King Saud University
College of Science
Physics & Astronomy Dept.

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

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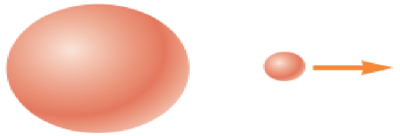
Analysis Model: Particle in a Field (Electric)

- 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)

- $\vec{E}$ 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.

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

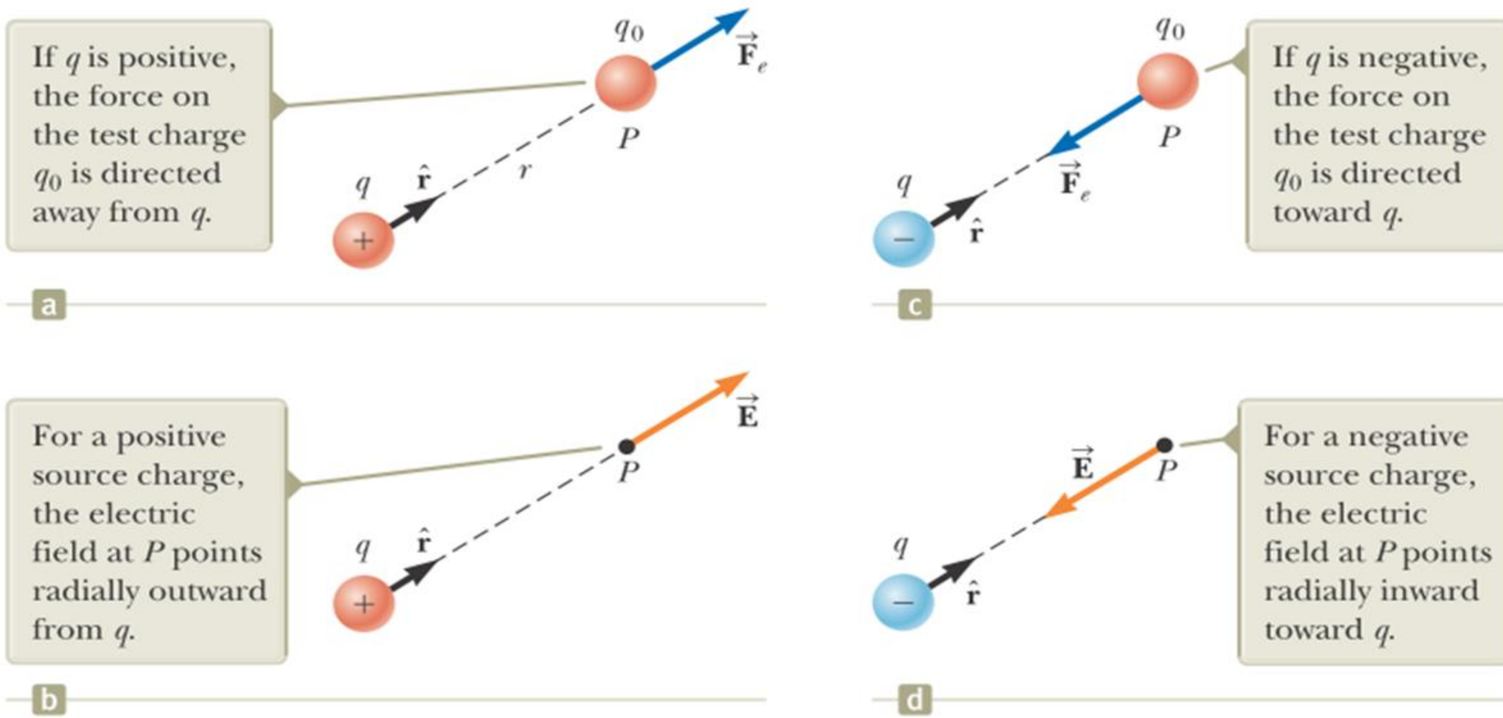
where $\hat{\mathbf{r}}$ is a unit vector directed from q toward q_0.

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.

Analysis Model: Particle in a Field (Electric)

Examples:

- an electron moves around the nucleus in the electric field established by the proton in a hydrogen atom as modeled by the Bohr theory (Chapter 42)
- a hole in a semiconducting material moves in response to the electric field established by applying a voltage to the material (Chapter 43)

Example 23.5 A Suspended Water Droplet

- A water droplet of mass 3.00×10^{-12} kg is located in the air near the ground during a stormy day. An atmospheric electric field of magnitude 6.00×10^{3} N/C points vertically downward in the vicinity of the water droplet. The droplet remains suspended at rest in the air. What is the electric charge on the droplet?

Write Newton's second law from the particle in equilibrium model in the vertical direction:

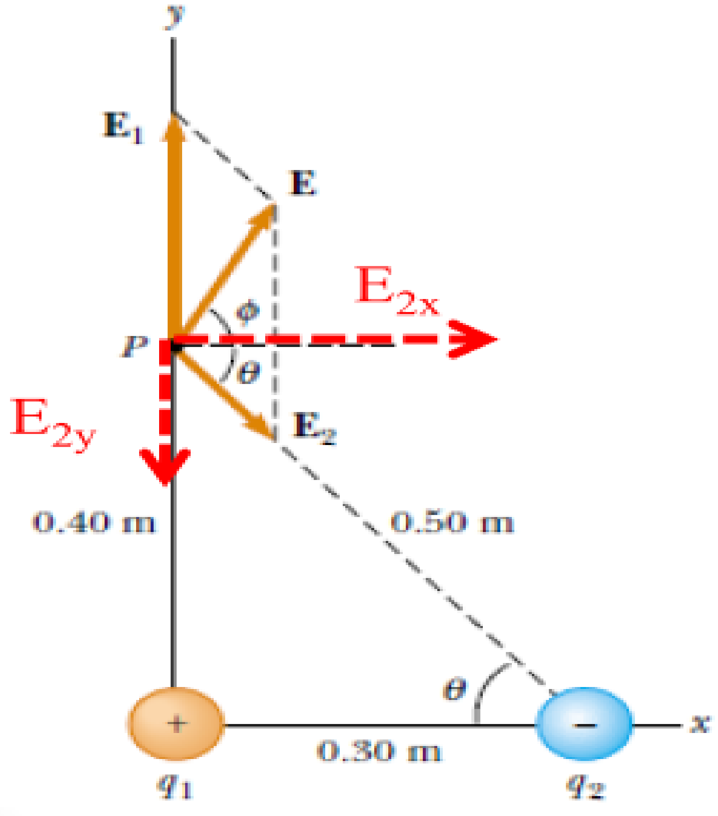
$$\sum F_y = 0 \rightarrow F_e - F_g = 0$$

$$q(-E) - mg = 0$$

$$q = -\frac{mg}{E} = -\frac{(3.00 \times 10^{-12}\,\text{kg})(9.80\,\text{m/s}^2)}{6.00 \times 10^{3}\,\text{N/C}} = -4.90 \times 10^{-15}\,\text{C}$$

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.

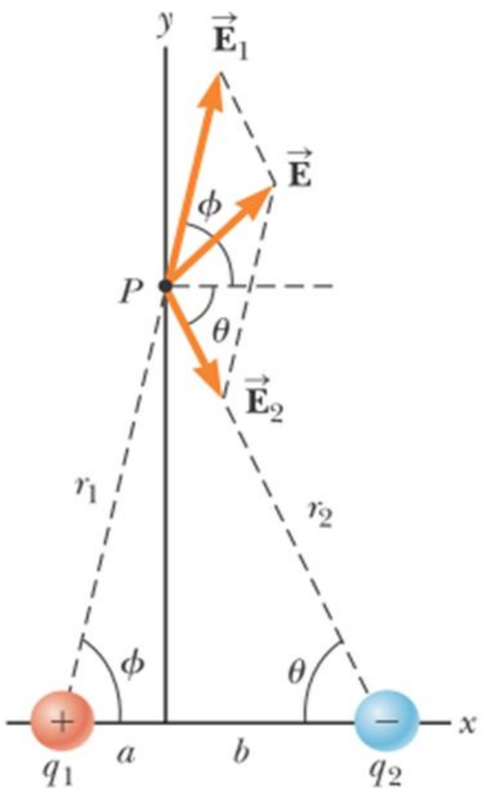
Solution 23.6 (A)

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

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

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

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



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

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

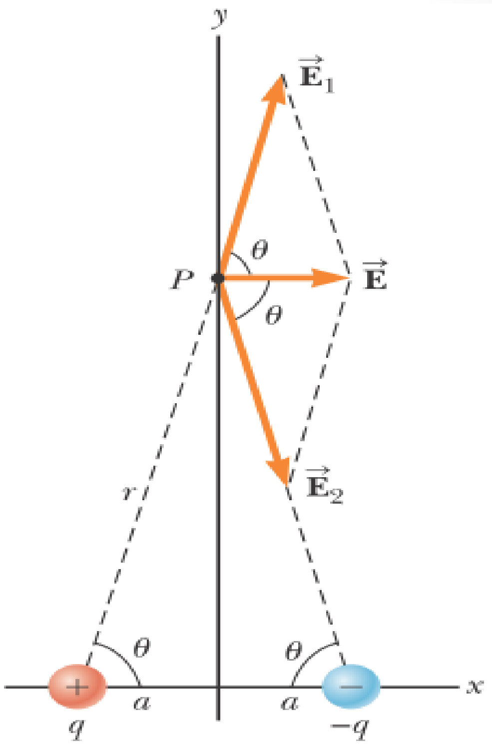
Solution 23.6 (B)

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

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

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

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



Solution 23.6 (C)

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