PHYS 111

1ST semester 1446

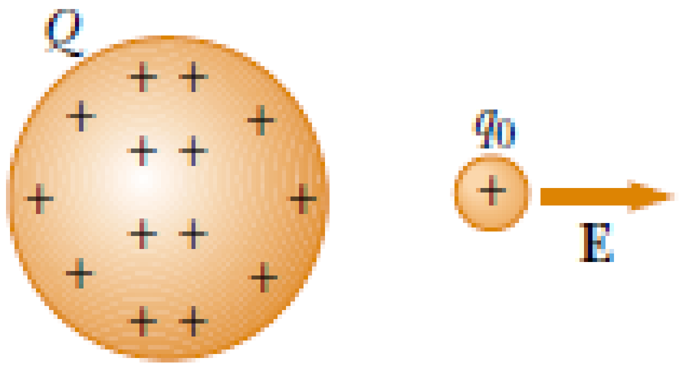
Prof. OMAR H. M. ABD-ELKADER

Lecture 3

23.4 The Electric Field

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

- **The electric field vector E** at a point in space is defined as the electric force **F**e acting on a positive test charge *q*0 placed at that point divided by the test charge:



$$\mathbf{E} \equiv \frac{\mathbf{F}_e}{q_0}$$

Relationship Between F and E

- $$\vec{\mathbf{F}}_e = q\vec{\mathbf{E}}$$
  - This is valid for a point charge only.
  - One of zero size
  - For larger objects, the field may vary over the size of the object.
- If q is positive, the force and the field are in the same direction.
- If q is negative, the force and the field are in opposite directions.

Electric Field, Vector Form

- Remember Coulomb's law, between the source and test charges, can be expressed as

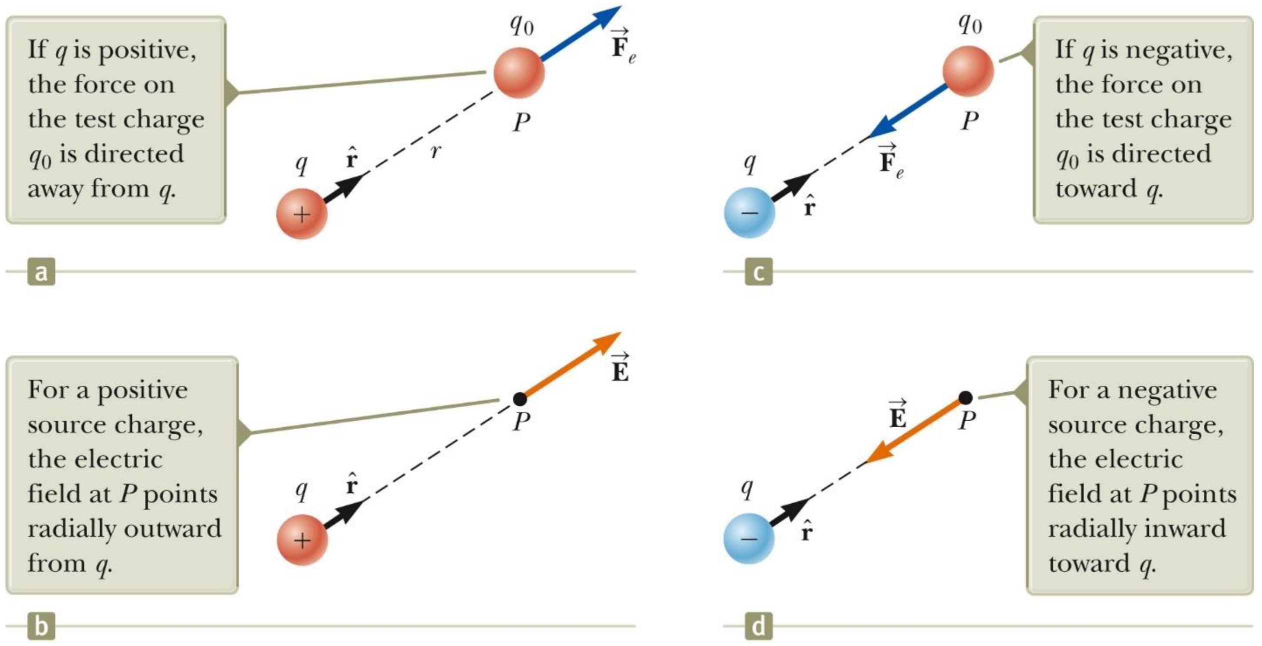
$$\vec{\mathbf{F}}_e = k_e \frac{q q_o}{r^2} \hat{\mathbf{r}}$$

- Then, the electric field will be

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

More About Electric Field Direction

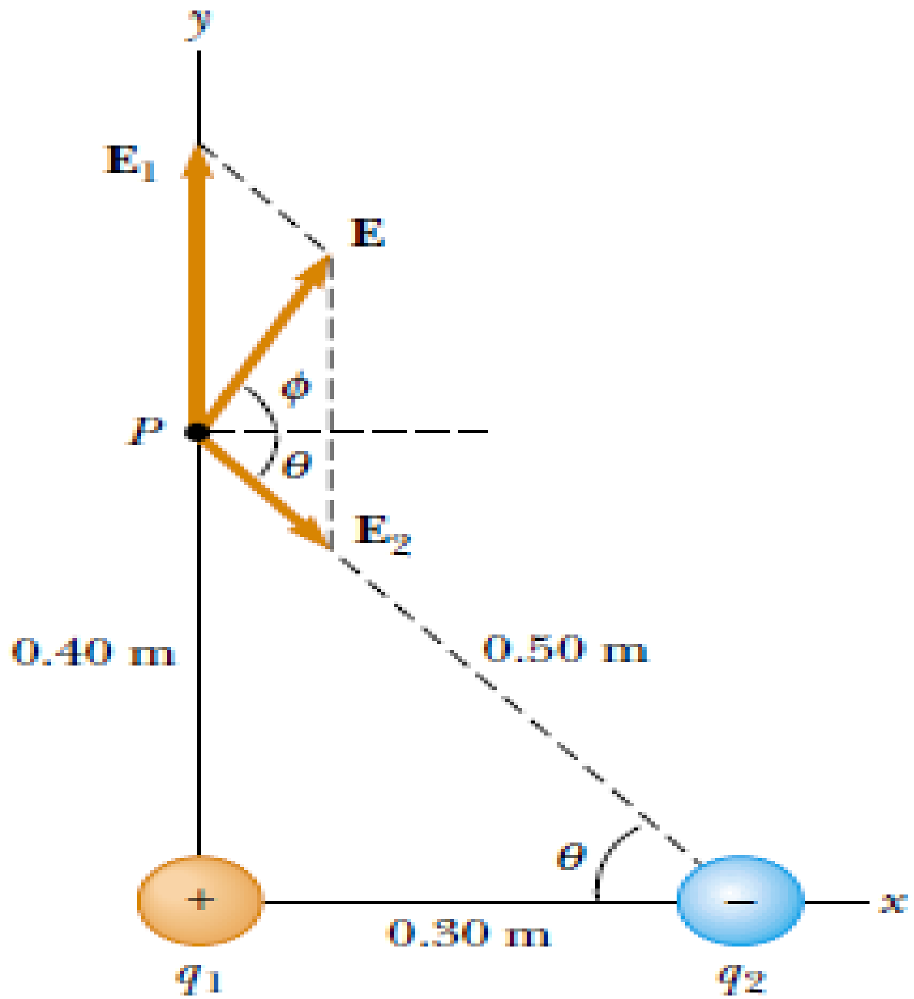
- a) q is positive, the force is directed away from q.
- b) The direction of the field is also away from the positive source charge.
- c) q is negative, the force is directed toward q.
- d) The field is also toward the negative source charge.



Section 23.4

Ex 4

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.



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

$$= 3.9 \times 10^5 \text{ N/C}$$

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

$$= 1.8 \times 10^5 \text{ N/C}$$

The vector $\mathbf{E}_1$ has only a y component. The vector $\mathbf{E}_2$ has an x component given by $E_2 \cos\theta = \frac{3}{5}E_2$ and a negative y component given by $-E_2 \sin\theta = -\frac{4}{5}E_2$. Hence, we can express the vectors as

$$\mathbf{E}_1 = 3.9 \times 10^5 \hat{\mathbf{j}} \text{ N/C}$$

$$\mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} - 1.4 \times 10^5 \hat{\mathbf{j}}) \text{ N/C}$$

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

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

From this result, we find that $\mathbf{E}$ makes an angle ϕ of 66° with the positive x axis and has a magnitude of 2.7×10^5 N/C.

Two 2.00-μC point charges are located on the x axis. One is at $x = 1.00$ m, and the other is at $x = -1.00$ m. (a) Determine the electric field on the y axis at $y = 0.500$ m. (b) Calculate the electric force on a -3.00-μC charge placed on the y axis at $y = 0.500$ m.

(a) $$E=\frac{k_e q}{r^2}=\frac{\left(8.99\times 10^9\right)\left(2.00\times 10^{-6}\right)}{(1.12)^2}=14\,400\ \text{N/C}$$

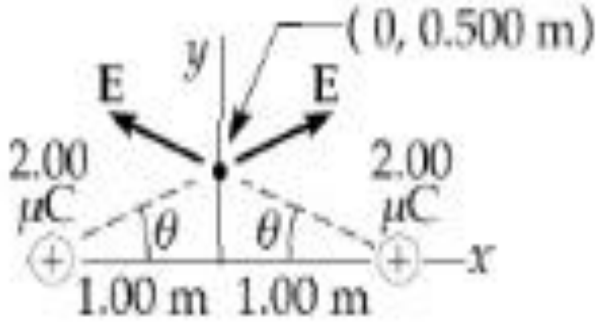


FIG. P23.20

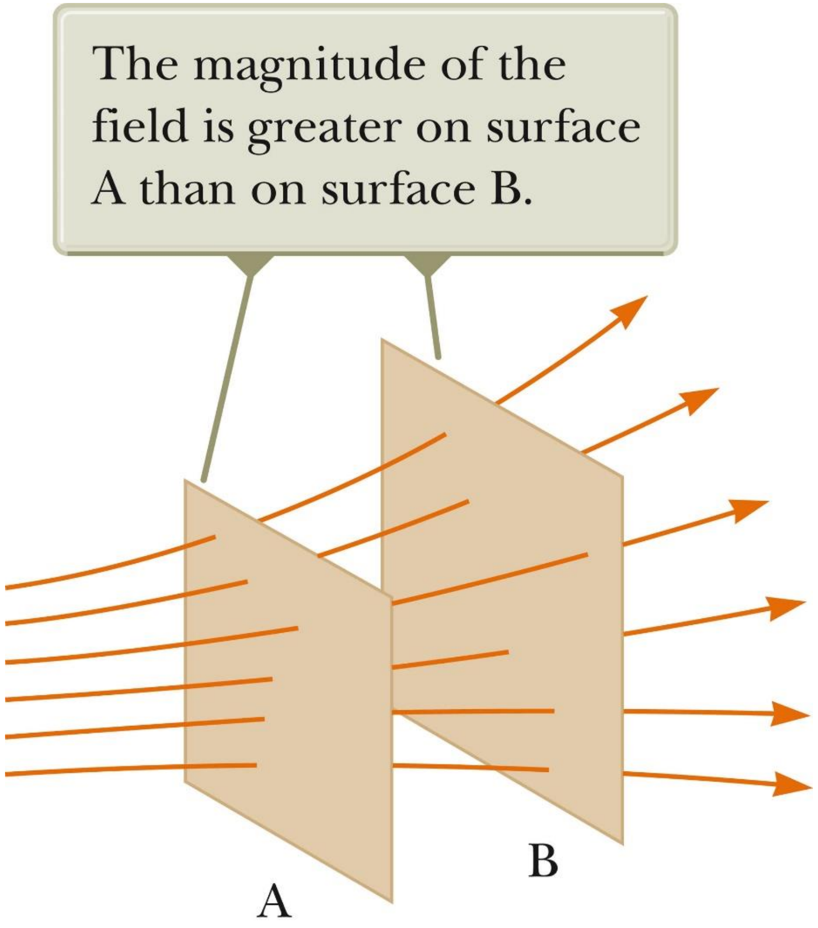
$E_x=0$ and $E_y=2(14\,400)\sin 26.6°=1.29\times 10^4\ \text{N/C}$

so $\boxed{\mathbf{E}=1.29\times 10^4\,\hat{\mathbf{j}}\ \text{N/C}}$.

(b) $$\mathbf{F}=q\mathbf{E}=\left(-3.00\times 10^{-6}\right)\left(1.29\times 10^4\,\hat{\mathbf{j}}\right)=\boxed{-3.86\times 10^{-2}\,\hat{\mathbf{j}}\ \text{N}}$$

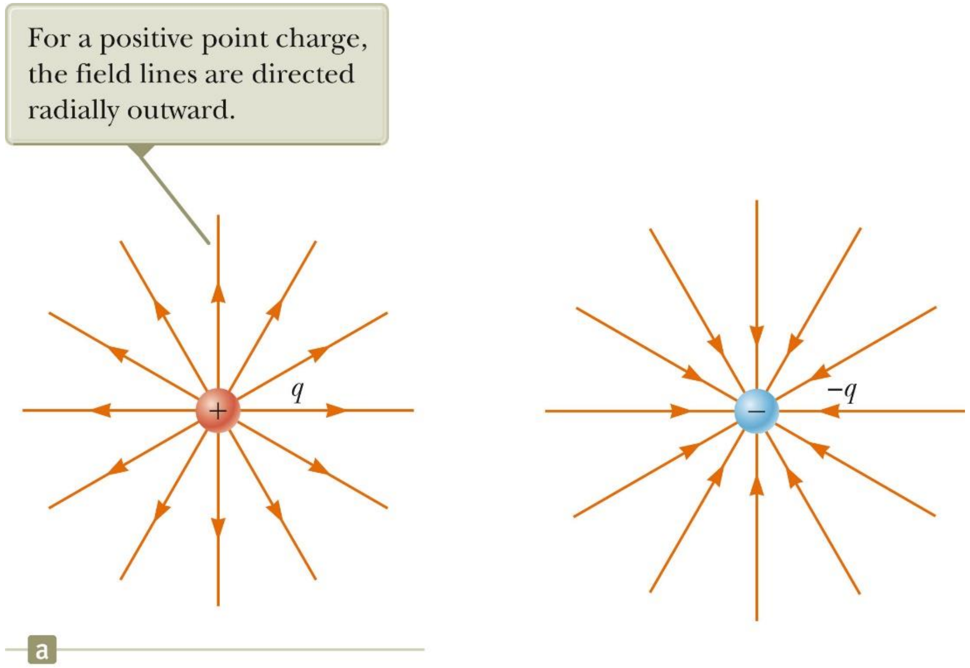
Electric Field Lines, General

- The density of lines through surface A is greater than through surface B.
- The magnitude of the electric field is greater on surface A than B.
- The lines at different locations point in different directions.
  - This indicates the field is nonuniform.



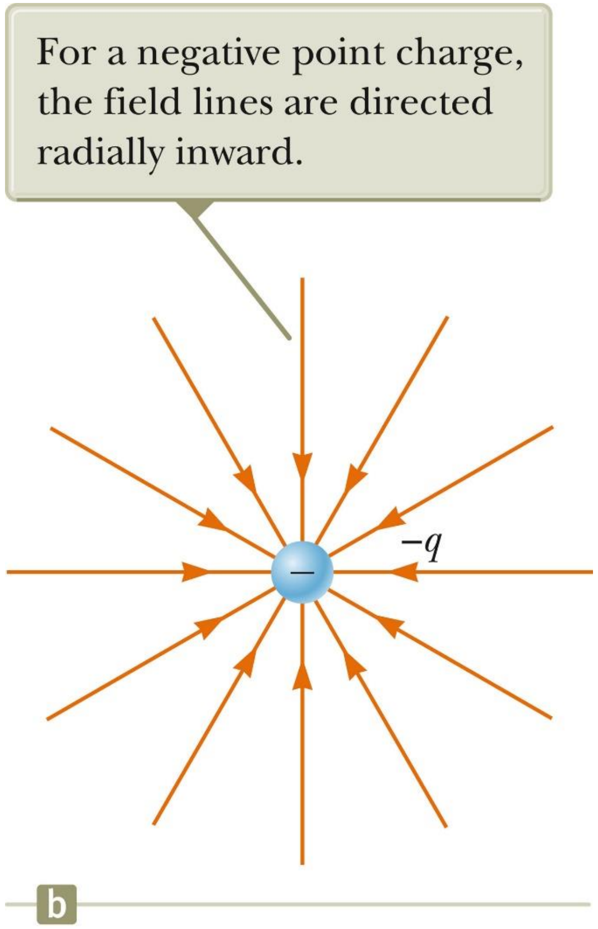
Electric Field Lines, Positive Point Charge

- The field lines radiate outward in all directions.
  - In three dimensions, the distribution is spherical.
- The lines are directed away from the source charge.
  - A positive test charge would be repelled away from the positive source charge.



Electric Field Lines, Negative Point Charge

- The field lines radiate inward in all directions.
- The lines are directed toward the source charge.
    - A positive test charge would be attracted toward the negative source charge.

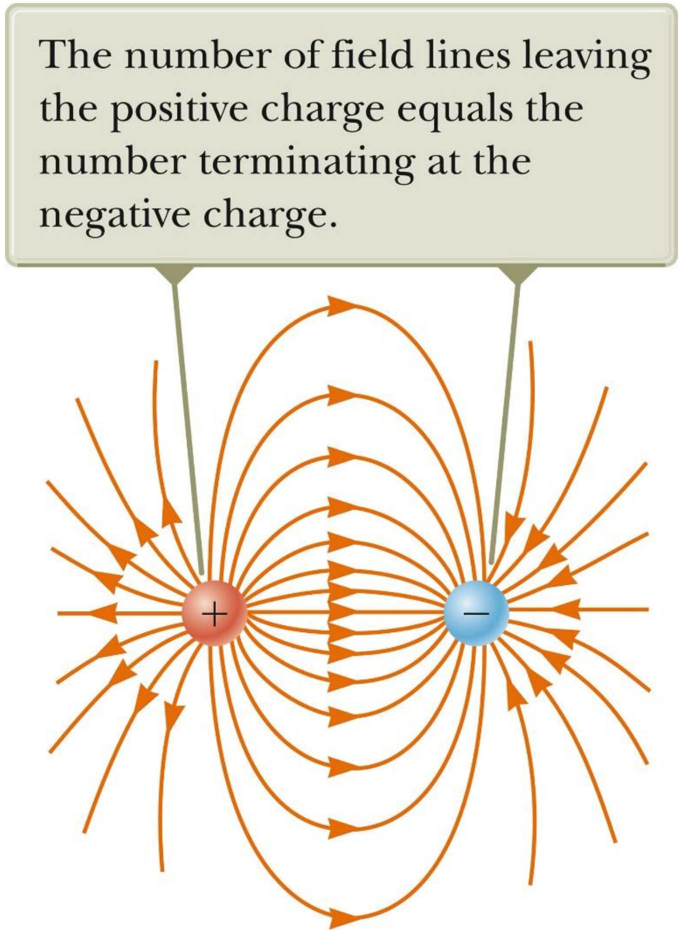


Electric Field Lines – Rules for Drawing

- The lines must begin on a positive charge and terminate on a negative charge.
  - In the case of an excess of one type of charge, some lines will begin or end infinitely far away.
- The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge.
- No two field lines can cross.
- Remember field lines are **not** material objects, they are a pictorial representation used to qualitatively describe the electric field.

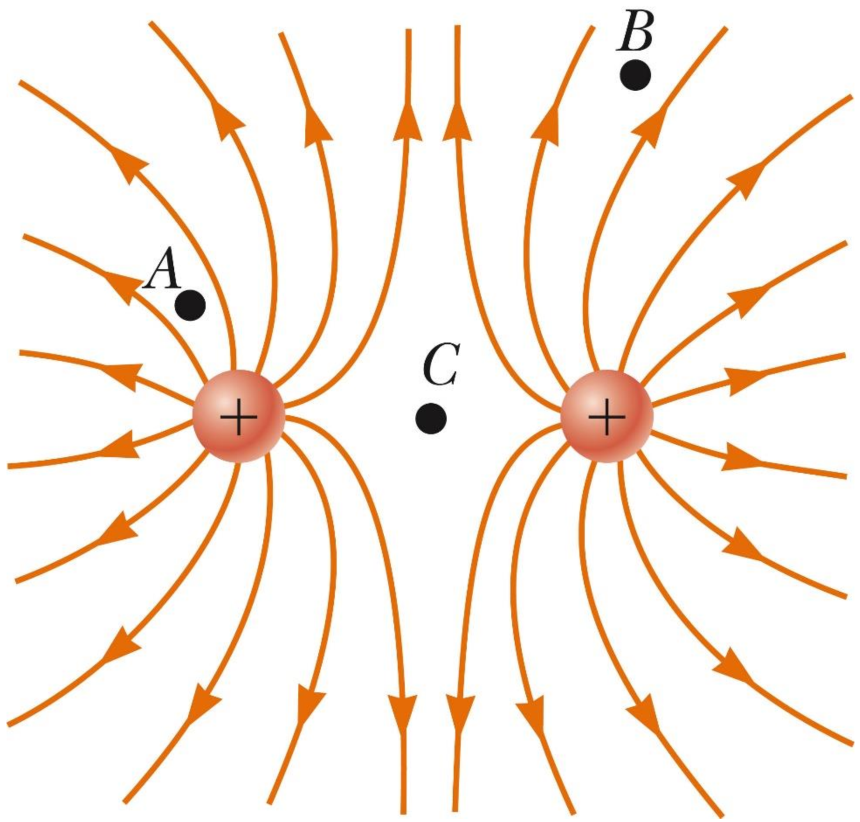
Electric Field Lines – Dipole

- The charges are equal and opposite.
- The number of field lines leaving the positive charge equals the number of lines terminating on the negative charge.



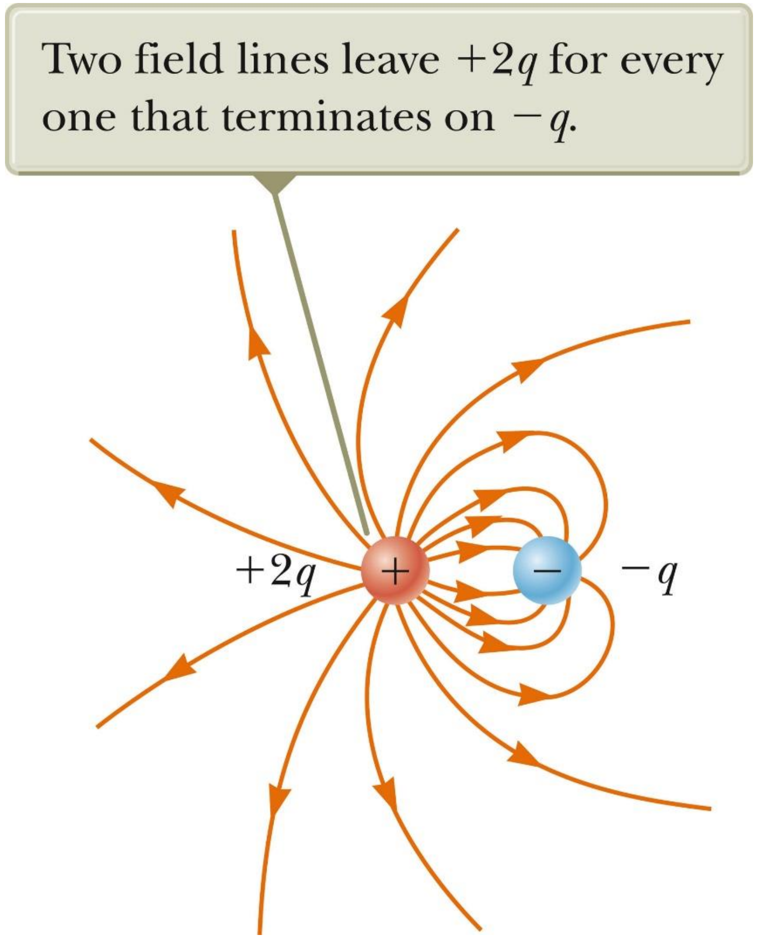
Electric Field Lines – Like Charges

- The charges are equal and positive.
- The same number of lines leave each charge since they are equal in magnitude.
- At a great distance, the field is approximately equal to that of a single charge of 2*q*.
- Since there are no negative charges available, the field lines end infinitely far away.



Electric Field Lines, Unequal Charges

- The positive charge is twice the magnitude of the negative charge.
- Two lines leave the positive charge for each line that terminates on the negative charge.
- At a great distance, the field would be approximately the same as that due to a single charge of $+q$.



Section 23.6

Motion of Charged Particles

- When a charged particle is placed in an electric field, it experiences an electrical force.
- If this is the only force on the particle, it must be the net force.
- The net force will cause the particle to accelerate according to Newton’s second law.

Motion of Particles, cont

- $$\vec{\mathbf{F}}_e = q\vec{\mathbf{E}} = m\vec{\mathbf{a}}$$

- If the field is uniform, then the acceleration is constant.
- The particle under constant acceleration model can be applied to the motion of the particle.
  - The electric force causes a particle to move according to the models of forces and motion.
- If the particle has a positive charge, its acceleration is in the direction of the field.
- If the particle has a negative charge, its acceleration is in the direction opposite the electric field.

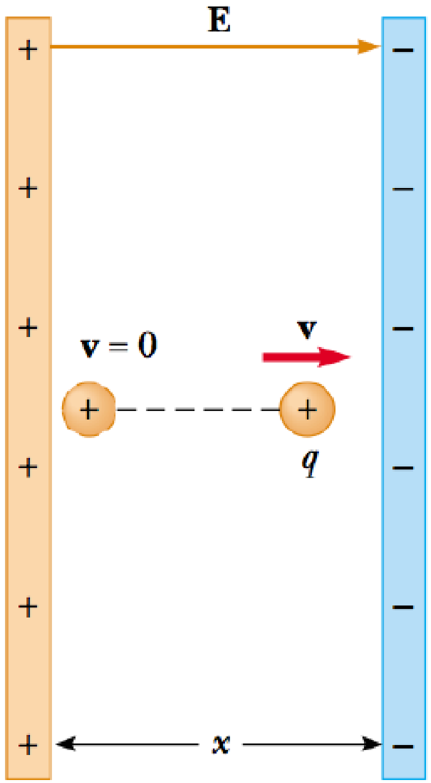
Example 23.10 **An Accelerating Positive Charge**

- A positive point charge *q* of mass *m* is released from rest in a uniform electric field **E** directed along the *x* axis, as shown in Figure 23.25. Describe its motion.

$$x_f = x_i + v_i t + \frac{1}{2}at^2$$

$$v_f = v_i + at$$

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$



Electron in a Uniform Field, Example

- The electron is projected horizontally into a uniform electric field.
- The electron undergoes a downward acceleration.
  - It is negative, so the acceleration is opposite the direction of the field.
- Its motion is parabolic while between the plates.