King Saud University
College of Science
Physics & Astronomy Dept.

PHYS 111 (GENERAL PHYSICS 2)
CHAPTER 23: Electric Fields
LECTURE NO. 3

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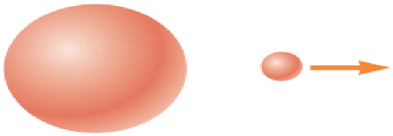
Analysis Model: Particle in a Field (Electric)

- The electric force is a **field force.**

- Field forces can act through space producing effect even with **no physical contact** between interacting objects.



- An **electric field** is said to exist in the region of space around a charged object. This charged object is the **source charge**.
- When another charged object, the test charge q_0 , enters this electric field, an electric force acts on it.

Analysis Model: Particle in a Field (Electric)

The electric field [E]: is defined as the electric force on the test charge per unit charge.

The electric field vector:, $\vec{\mathbf{E}}$, at a point in space is defined as the electric force $\vec{\mathbf{F}}$ acting on a positive test charge, q_o, placed at that point divided by the test charge:

$$\vec{\mathbf{E}} \equiv \frac{\vec{\mathbf{F}}}{q_o}$$

, the SI unit of E is N/C

Analysis Model: Particle in a Field (Electric)

- $\vec{\mathbf{E}}$ is the field produced by some charge or charge distribution (source charge), separate from the test charge.

- The existence of an electric field is a property of the source charge: the presence of the test charge q_0. is not necessary for the field to exist.

- The test charge q_0., serves as a detector of the field.

Analysis Model: Particle in a Field (Electric)

Relation between E and F

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

If q is positive, the force is in the same direction as the field. If q is negative, the force and the field are in opposite directions.

Similar to, $\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$

Analysis Model: Particle in a Field (Electric)

The direction of the electric force and therefore that of the electric field

Suppose there is a charged object (charge source, q) create electric force F and then electric field acting on a test charge q_0 at point P where r is distance between q and q_0.

$$\vec{\mathbf{F}}_e = k_e \frac{q q_0}{r^2} \hat{\mathbf{r}}$$

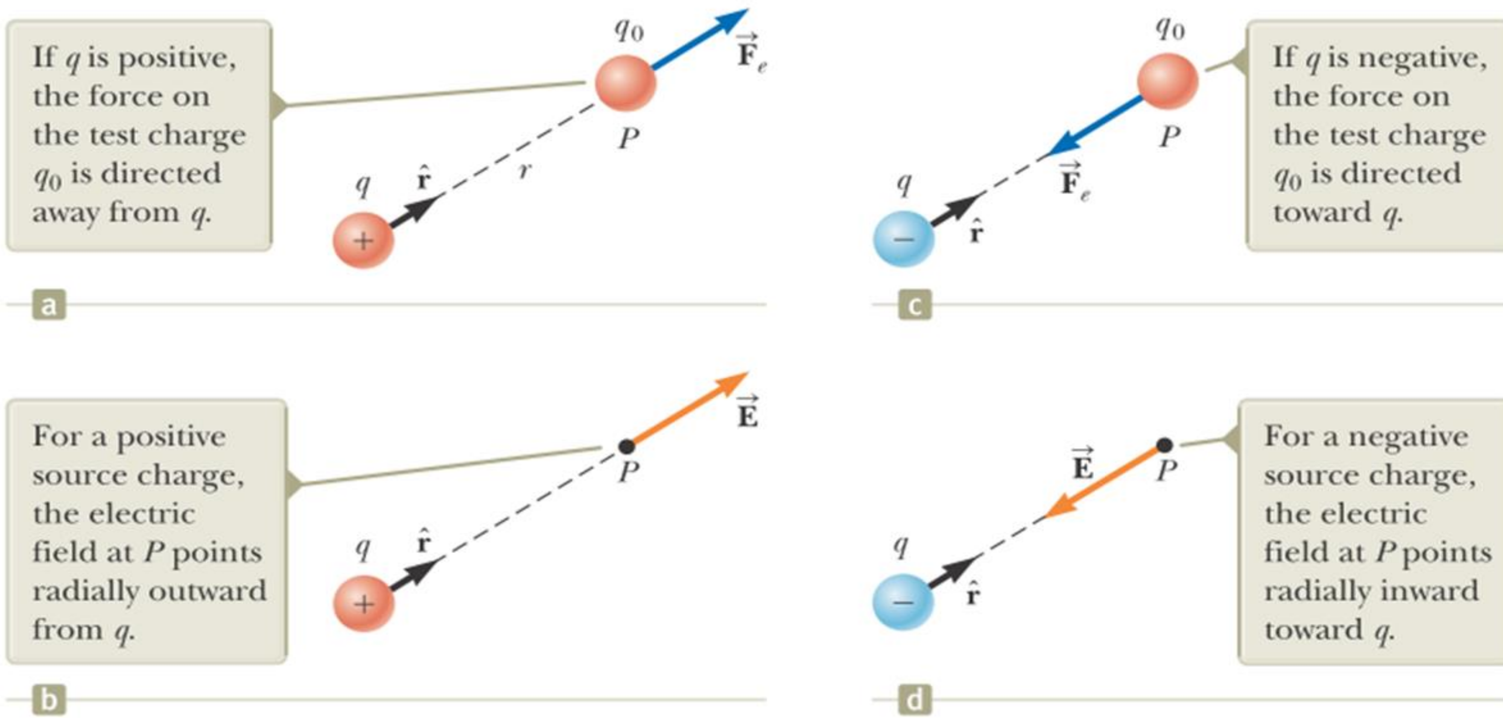
where $\hat{\mathbf{r}}$ is a unit vector directed from q toward q_0.

Since, $\vec{\mathbf{E}} = \vec{\mathbf{F}}_e / q_0$:

the electric field at P created by q is

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

Analysis Model: Particle in a Field (Electric)



Analysis Model: Particle in a Field (Electric)

Electric field Calculation

at any point P,

- **electric field due to a source charge can be calculated by**

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

- **electric field due to a group of source charges can be expressed as the vector sum**

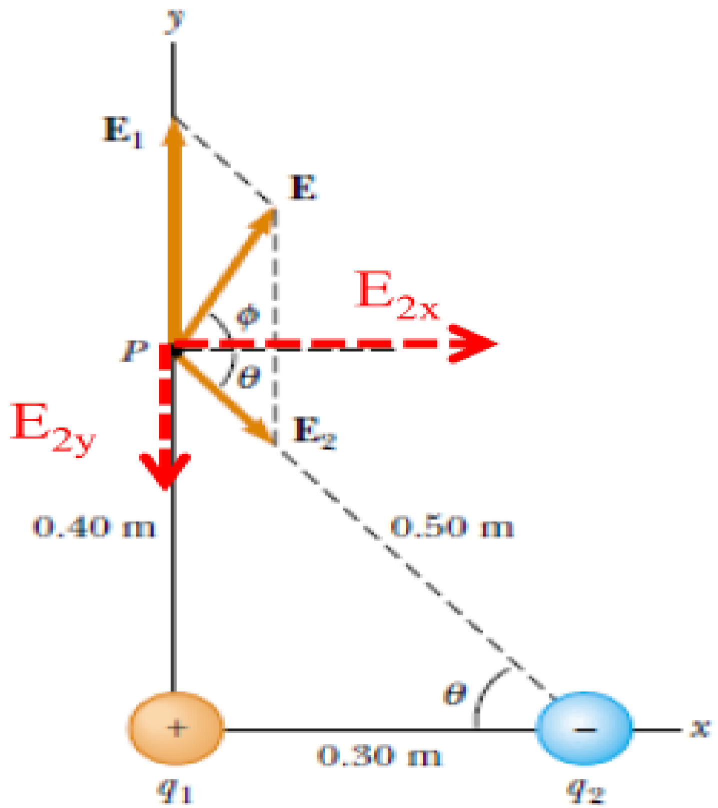
$$\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r_i^2}\hat{\mathbf{r}}_i$$

Analysis Model: Particle in a Field (Electric)

Quick Quiz 23.4 A test charge of $+3\ \mu C$ is at a point P where an external electric field is directed to the right and has a magnitude of 4×10^6 N/C. If the test charge is replaced with another test charge of $-3\ \mu C$, what happens to the external electric field at P? **(a)** It is unaffected. **(b)** It reverses direction. **(c)** It changes in a way that cannot be determined.

Example: Electric Field Due to Tow Charges

A charge $q_1 = 7.0\ \mu C$ is located at the origin, and a second charge $q_2 = -5.0\ \mu C$ is located on the x axis, 0.30 m from the origin (Fig. 23.14). Find the electric field at the point P, which has coordinates (0, 0.40) m.



Solution

$$E_1 = k_e \frac{|q_1|}{r_1^2} = (8.99 \times 10^9 \ \mathrm{N \cdot m^2/C^2}) \frac{(7.0 \times 10^{-6} \ \mathrm{C})}{(0.40 \ \mathrm{m})^2}$$
$$= 3.9 \times 10^5 \ \mathrm{N/C}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = (8.99 \times 10^9 \ \mathrm{N \cdot m^2/C^2}) \frac{(5.0 \times 10^{-6} \ \mathrm{C})}{(0.50 \ \mathrm{m})^2}$$
$$= 1.8 \times 10^5 \ \mathrm{N/C}$$

Vector E1 has only y component in the positive direction then : $\mathbf{E}_1 = 3.9 \times 10^5 \hat{\mathbf{j}} \ \mathrm{N/C}$

While vector E2 has x component in the positive direction, and y component in the negative direction then: $\mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} - 1.4 \times 10^5 \hat{\mathbf{j}}) \ \mathrm{N/C}$

The resultant field $\mathbf{E}$ at P is the superposition of $\mathbf{E}_1$ and $\mathbf{E}_2$:

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} + 2.5 \times 10^5 \hat{\mathbf{j}}) \ \mathrm{N/C}$$

The magnitude of E $2.7 \times 10^5 \ \mathrm{N/C}$. at angle $\phi = 66^\circ$

Example 23.6 Electric Field Due to Two Charges

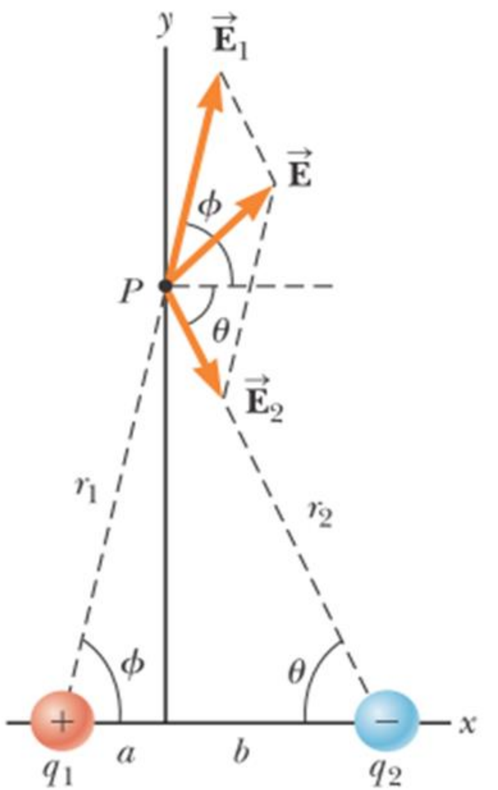
Charges q_1 and q_2 are located on the x axis, at distances a and b, respectively, from the origin as shown in Figure 23.12.

(A) Find the components of the net electric field at the point P, which is at position $(0, y)$.

(B) Evaluate the electric field at point P in the special case that $|q_1| = |q_2|$ and $a = b$.

C) Find the electric field due to the electric dipole when point P is a distance $y >> a$ from the origin.

Solution 23.6 (A)



$$E_1 = k_e \frac{|q_1|}{r_1^2} = k_e \frac{|q_1|}{a^2 + y^2}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = k_e \frac{|q_2|}{b^2 + y^2}$$

$$\vec{\mathbf{E}}_1 = k_e \frac{|q_1|}{a^2 + y^2} \cos\phi\,\hat{\mathbf{i}} + k_e \frac{|q_1|}{a^2 + y^2} \sin\phi\,\hat{\mathbf{j}}$$

$$\vec{\mathbf{E}}_2 = k_e \frac{|q_2|}{b^2 + y^2} \cos\theta\,\hat{\mathbf{i}} - k_e \frac{|q_2|}{b^2 + y^2} \sin\theta\,\hat{\mathbf{j}}$$

$$(1) \quad E_x = E_{1x} + E_{2x} = \boxed{k_e \frac{|q_1|}{a^2 + y^2} \cos\phi + k_e \frac{|q_2|}{b^2 + y^2} \cos\theta}$$

$$(2) \quad E_y = E_{1y} + E_{2y} = \boxed{k_e \frac{|q_1|}{a^2 + y^2} \sin\phi - k_e \frac{|q_2|}{b^2 + y^2} \sin\theta}$$

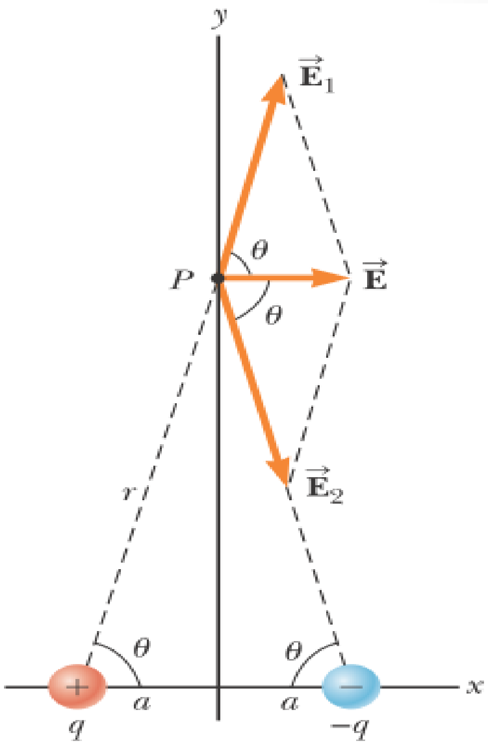
Solution 23.6 (B)

$$(3) \quad E_x = k_e \frac{q}{a^2 + y^2} \cos\theta + k_e \frac{q}{a^2 + y^2} \cos\theta = 2k_e \frac{q}{a^2 + y^2} \cos\theta$$

$$E_y = k_e \frac{q}{a^2 + y^2} \sin\theta - k_e \frac{q}{a^2 + y^2} \sin\theta = 0$$

$$(4) \quad \cos\theta = \frac{a}{r} = \frac{a}{(a^2 + y^2)^{1/2}}$$

$$E_x = 2k_e \frac{q}{a^2 + y^2} \left[\frac{a}{(a^2 + y^2)^{1/2}}\right] = \boxed{k_e \frac{2aq}{(a^2 + y^2)^{3/2}}}$$



Solution 23.6 (C)

$$(5) \quad E \approx \boxed{k_e \frac{2aq}{y^3}}$$

23.6 Electric Field Lines

- A convenient way of visualizing electric field patterns is to draw lines, called **electric field lines** and first introduced by **Faraday**.

- ✓ $\vec{\mathbf{E}}$ is tangent to the electric field line at each point.
- ✓ The direction, indicated by an arrowhead of the line.
- ✓ The direction of the line is that of the force on a positive charge placed in the field.
- ✓ The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field. When lines close together **E** is strong while if they are far apart E is weak.

23.6 Electric Field Lines

<u>The relationship between strength of E and the density of field lines:</u>

Increase the number of electric field line (N) per unit area of a surface means increase the electric field density→→ increase the strength of E

For example:

- consider an imaginary spherical surface of radius, r, concentric with a point charge.

  $N/4\pi r^2$

E is proportional to the number of lines per unit area, we see that E varies as $1/r^2$ as the finding of

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

23.6 Electric Field Lines

Electric lines of a positive source charge:

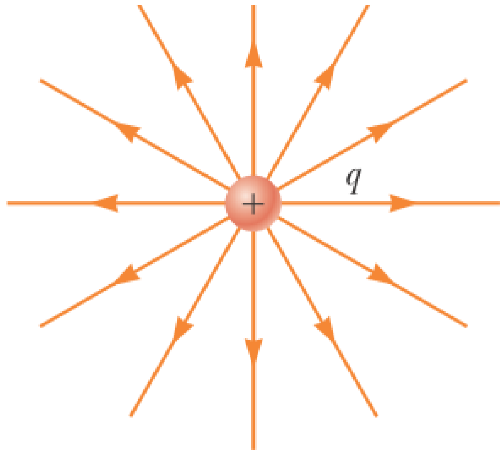
✓ directed radially away from the source charge to infinity.

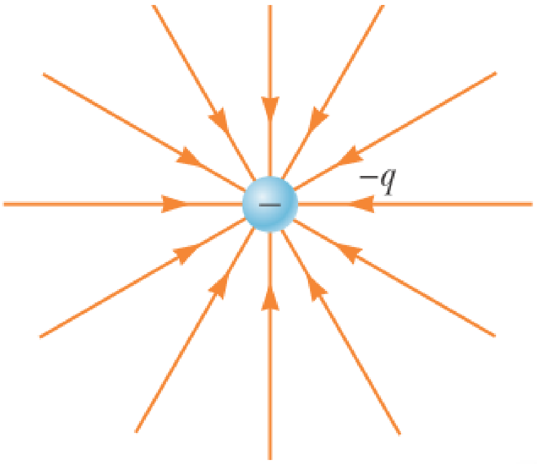
Electric lines of a negative source charge:

✓directed radially toward the source charge from infinity.

Notice that:

lines become closer together as they approach the charge, indicating that the strength.





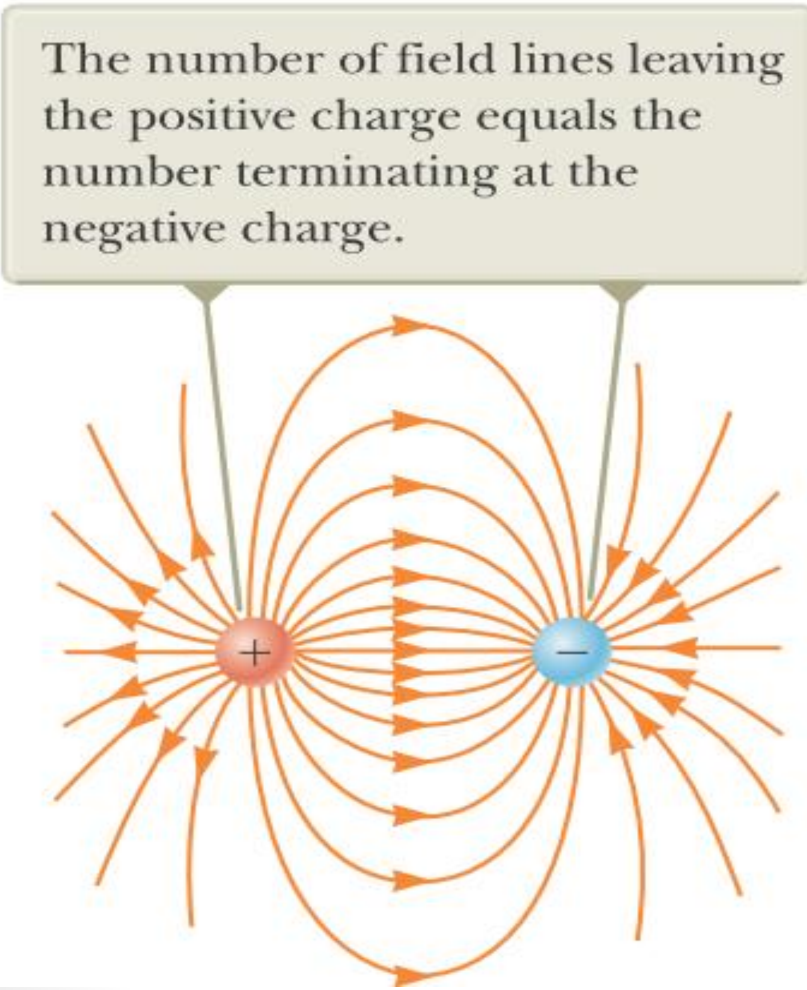
23.6 Electric Field Lines

The rules for drawing electric field lines:

- The lines must begin on a positive charge and terminate on a negative, some lines will begin or end infinitely far away.
- The number of lines drawn is proportional to the magnitude of the charge.
- No two field lines can cross.

23.6 Electric Field Lines

Electric Field Lines of +Q, -Q: Electric Field Lines of +Q, +Q:



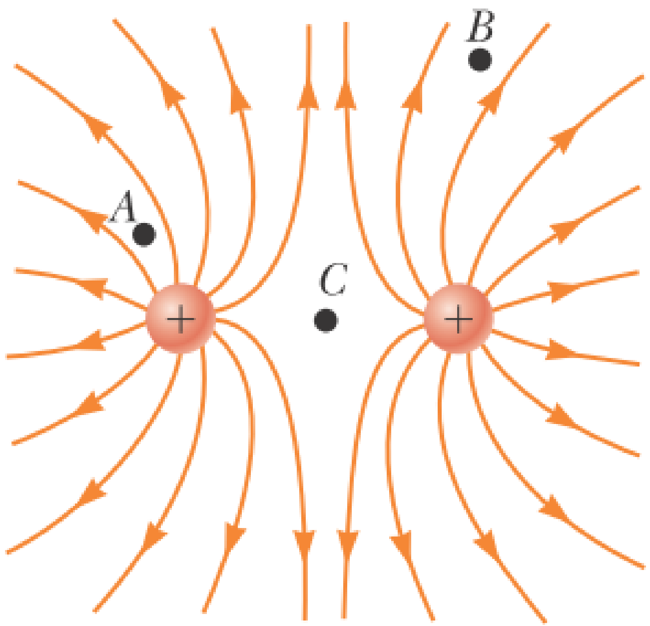


Figure 23.21 The electric field lines for two positive point charges. (The locations A, B, and C are discussed in Quick Quiz 23.5.)

23.6 Electric Field Lines

Electric Field Lines of +2q, -q

The number of lines leaving +2q is twice the number terminating at 2q. Hence, only half the lines that leave the positive charge reach the negative charge. The remaining half terminate on a negative charge we assume to be at infinity.

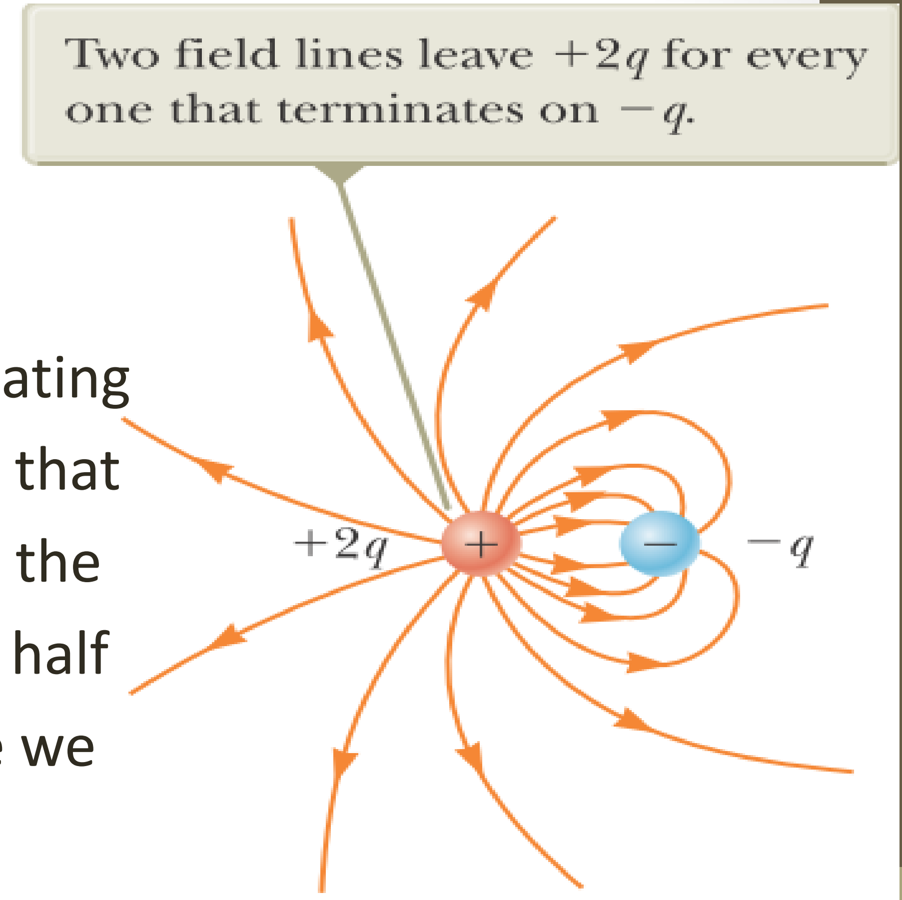


Figure 23.22 The electric field lines for a point charge $+2q$ and a second point charge $-q$.

Summary

- The Electric field
- The Electric field vector
- Analysis Model: Particle in a Field (Electric)
- Electric field calculation
- Electric field Line

The End