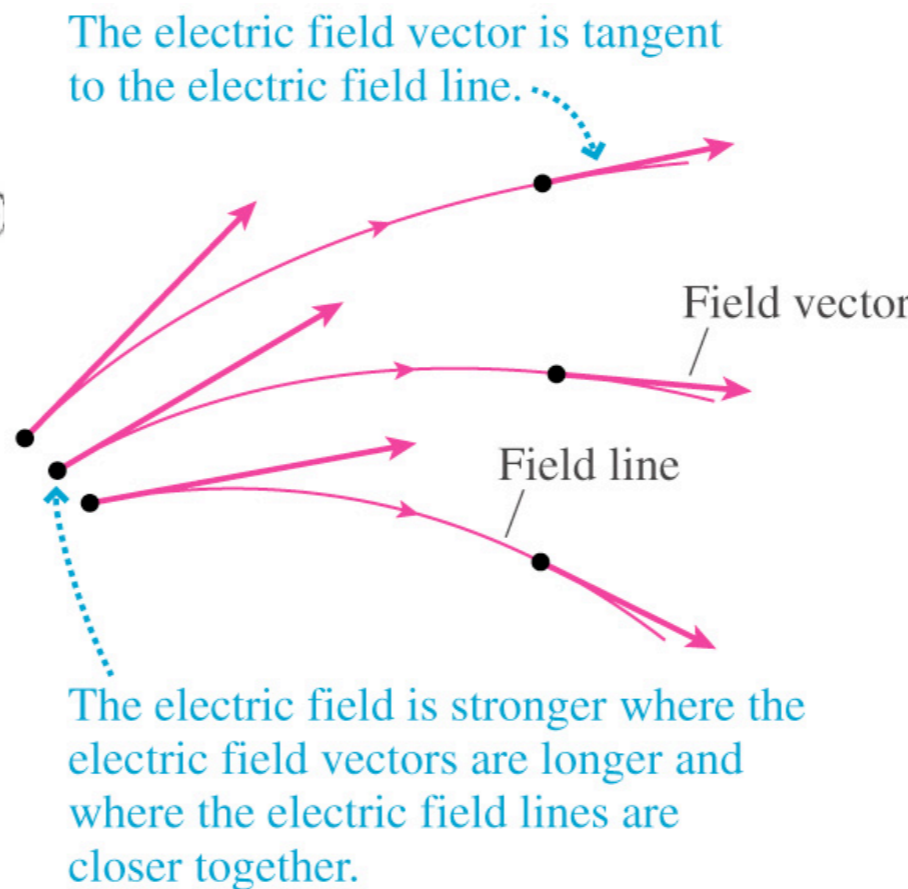
$$\vec{E}_{dipole} \approx -\frac{1}{4\pi\epsilon_0} \frac{\vec{p}}{r^3} \quad (\text{in the plane perpendicular to an electric dipole})$$



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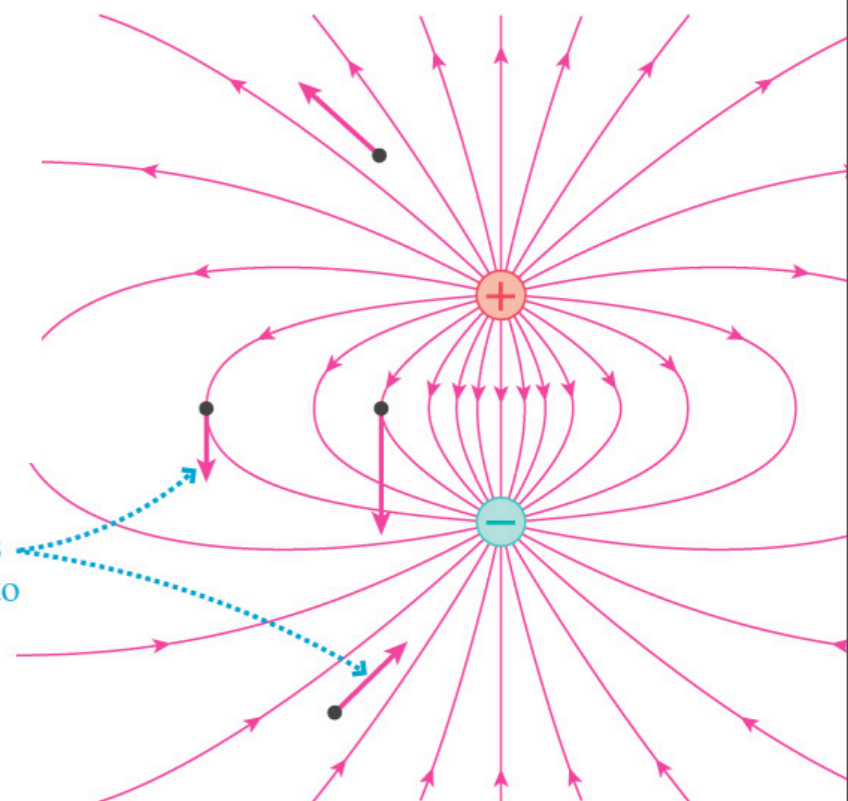
Picturing \vec{E}

- draw vectors or lines
- tangent: direction of \vec{E}
- closer together for larger \vec{E}
- starts on +ve, end -ve
- cannot cross (unique direction at point)



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The electric field vectors are tangent to the electric field lines.



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Electric Field of a Continuous Charge Distribution

- even if charge is discrete, consider it continuous, describe how it's distributed (like density, even if atoms
- Strategy (based on of point charge and principle of superposition)

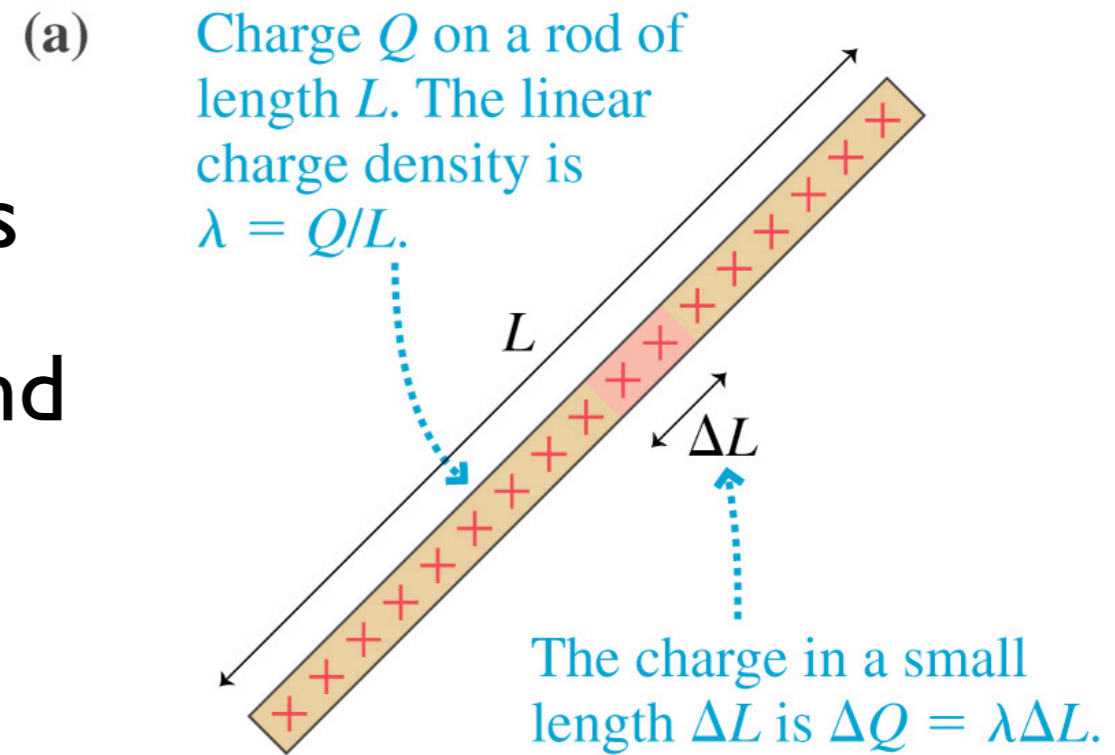
divide Q into point-like charges ΔQ

find \vec{E} due to ΔQ

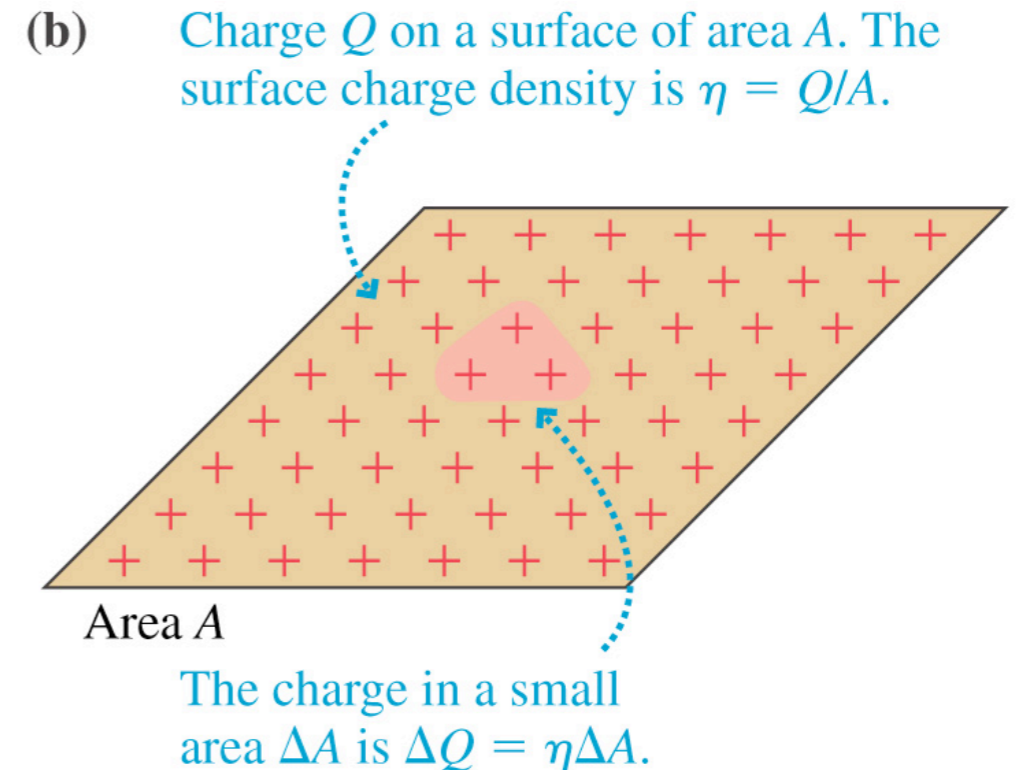
convert sum to integral:

$\Delta Q \rightarrow \text{density} \times dx$

(x describes shape of ΔQ)



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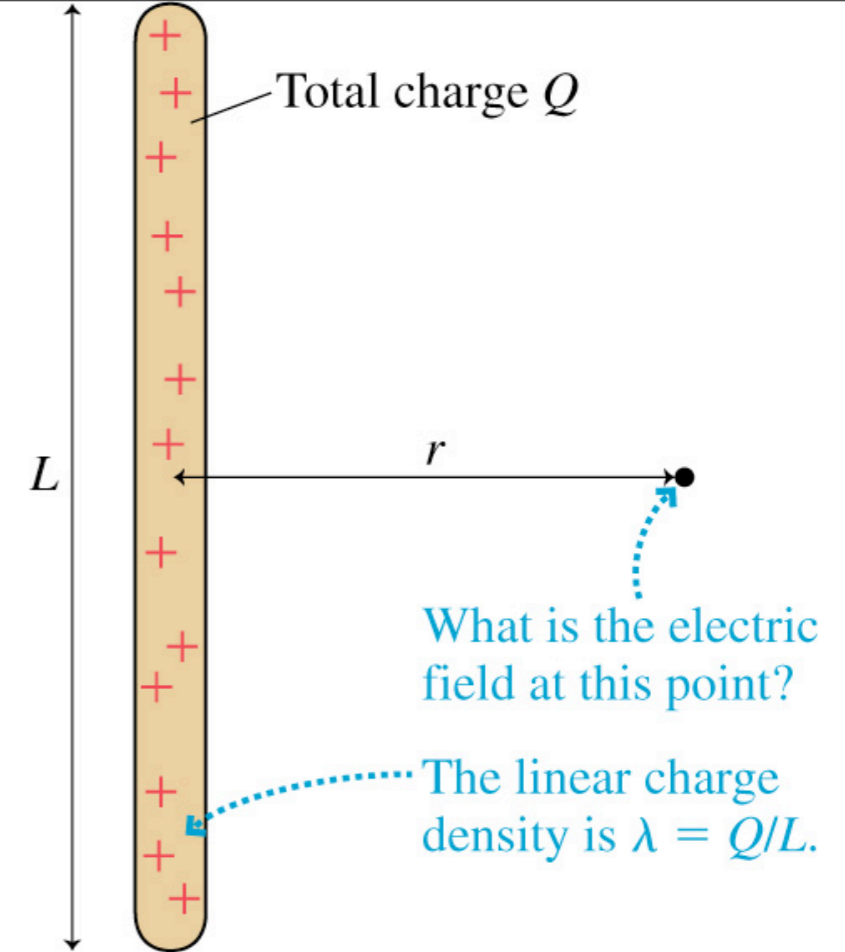


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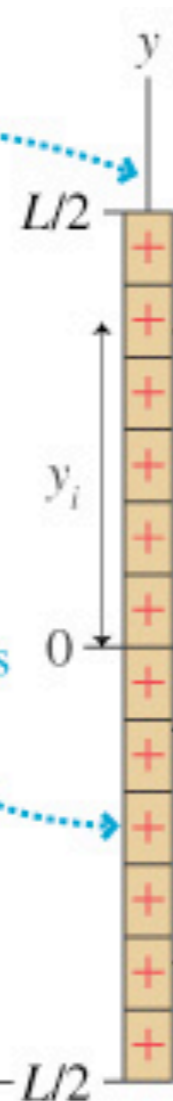
Electric Field of a Line of Charge

- Problem
- Strategy

- Solution...:
$$E_{rod} = \frac{1}{4\pi\epsilon_0} \frac{|Q|}{r\sqrt{r^2 + (L/2)^2}}$$



1 Choose a coordinate system with the origin at the center of the rod.



2 Identify the point at which we're going to calculate the field.

3 Divide the rod into N small segments of length Δy and charge $\Delta Q = \lambda\Delta y$.

4 Draw the field vector of charge segment i .

5 Note that the field from a symmetrically located charge segment will cancel $(E)_y$.

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Infinite line of charge:
$$E_{line} = \lim_{L \rightarrow \infty} \frac{1}{4\pi\epsilon_0} \frac{|Q|}{r\sqrt{r^2 + (L/2)^2}} = \frac{1}{4\pi\epsilon_0} \frac{|Q|}{rL/2} = \frac{1}{4\pi\epsilon_0} \frac{2|\lambda|}{r}$$