19.4–19.6

Electrostatic Forces; Coulomb's Law

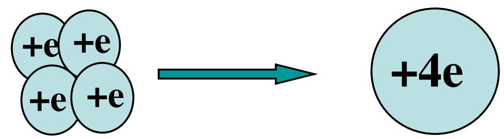
Electrostatic Forces from multiple charges

Electric Fields: point charges

Electric Fields: multiple point charges, continuous charge distributions

Electric Field Lines

Electric Force



A collection of 4 charges, each with +1e…

…equivalent to "a charge" with +4e

Given two objects with charges q_1 & q_2:

Coulomb's Law: $$|F_e| = \frac{k_e\,|q_1|\,|q_2|}{r^2}$$

Coulomb constant $k_e = 8.99 \times 10^9\ N\ m^2 / C^2 = 1/(4\pi\varepsilon_0)$

Permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2 /(Nm^2)$

Electric vs. Gravitational Forces

Consider a hydrogen atom: One proton, one electron, $r = 5.3 \times 10^{-11}$ m

$$F_e = \frac{k_e q_1 q_2}{r^2} = \frac{8.99\text{x}10^9 \text{Nm}^2/\text{C}^2 (1.6\text{x}10^{-19}\text{ C})^2}{(5.3\text{x}10^{-11}\text{ m})^2}$$

$$= 8.2\text{x}10^{-8}\text{ N}$$

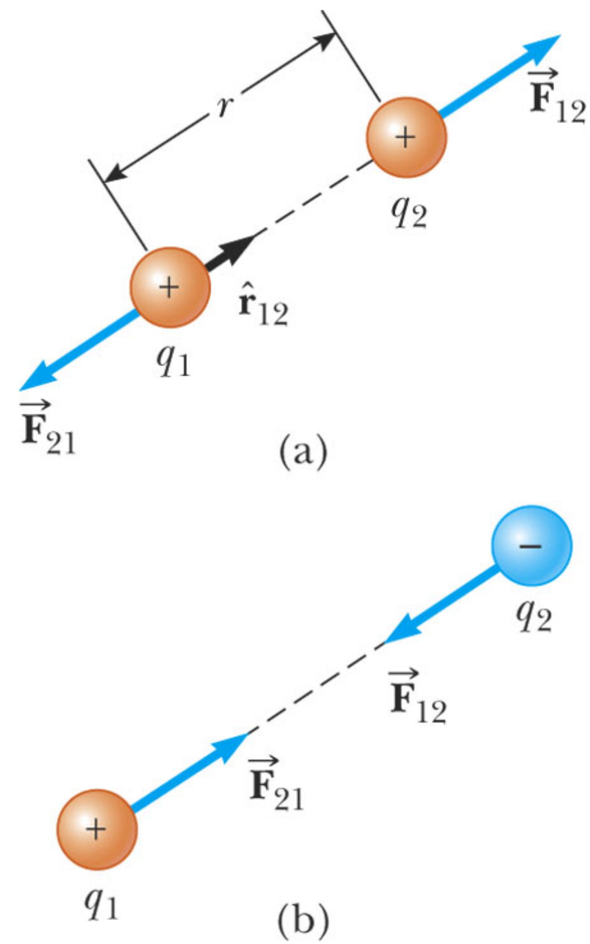
$$F_g = \frac{G m_1 m_2}{r^2} = \frac{6.67\text{x}10^{-11}\text{ Nm}^2/\text{kg}^2 (1.67\text{x}10^{-27}\text{ kg})(9.11\text{x}10^{-31}\text{ kg})}{(5.3\text{x}10^{-11}\text{ m})^2}$$

$$= 3.6\text{x}10^{-47}\text{ N}$$

Both forces are prop. to $1/r^2$, but gravity is **much** weaker!

Force is a vector quantity

$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$



19.4–19.6

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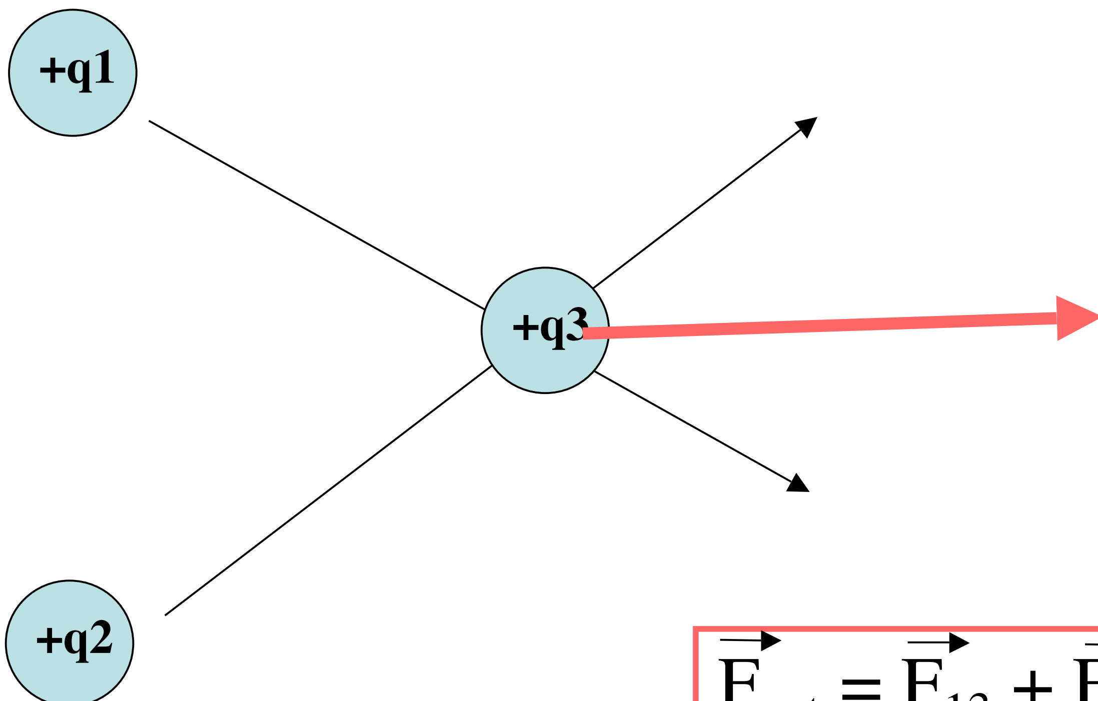
Superposition

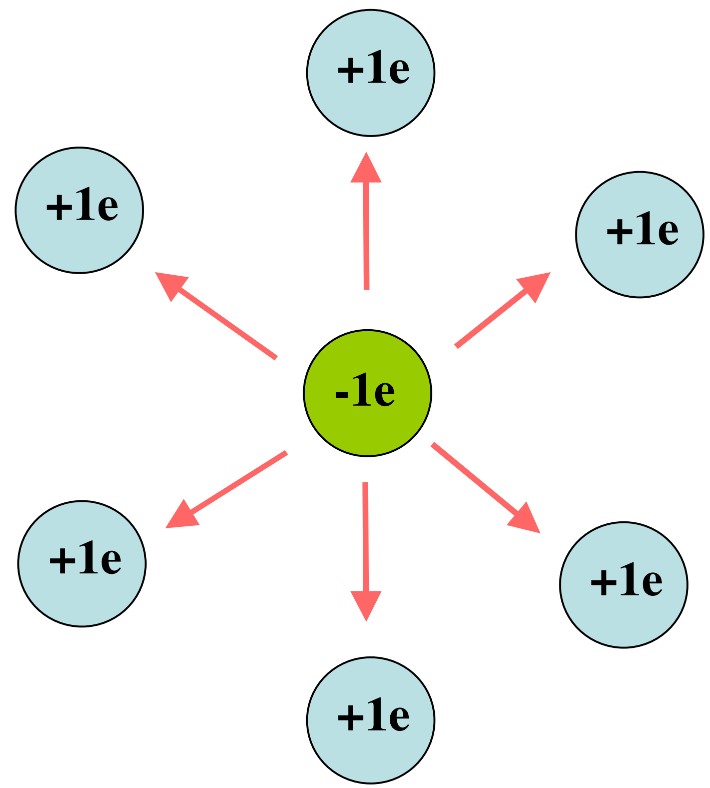
Use superposition (vector addition) to find net force!



$$\vec{F}_{net} = \vec{F}_{13} + \vec{F}_{23}$$

Example

Example of superposition: One e⁻ surrounded by a hexagon of protons, all held fixed: What's the net electrostatic force on the e⁻?



Example

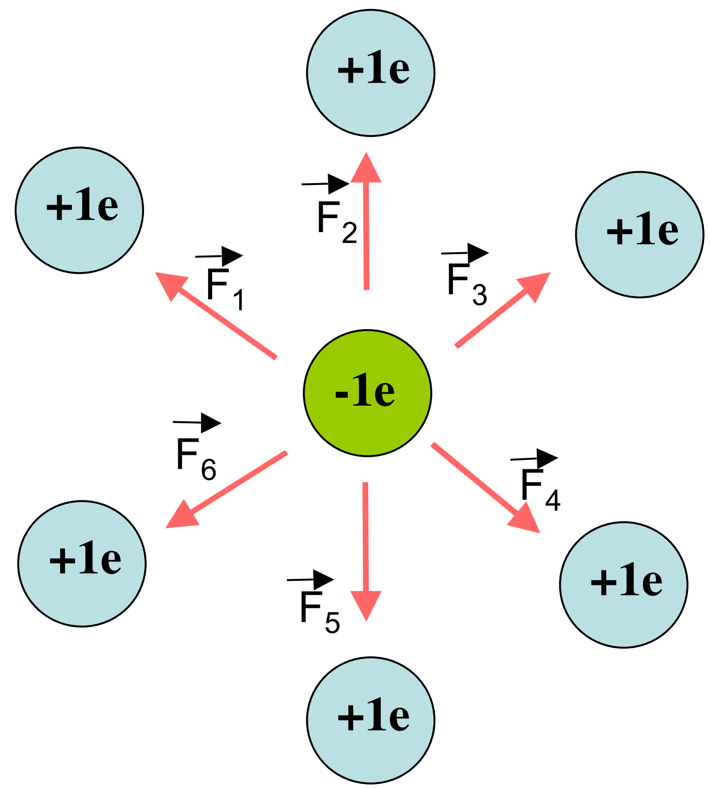
Example of superposition: One e^- surrounded by a hexagon of protons, all held fixed: What's the net electrostatic force on the e^-?

$\vec{F}_1 + \vec{F}_4 = 0$

$\vec{F}_2 + \vec{F}_5 = 0$

$\vec{F}_3 + \vec{F}_6 = 0$

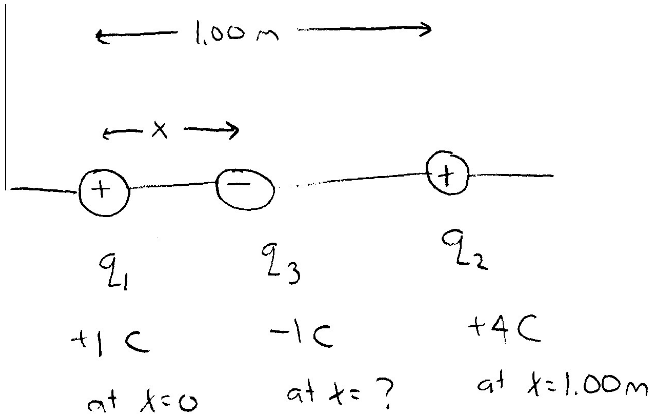
Total $\vec{F} = 0$!



Example: where is net force zero?

Given a charge q_1=+1C held fixed at x=0, and a charge q_2=+4C held fixed at x=1.00m, where can one place a charge q_3=–1C such that the net electrostatic force on it is zero?

Example: where is net force zero?



$\vec{F}_{13}$ and $\vec{F}_{23}$ are both attractive forces

$$\sum \vec{F} = 0$$

$$\vec{F}_{13} = \frac{k_e q_1 q_3}{x^2}\hat{r}_{13} = \frac{k_e q_1 q_3}{x^2}\hat{\imath}$$

$$\vec{F}_{23} = \frac{k_e q_2 q_3}{(1.00-x)^2}\hat{r}_{23} = -\frac{k_e q_2 q_3}{(1.00-x)^2}\hat{\imath}$$

$$\frac{k_e q_1 q_3}{x^2}\hat{\imath} - \frac{k_e q_2 q_3}{(1.00-x)^2}\hat{\imath} = 0$$

$$\frac{q_1}{x^2} = \frac{q_2}{(1.00-x)^2}$$

$$\frac{(+1C)}{x^2} = \frac{(+4C)}{(1.00-x)^2}$$

$$4x^2 = (1.00-x)^2 = 1 - 2x + x^2$$

$$3x^2 + 2x - 1 = 0$$

$$x = 1/3$$

19.4–19.6

Electrostatic Forces; Coulomb's Law

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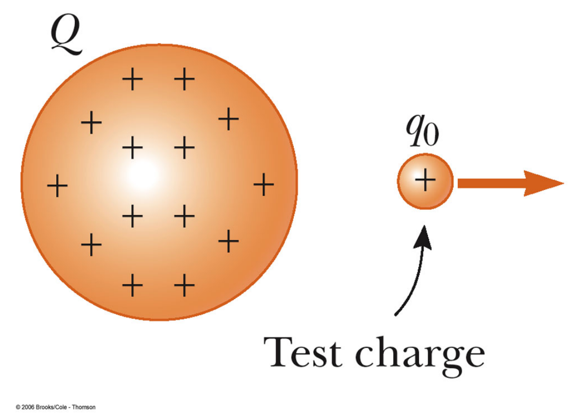
Electric Field Lines

19.5 Electric Fields

Electric field in any point space: defined in terms of the electrostatic force affecting a test particle q_0 placed there.

$$\vec{\mathbf{E}} = \vec{\mathbf{F}}_e / q_o$$



Source particle = particle creating the E-field in the surrounding space

If the electric field is known, F can be found via $\vec{\mathbf{F}}_e = q\vec{\mathbf{E}}$

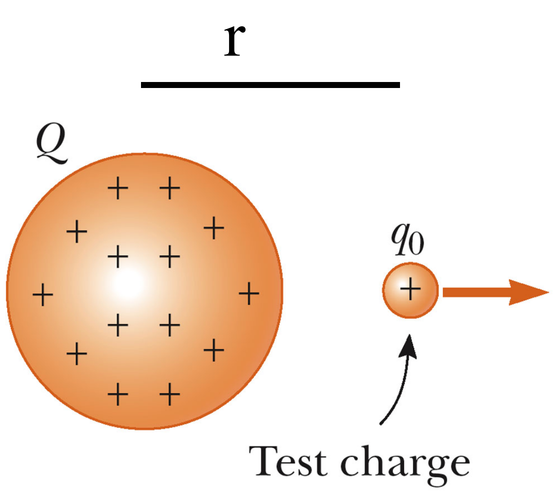
Electric Field due to a point charge

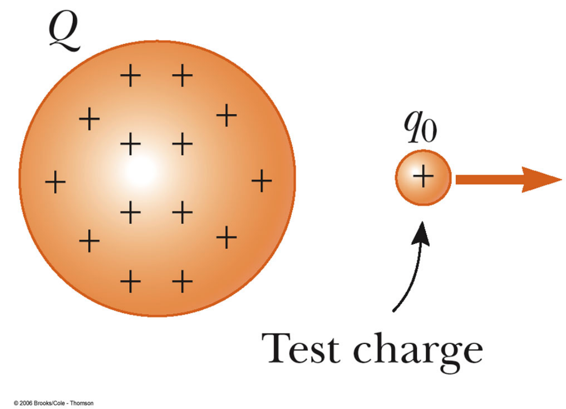
$\vec{E}$ is a vector quantity

Magnitude & direction vary with position--but depend on object w/ charge Q setting up the field

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{\frac{k_e Q q_0}{r^2}}{q_0}\,\hat{r}$$

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





The electric field experienced by the test charge depends on Q, not q_0. It also depends on r. (we're ignoring the much smaller E-field due to q_0 here)

If you replace q_0 with $-q_0$ or $2q_0$, the direction & magnitude of the E-field vector at that point in space remain the same

The electrostatic FORCE, however, depends on Q AND q_0 as well as r.

19.4–19.6

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Electric Field Lines

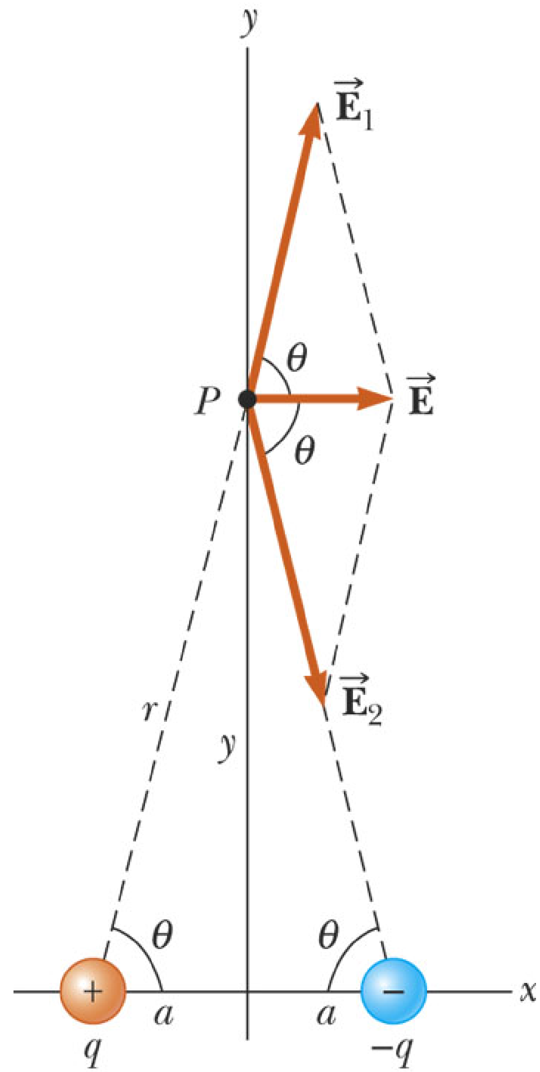
Total E-field due to a finite number of point charges:

At any point in space, the total electric field will be equal to the vector sum of the electric fields at that point due to each of the particles:

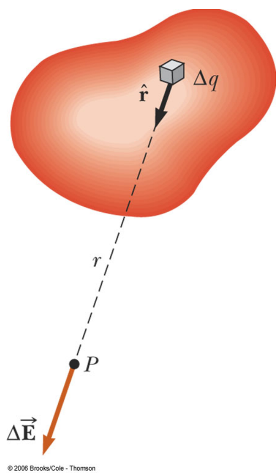
Eqn 19.6:

$$\vec{\mathbf{E}} = k_e \sum_i \frac{q}{r_i^2} \hat{\mathbf{r}}_i$$

Electric Field due to a Dipole: example 19.3



E-field due to continuous charge distributions



$$\Delta\vec{\mathbf{E}}_i = k_e \frac{\Delta q_i}{r_i^2}\hat{\mathbf{r}}_i$$

The total E-field at point P is the vector sum of the fields $\Delta\vec{E}$ due to each element Δq in the charge distribution.

$$\vec{\mathbf{E}} = \lim_{\Delta q_i \to 0} k_e \sum_i \frac{\Delta q_i}{r_i^2}\hat{\mathbf{r}}_i = k_e \int \frac{dq}{r^2}\hat{\mathbf{r}}$$

Charge densities

- Volume charge density – when a charge is distributed evenly throughout a volume

  $\rho = Q / V$

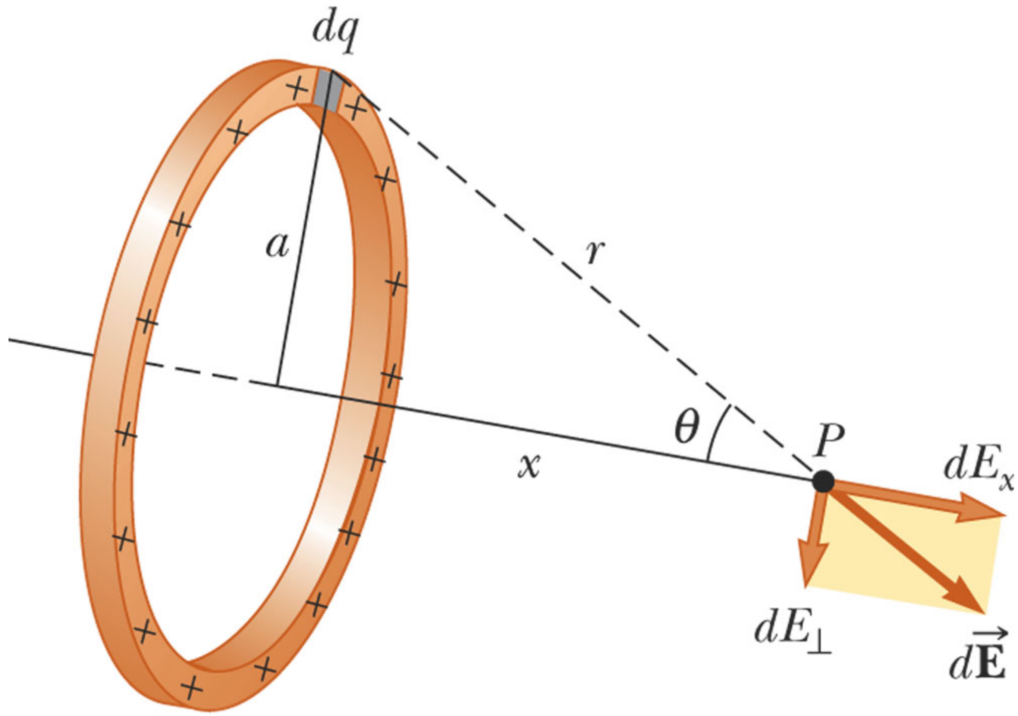
- Surface charge density – when a charge is distributed evenly over a surface area

  $\sigma = Q / A$

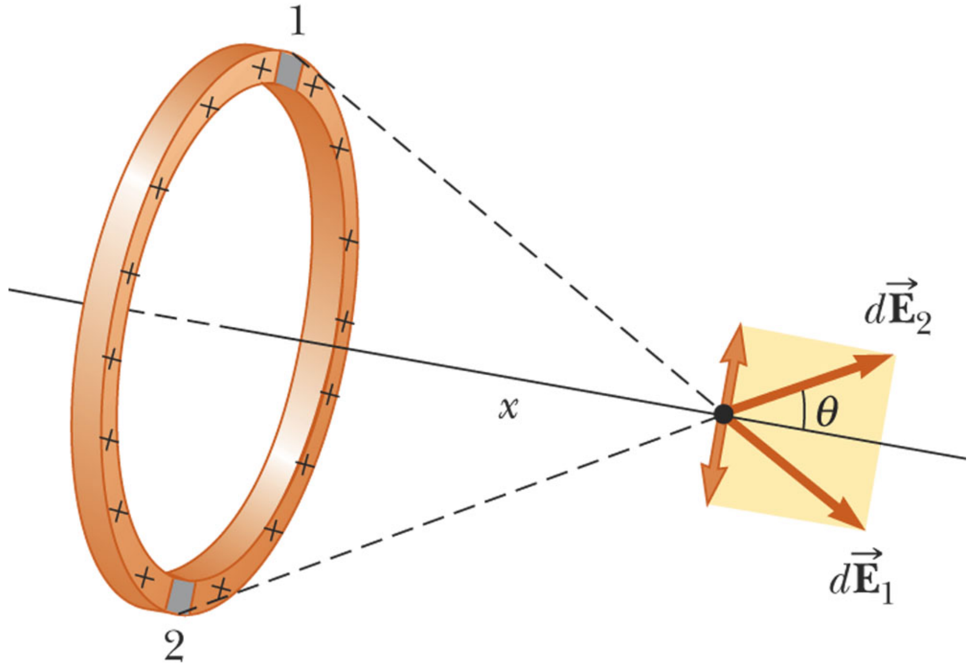
- Linear charge density – when a charge is distributed along a line

  $\lambda = Q / \ell$

Example 19.5: E-field of a uniform ring of charge



Example 19.5: E-field of a uniform ring of charge



19.4–19.6

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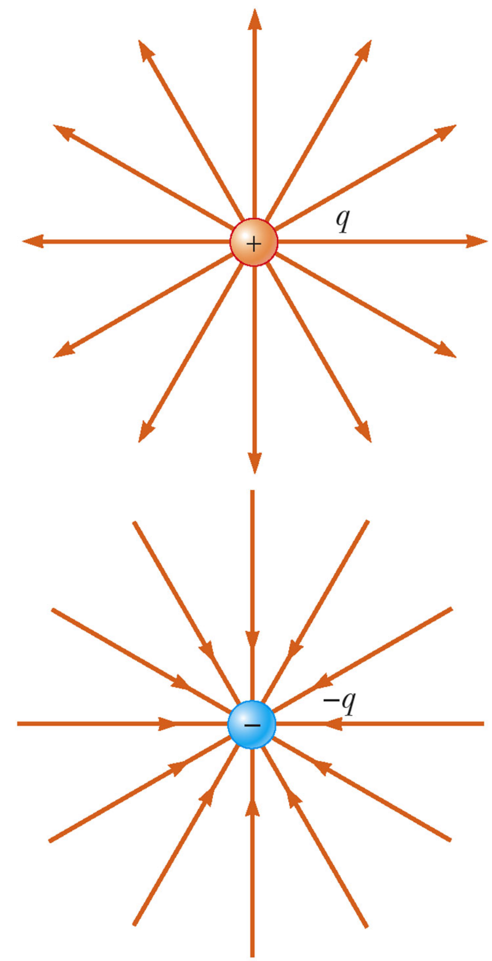
Electric Field Lines

19.6: Electric Field Lines

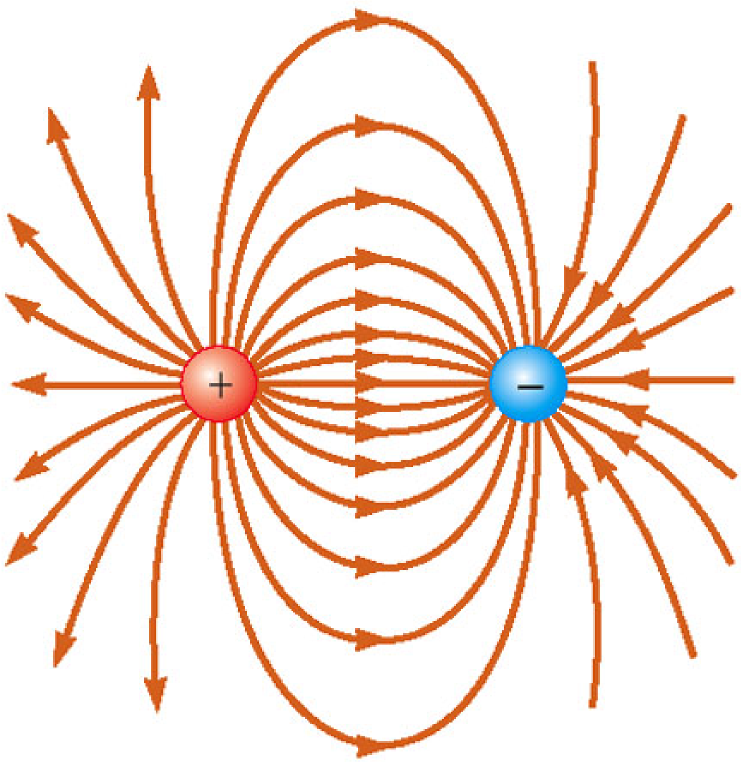
Field lines are a way of visualizing strength and direction of E-field at a given point in space

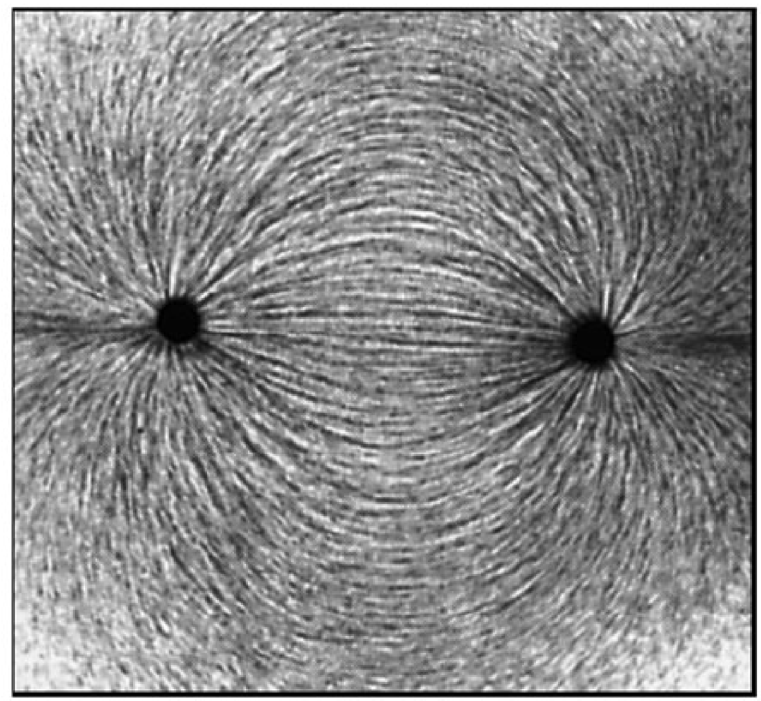
Density of field lines prop. to magnitude of $\vec{E}$

$\vec{E}$ is tangent to E-field lines at each point in space



Electric Field Lines

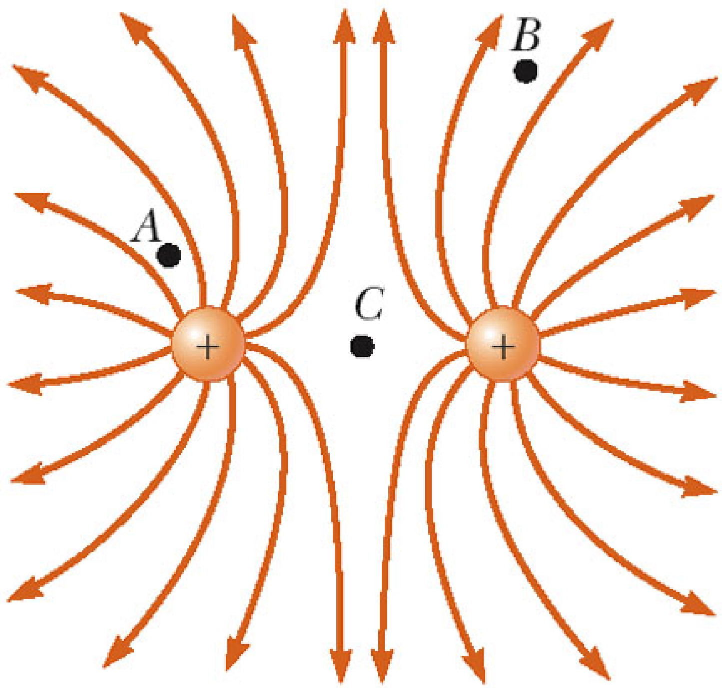


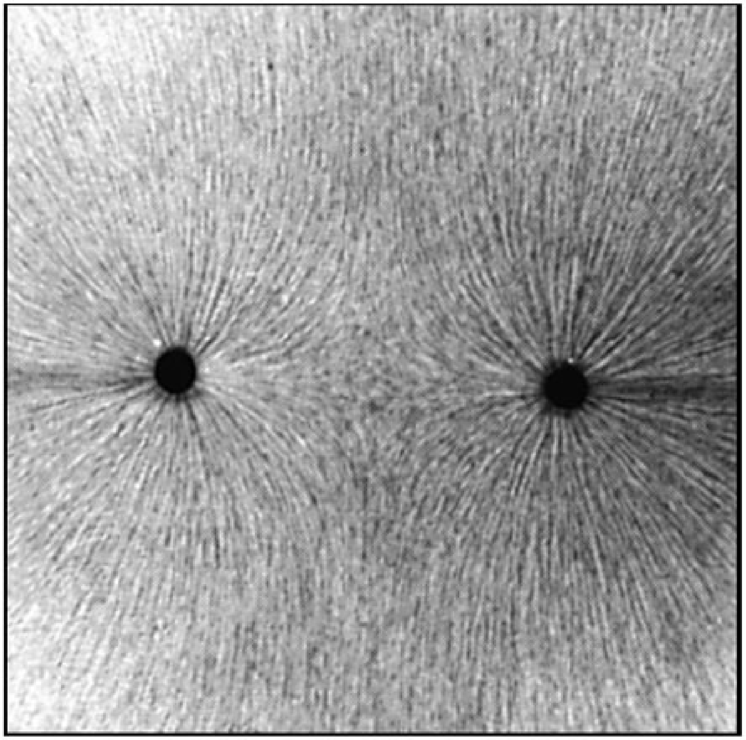


An Electric Dipole

Electric Field Lines

Two positive charges



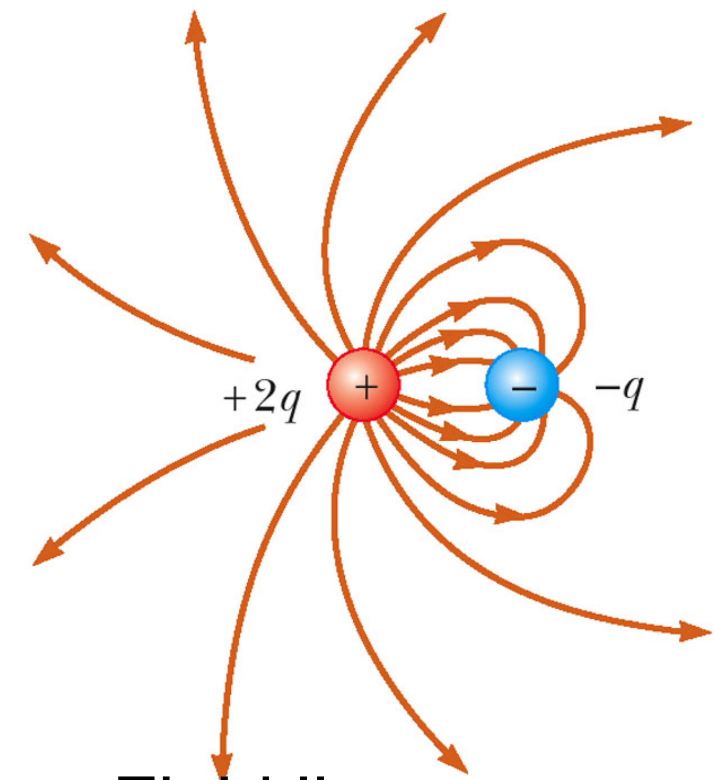


Electric Field Lines

Field lines begin on + charges and terminate on – charges

If there’s excess +(–) charge, some lines will end(begin) at infinity

Number of lines beginning/ terminating at a point charge is prop. to amount of charge



Field lines may not cross each other