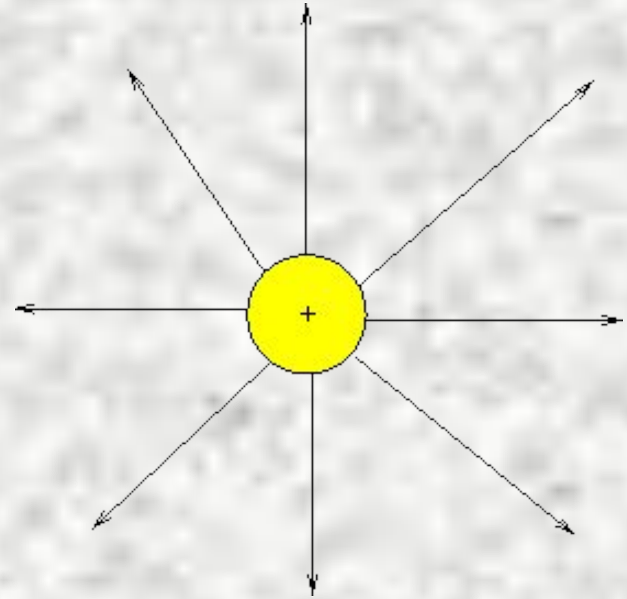
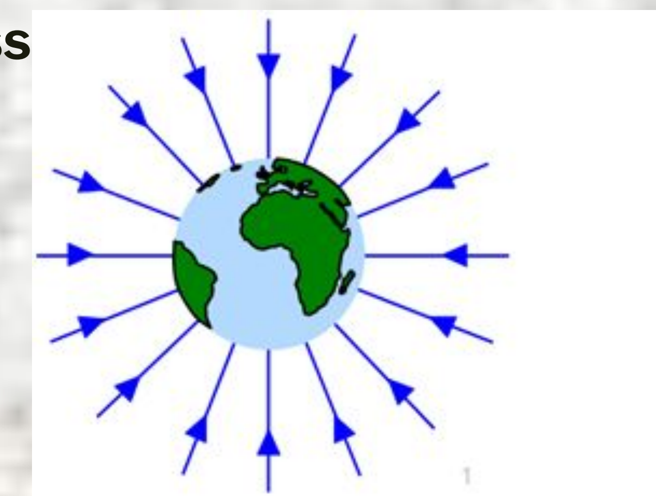
Analogy



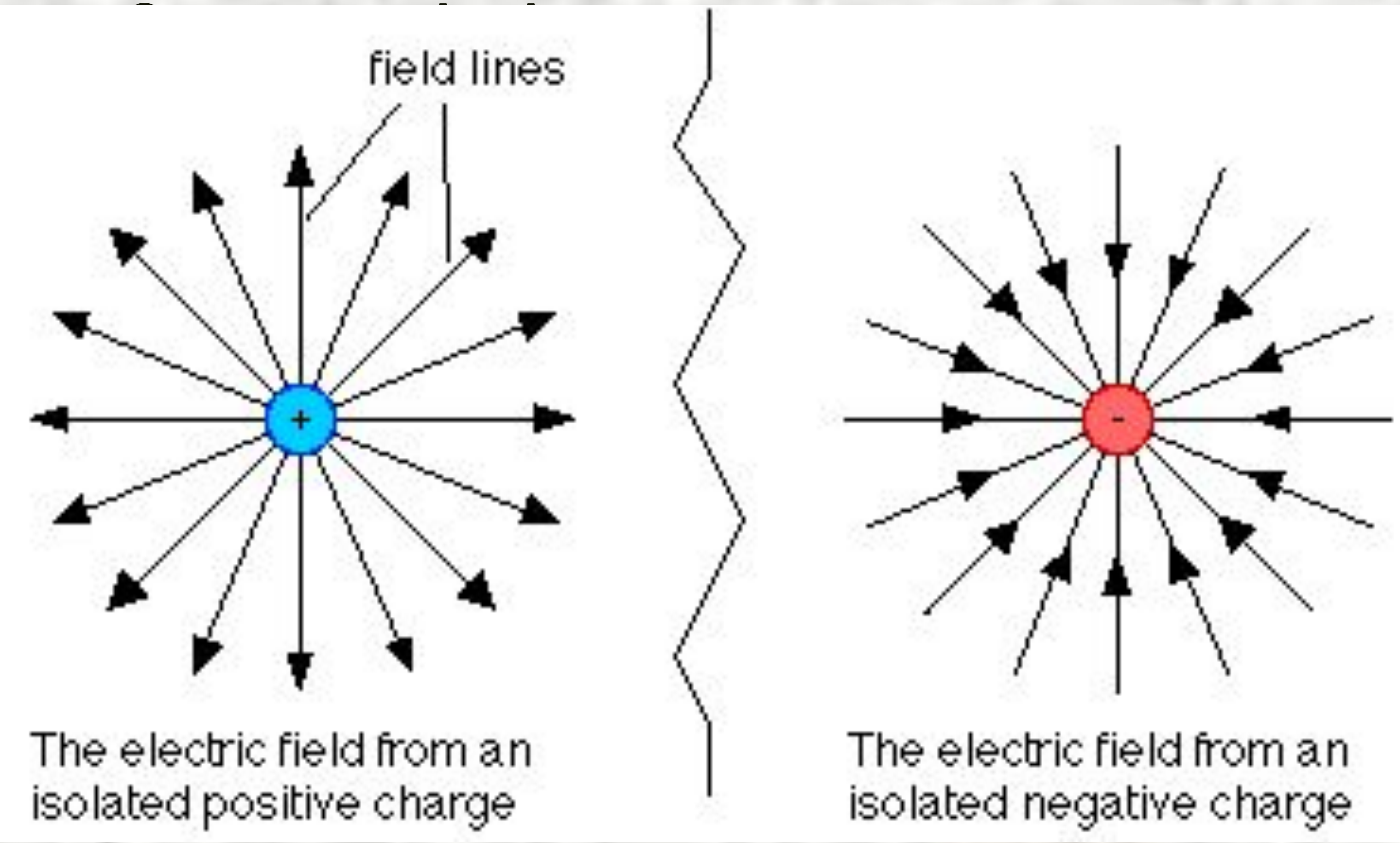
The electric field is the space around an **electrical charge**

just like

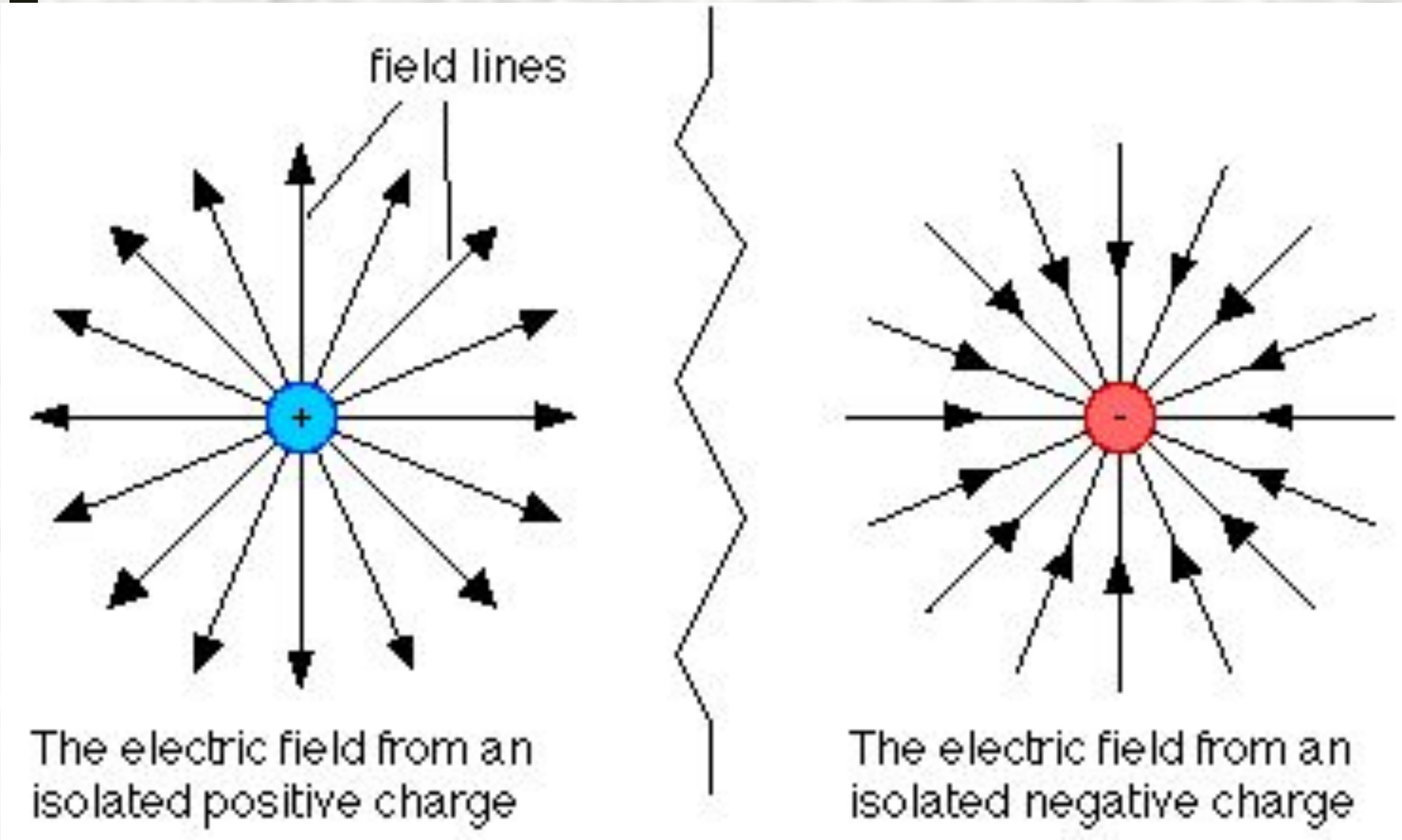
a gravitational field is the space around a **mass**



Electric Field

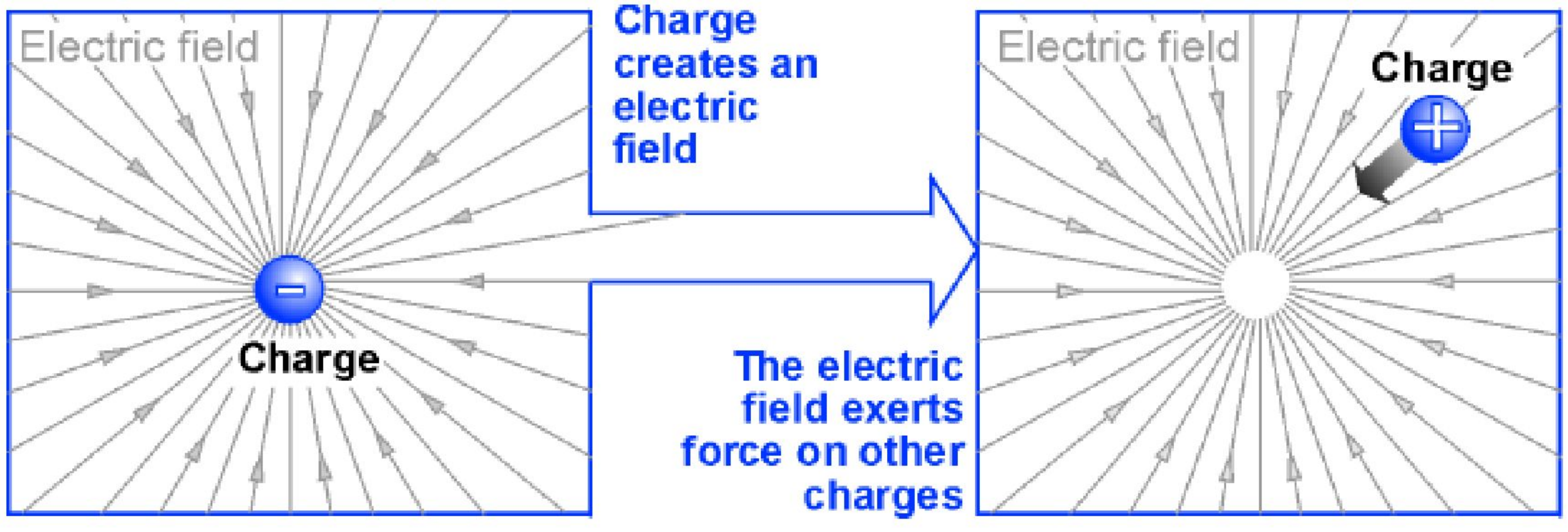


What is the difference?

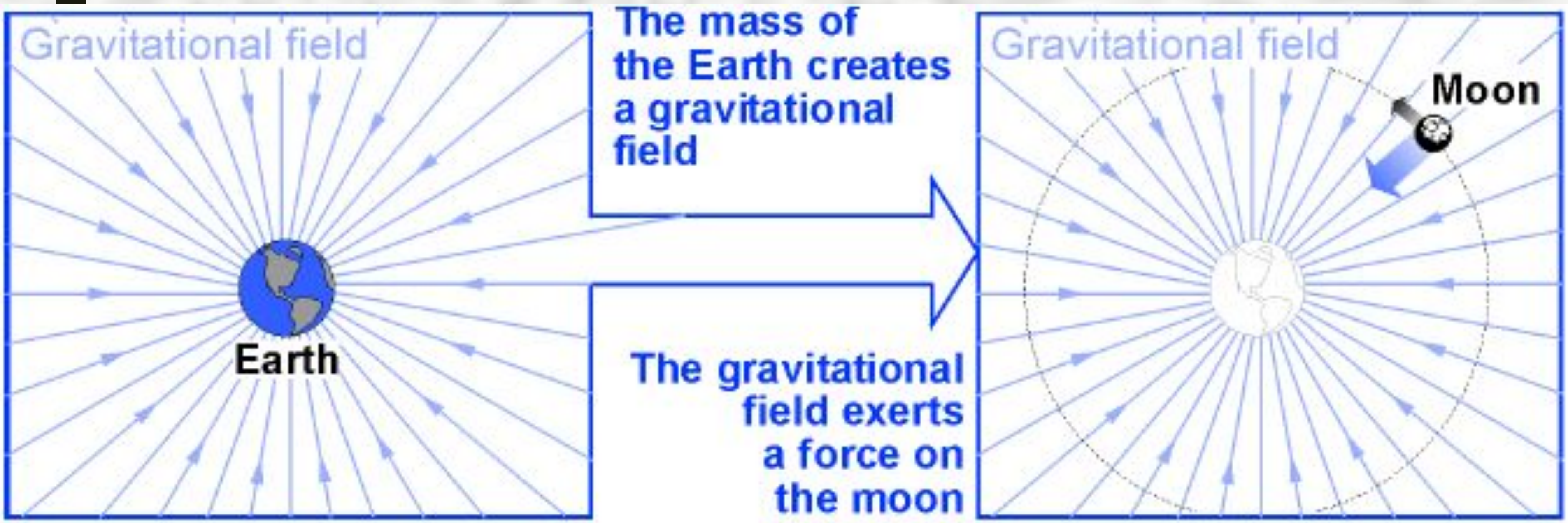


Fields and forces

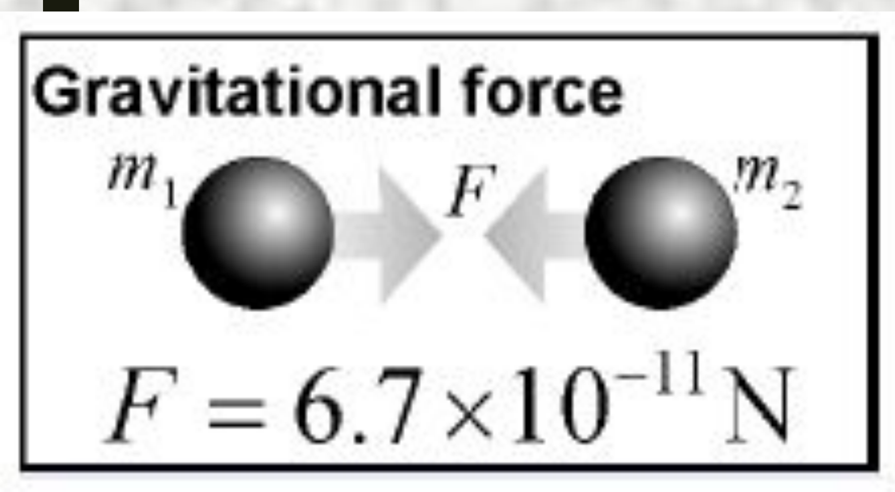
- The concept of a field is used to describe any quantity that has a value for all points in space.
- You can think of the field as the *way* forces are transmitted between objects.
- Charge creates an electric field that creates forces on other charges.

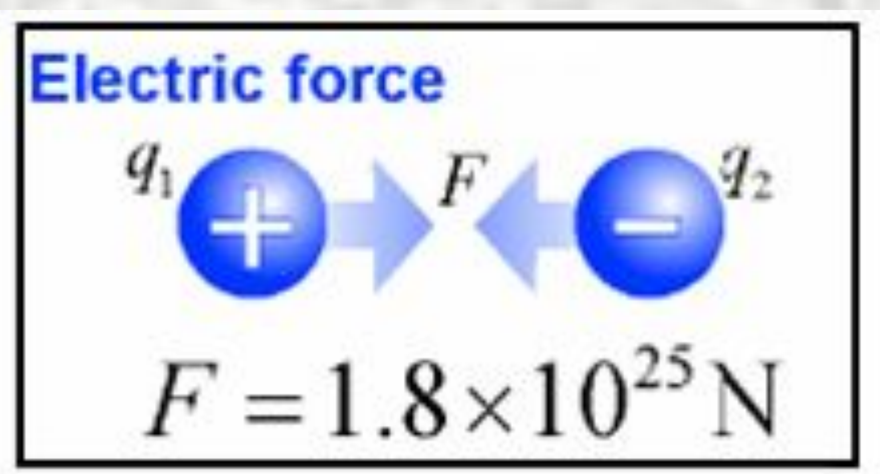


- Mass creates a gravitational field that exerts forces on other masses.



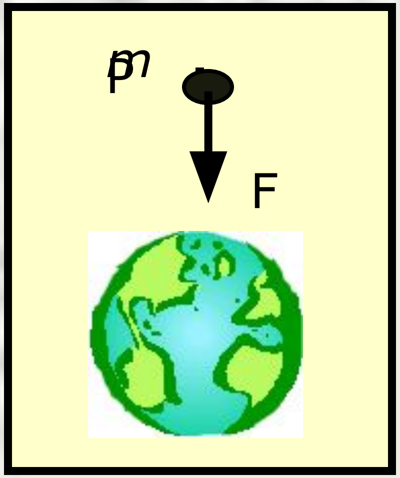
Gravitational forces are far weaker than electric f





The Concept of a Field

A field is defined as a property of space in which a material object experiences a force.



Above earth, we say there is a gravitational field at P.

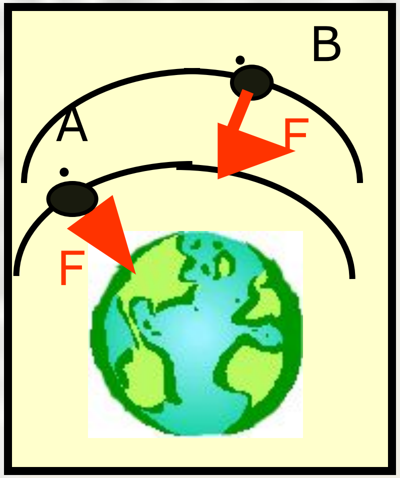
Because a mass *m* experiences a downward force at that point.

No force, no field; No field, no force!

The direction of the field is determined by the force.

The Gravitational Field

Consider points A and B above the surface of the earth—just points in space.



Note that the force F is real, but the field is just a convenient way of describing space.

The field at points A or B might be found from:

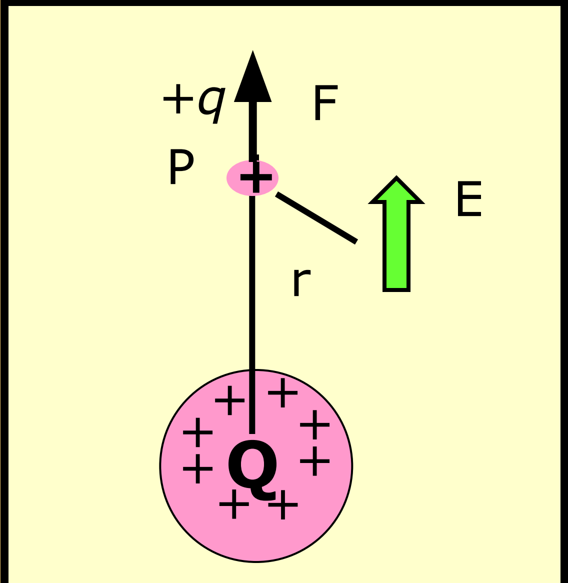
$$g = \frac{F}{m}$$

If g is known at every point above the earth then the force F on a given mass can be found.

The magnitude and direction of the field g is depends on the weight, which is the force F.

The Electric Field

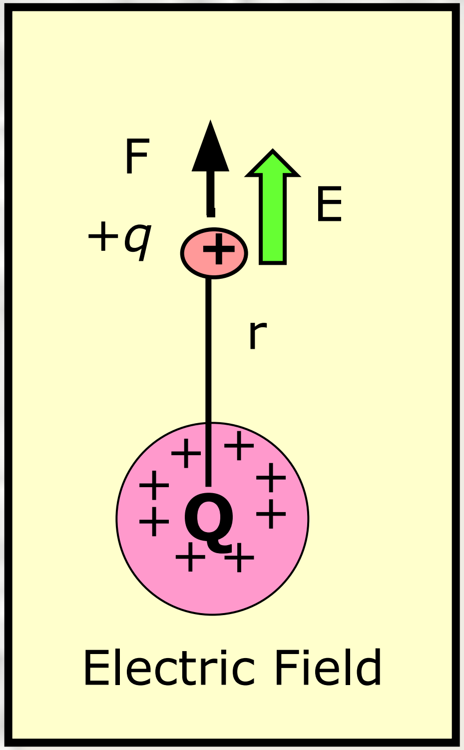
1. Now, consider point P a distance r from +Q.
2. An electric field E exists at P if a test charge +q has a force F at that point.
3. The direction of the E is the same as the direction of a force on + (pos) charge.
4. The magnitude of E is given by the formula:



Electric Field

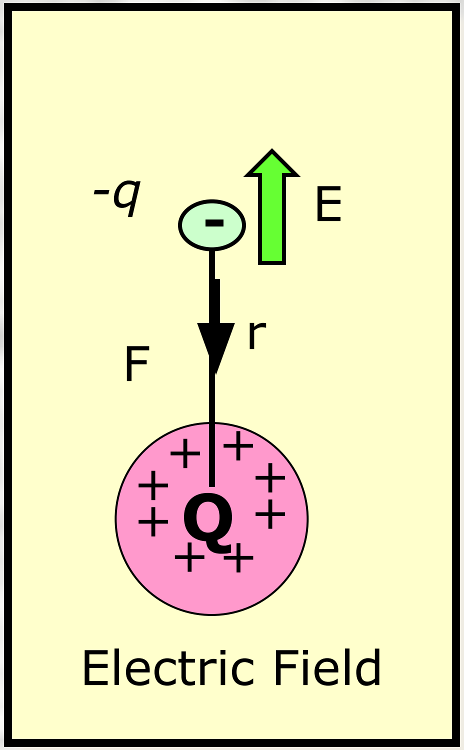
$$\boxed{E = \frac{F}{q};\ \text{Units}\ \frac{\mathrm{N}}{\mathrm{C}}}$$

Field is Property of Space



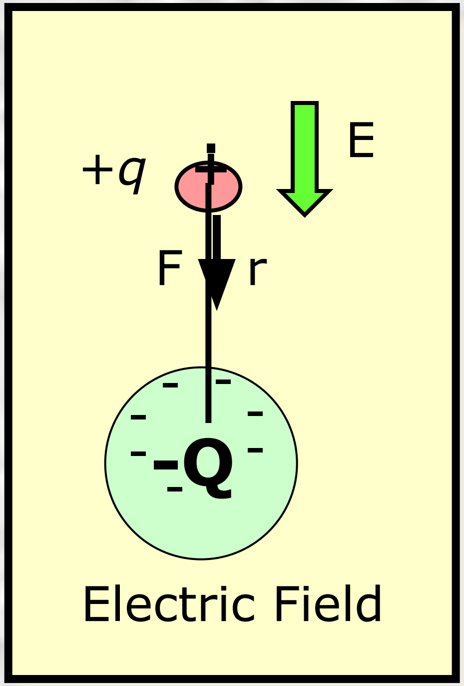
Force on +q is with field direction.

Force on -q is against field direction.



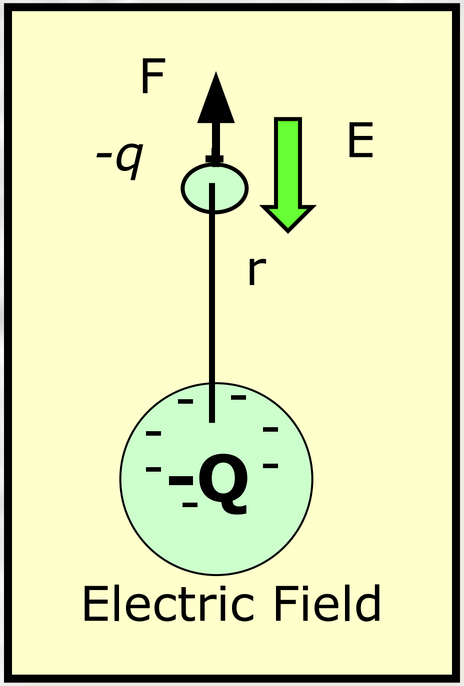
The field E at a point exists whether there is a charge at that point or not. The direction of the field is away from the +Q charge.

Field Near a Negative Charge



Force on +q is with field direction.

Force on -q is against field direction.



Note that the field E in the vicinity of a negative charge –Q is toward the charge—the direction that a +q test charge would move.

The Magnitude of E-Field

The magnitude of the electric field intensity at a point in space is defined as the force per unit charge (N/C) that would be experienced by any test charge placed at that point.

Electric Field Intensity E

$$E = \frac{F}{q}; \text{ Units } \left(\frac{\text{N}}{\text{C}}\right)$$

The direction of E at a point is the same as the direction that a positive charge would move IF placed at that point.

Relationship Between F and E

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

- If q is placed in electric field , then we have
  - *This is valid for a point charge only*
  - *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

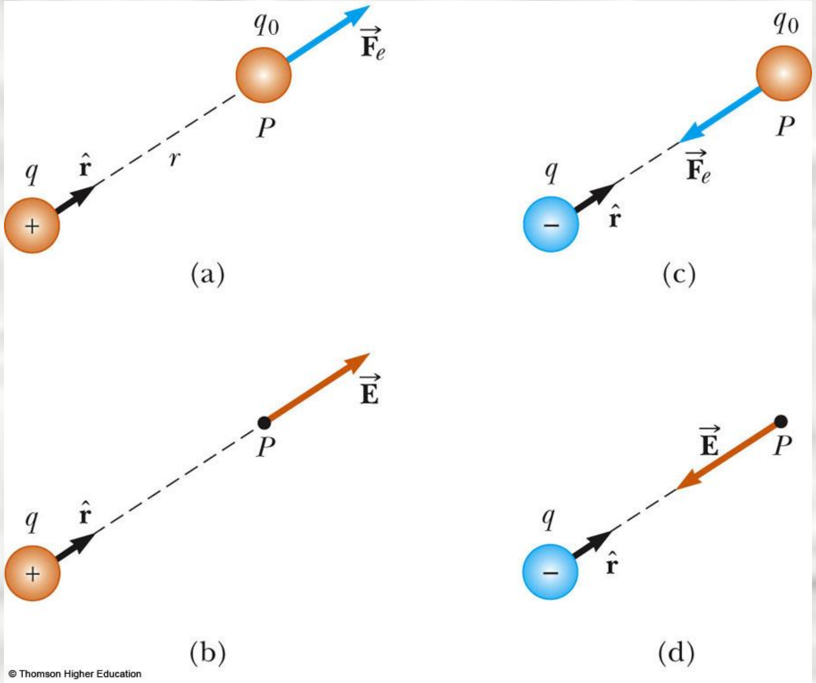
Electric Field, Vector Form

- From Coulomb's law, force 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

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



Superposition with Electric Fields

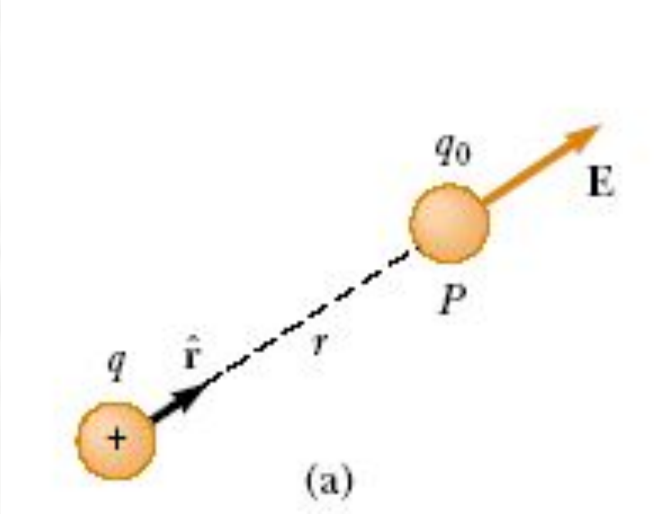
- At any point *P*, the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges

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

Definition of electric field

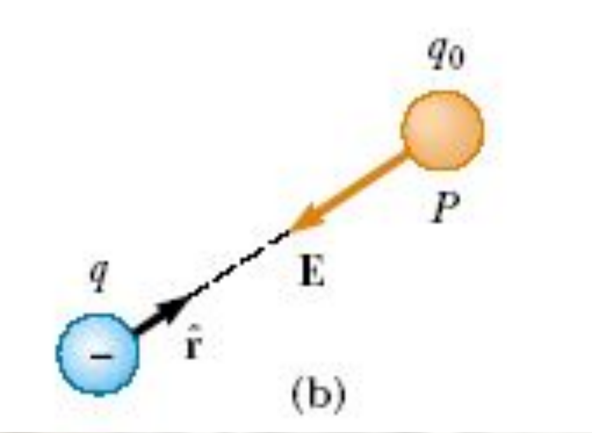
the electric field E at a point in space is defined as the electric force $\mathbf{F}_e$ acting on a positive test charge q_0 placed at that point divided by the magnitude of the test charge:

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



To determine the direction of an electric field, consider a point charge *q located* a distance *r from a test charge q0 located at a point P,* According to Coulomb's law, the force exerted by *q on the test charge is*

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

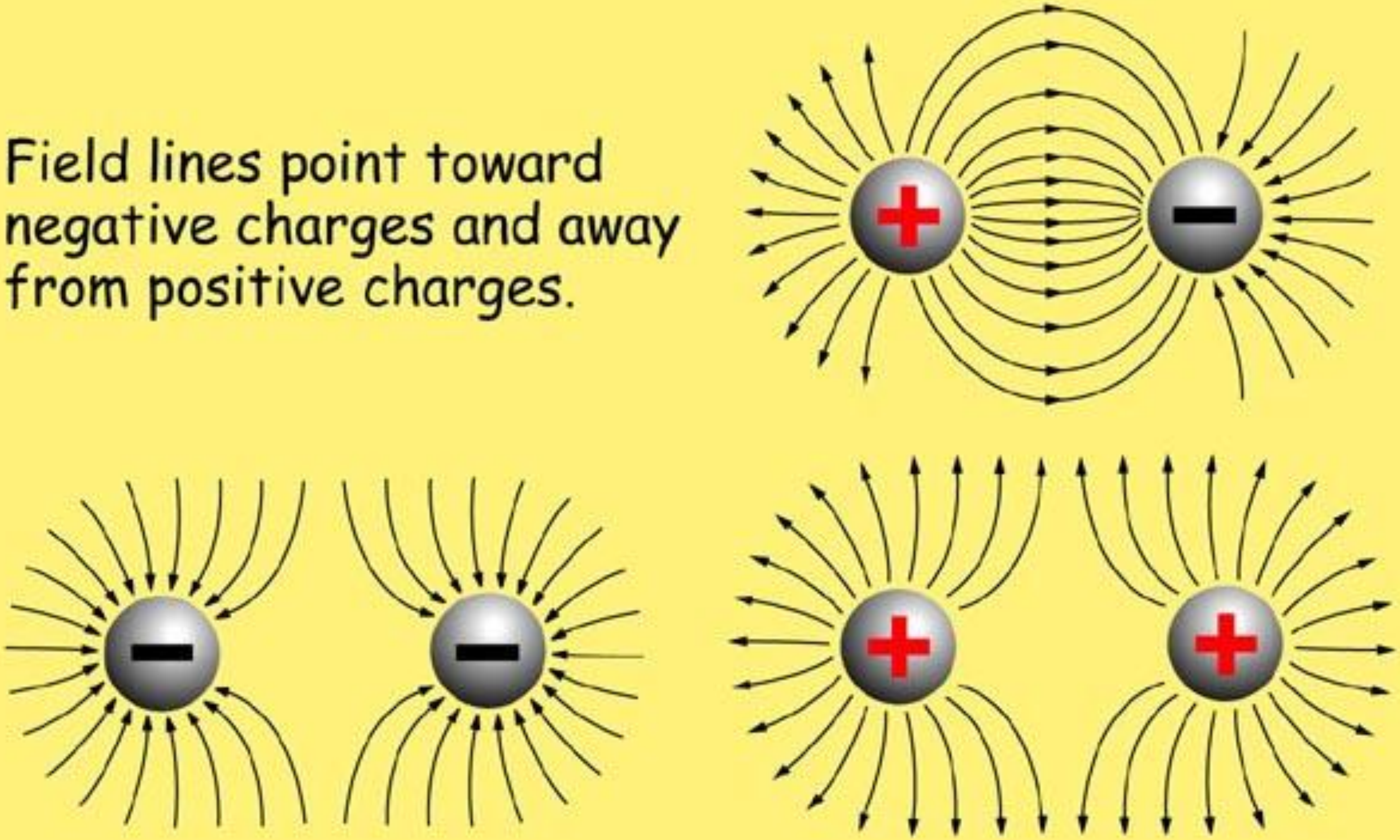


The electric field created by *q is*

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

Drawing the Electric Field

Field lines point toward negative charges and away from positive charges.



Electric Field Due to Two Charges

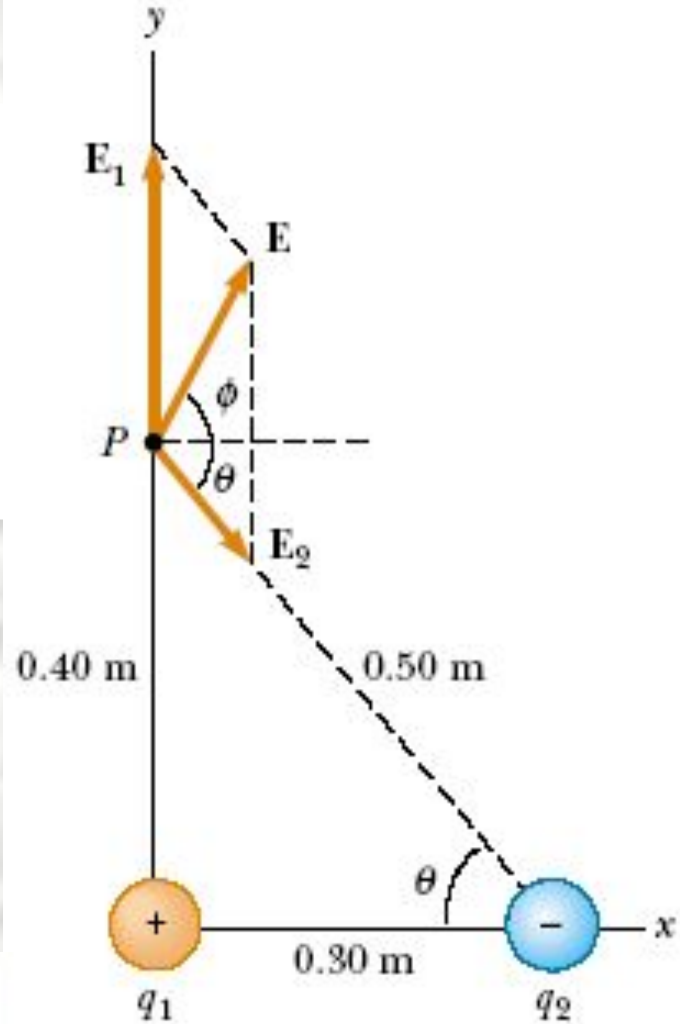
$$E_1 = k_e \frac{|q_1|}{r_1^2} = \left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right) \frac{(7.0 \times 10^{-6}\ \text{C})}{(0.40\ \text{m})^2}$$
$$= 3.9 \times 10^5\ \text{N/C}$$

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

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

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

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



Electric Field of a Dipole

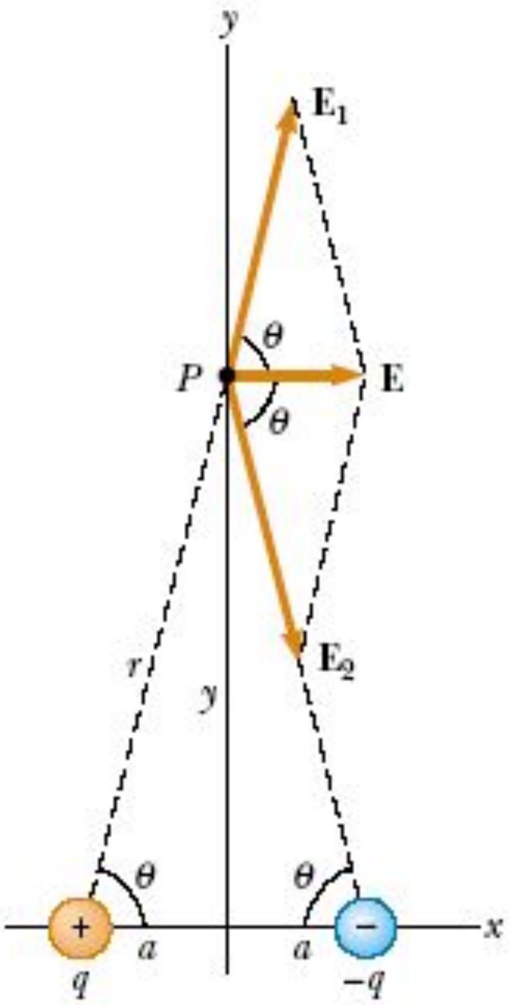
$$E_1 = E_2 = k_e \frac{q}{r^2} = k_e \frac{q}{y^2 + a^2}$$

$$E = 2E_1 \cos\theta = 2k_e \frac{q}{(y^2 + a^2)} \frac{a}{(y^2 + a^2)^{1/2}}$$

$$= k_e \frac{2qa}{(y^2 + a^2)^{3/2}}$$

Because $y \gg a$, we can neglect a^2 and write

$$E \approx k_e \frac{2qa}{y^3}$$



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

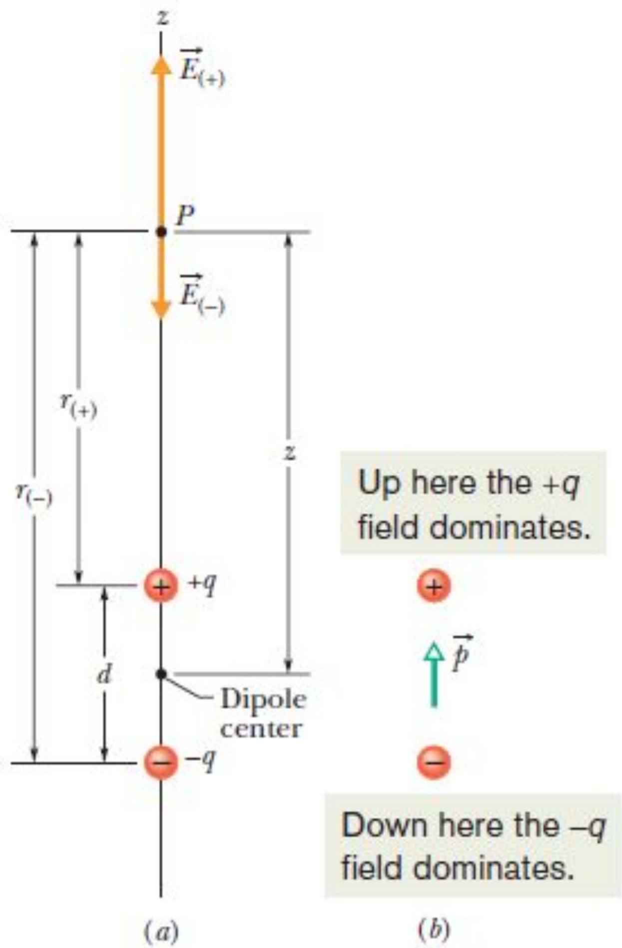


Figure 22-9 (*a*) An electric dipole. The electric field vectors $\vec{E}_{(+)}$ and $\vec{E}_{(-)}$ at point P on the dipole axis result from the dipole's two charges. Point P is at distances $r_{(+)}$ and $r_{(-)}$ from the individual charges that make up the dipole. (*b*) The dipole moment $\vec{p}$ of the dipole points from the negative charge to the positive charge.

$$
\begin{aligned}
E &= E_{(+)} - E_{(-)} \\
&= \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(+)}^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(-)}^2} \\
&= \frac{q}{4\pi\varepsilon_0(z-\frac{1}{2}d)^2} - \frac{q}{4\pi\varepsilon_0(z+\frac{1}{2}d)^2}.
\end{aligned}
$$

After a little algebra, we can rewrite this equation as

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{1}{\left(1-\frac{d}{2z}\right)^2} - \frac{1}{\left(1+\frac{d}{2z}\right)^2}\right).$$

After forming a common denominator and multiplying its terms, we come

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\frac{2d/z}{\left(1-\left(\frac{d}{2z}\right)^2\right)^2} = \frac{q}{2\pi\varepsilon_0 z^3}\frac{d}{\left(1-\left(\frac{d}{2z}\right)^2\right)^2}.$$

We are usually interested in the electrical effect of a dipole only at distances that are large compared with the dimensions of the dipole—that is, at distances such that $z \gg d$. At such large distances, we have $d/2z \ll 1$ in Eq. 22-7. Thus, in our approximation, we can neglect the $d/2z$ term in the denominator, which leaves us with

$$E = \frac{1}{2\pi\varepsilon_0}\frac{qd}{z^3}. \tag{22-8}$$

••7 SSM ILW WWW In Fig. 22-30, the four particles form a square of edge length $a = 5.00$ cm and have charges $q_1 = +10.0$ nC, $q_2 = -20.0$ nC, $q_3 = +20.0$ nC, and $q_4 = -10.0$ nC. In unit-vector notation, what net electric field do the particles produce at the square's center?

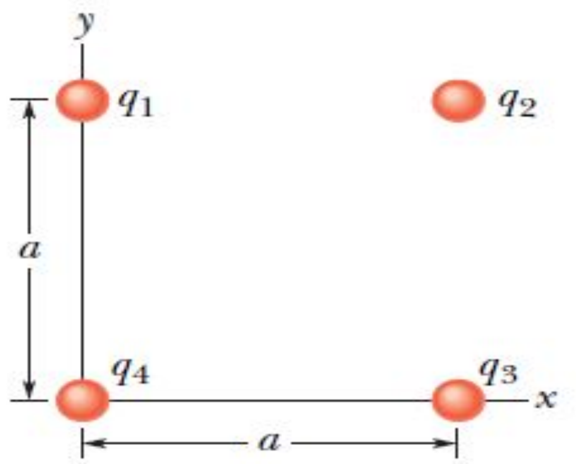


Fig. 22-30 Problem 7.

••8 GO In Fig. 22-31, the four particles are fixed in place and have charges $q_1 = q_2 = +5e$, $q_3 = +3e$, and $q_4 = -12e$. Distance $d = 5.0\ \mu\text{m}$. What is the magnitude of the net electric field at point P due to the particles?

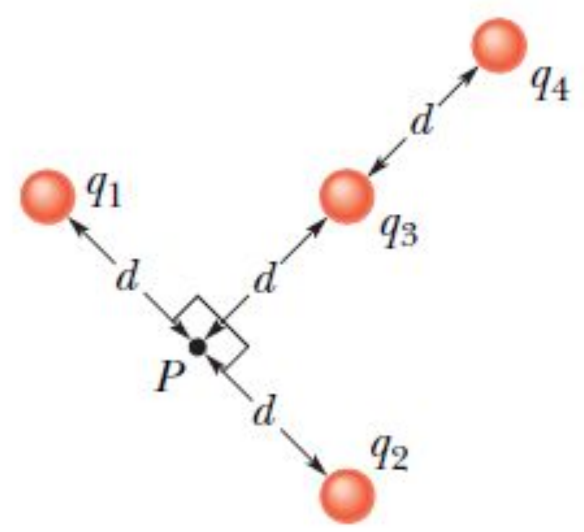


Fig. 22-31 Problem 8.