Charles Coulomb

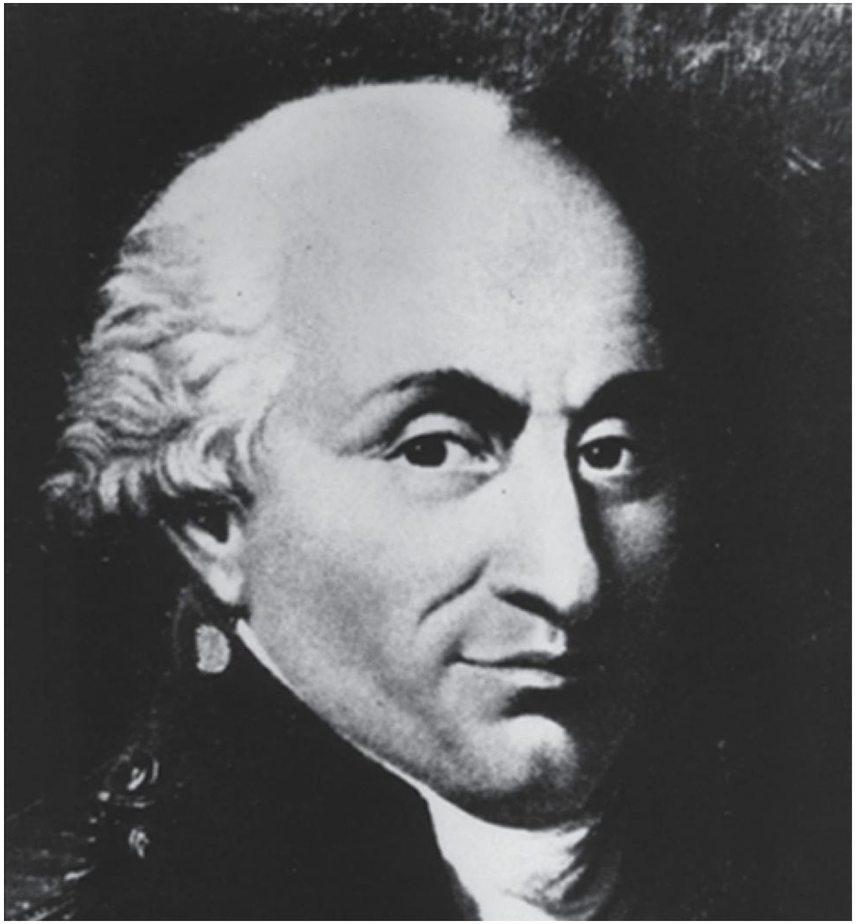
1736 – 1806

French physicist

Major contributions were in areas of electrostatics and magnetism

Also investigated in areas of

- Strengths of materials
- Structural mechanics
- Ergonomics



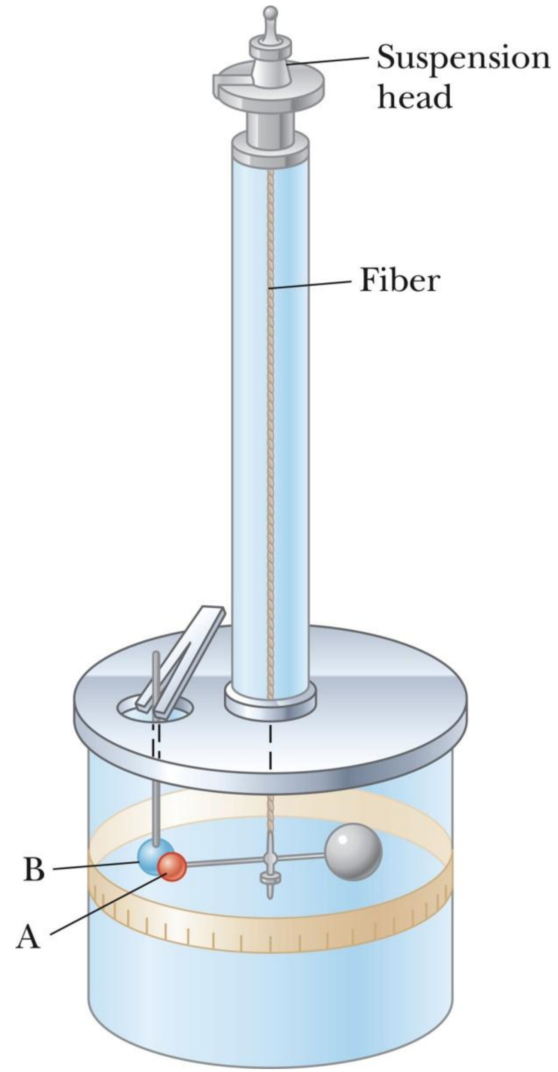
Coulomb's Law

Charles Coulomb measured the magnitudes of electric forces between two small charged spheres.

The force is inversely proportional to the square of the separation r between the charges and directed along the line joining them.

The force is proportional to the product of the charges, q_1 and q_2, on the two particles.

The electrical force between two stationary point charges is given by Coulomb's Law.



Point Charge

The term **point charge** refers to a particle of zero size that carries an electric charge.

- The electrical behavior of electrons and protons is well described by modeling them as point charges.

Coulomb’s Law, cont.

The force is attractive if the charges are of opposite sign.

The force is repulsive if the charges are of like sign.

The force is a conservative force.

Coulomb's Law, Equation

Mathematically,

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

The SI unit of charge is the **coulomb** ©.

k_e is called the **Coulomb constant.**

- k_e = 8.9876 x 10^9 N·m^2/C^2 = 1/(4πe_o)
- e_o is the **permittivity of free space.**
- e_o = 8.8542 x 10^{-12} C^2 / N·m^2

Coulomb's Law, Notes

Remember the charges need to be in coulombs.

- *e* is the smallest unit of charge.
    - except quarks
- $e = 1.6 \times 10^{-19}$ C
- So 1 C needs 6.24×10^{18} electrons or protons

Typical charges can be in the μC range.

Remember that force is a *vector* quantity.

Particle Summary

TABLE 23.1 *Charge and Mass of the Electron, Proton, and Neutron*

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.602\ 176\ 5 \times 10^{-19}$	$9.109\ 4 \times 10^{-31}$
Proton (p)	$+1.602\ 176\ 5 \times 10^{-19}$	$1.672\ 62 \times 10^{-27}$
Neutron (n)	0	$1.674\ 93 \times 10^{-27}$

The electron and proton are identical in the magnitude of their charge, but very different in mass.

The proton and the neutron are similar in mass, but very different in charge.

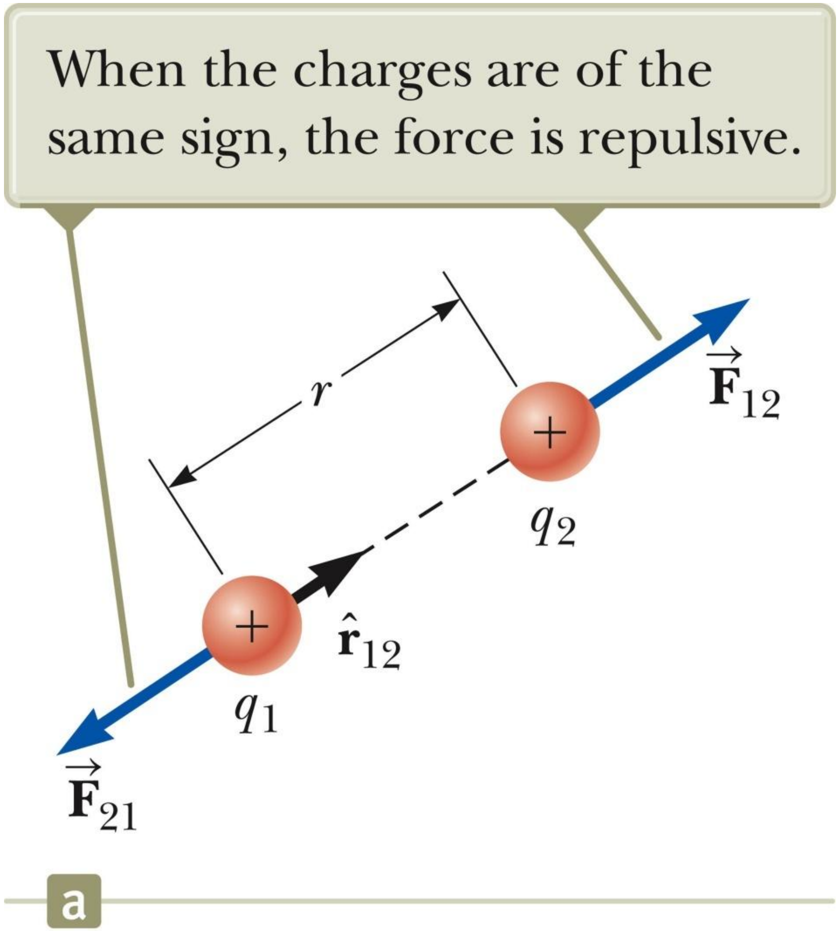
Vector Nature of Electric Forces

In vector form,

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

$\hat{\mathbf{r}}_{12}$ is a unit vector directed from q_1 to q_2.

The like charges produce a repulsive force between them.



Vector Nature of Electrical Forces, cont.

Electrical forces obey Newton's Third Law.

The force on q_1 is equal in magnitude and opposite in direction to the force on q_2

- $\vec{\mathbf{F}}_{21} = -\vec{\mathbf{F}}_{12}$

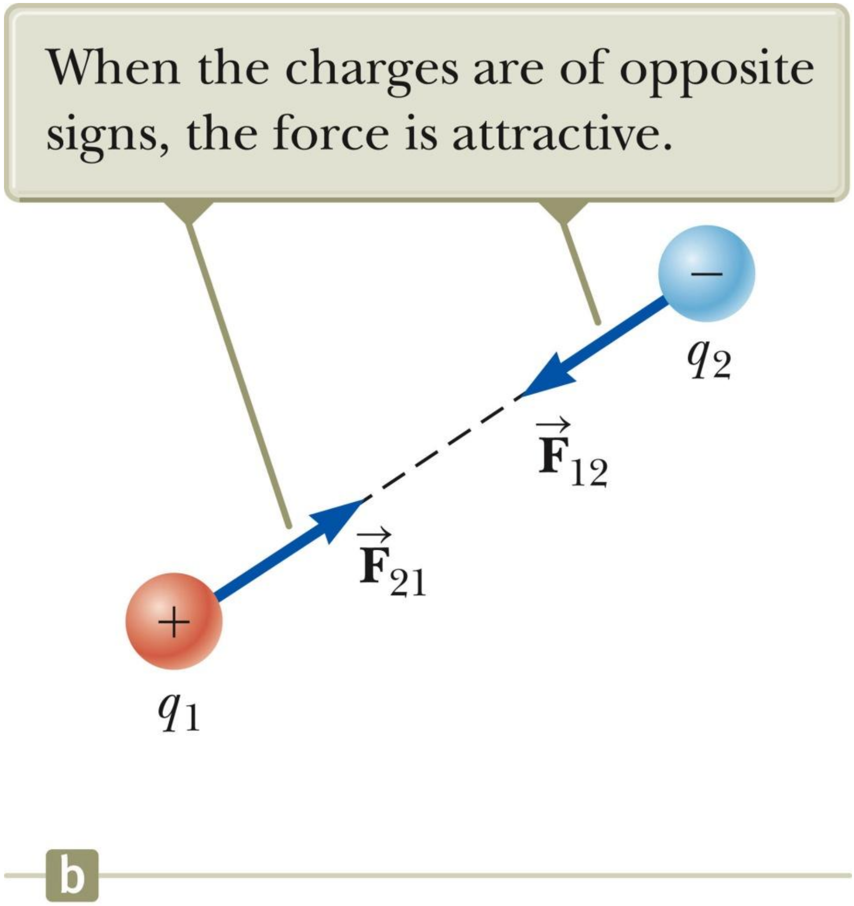
With like signs for the charges, the product q_1q_2 is positive and the force is repulsive.

Vector Nature of Electrical Forces, 3

Two point charges are separated by a distance *r.*

The unlike charges produce an attractive force between them.

With unlike signs for the charges, the product q_1q_2 is negative and the force is attractive.



A Final Note about Directions

The sign of the product of q_1q_2 gives the *relative* direction of the force between q_1 and $q_{2.}$

The *absolute* direction is determined by the actual location of the charges.

Multiple Charges

The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present.

- Remember to add the forces *as vectors.*

The resultant force on q_1 is the vector sum of all the forces exerted on it by other charges.

For example, if four charges are present, the resultant force on one of these equals the vector sum of the forces exerted on it by each of the other charges.

$$\vec{\mathbf{F}}_1 = \vec{\mathbf{F}}_{21} + \vec{\mathbf{F}}_{31} + \vec{\mathbf{F}}_{41}$$

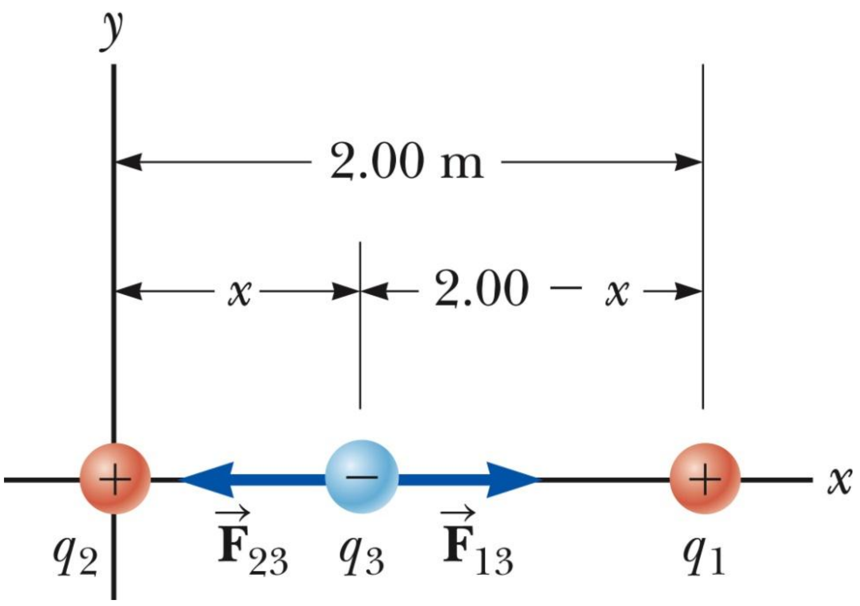
Zero Resultant Force, Example

Where is the resultant force equal to zero?

- The magnitudes of the individual forces will be equal.
- Directions will be opposite.

Will result in a quadratic

Choose the root that gives the forces in opposite directions.



Electrical Force with Other Forces, Example

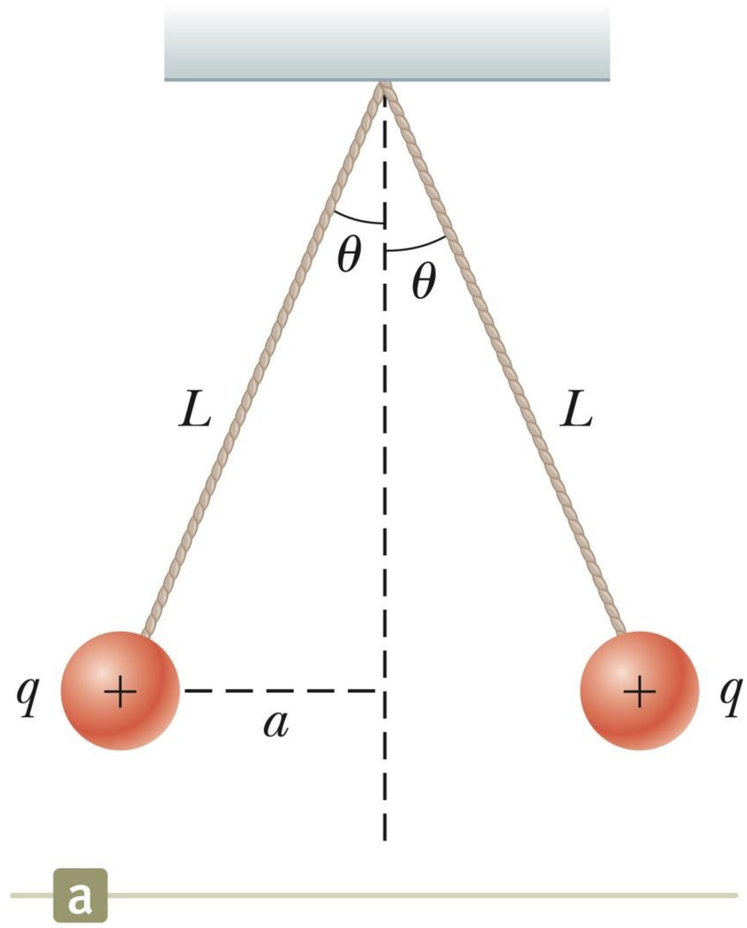
The spheres are in equilibrium.

Since they are separated, they exert a repulsive force on each other.

- Charges are like charges

Model each sphere as a particle in equilibrium.

Proceed as usual with equilibrium problems, noting one force is an electrical force.

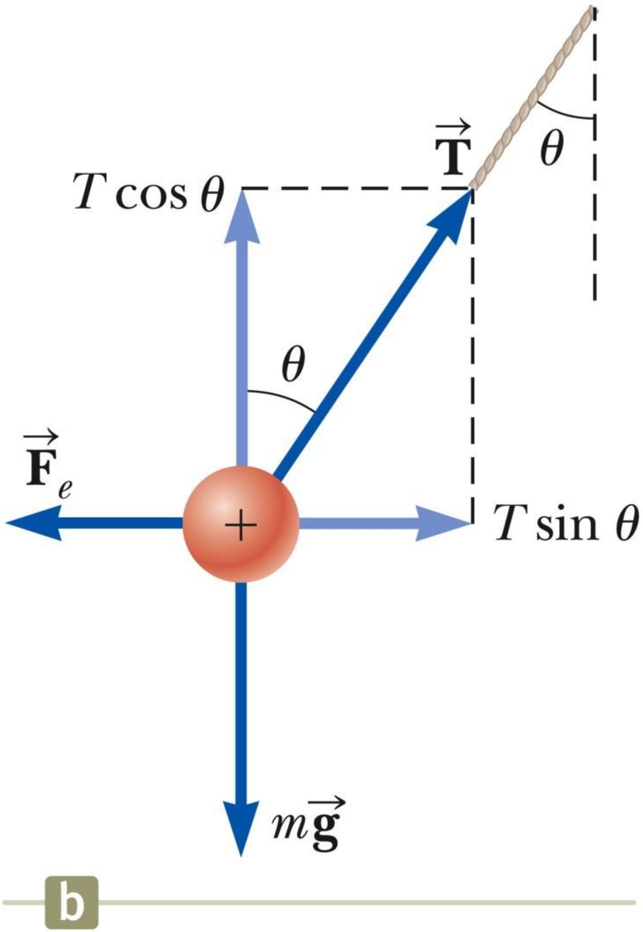


Electrical Force with Other Forces, Example cont.

The force diagram includes the components of the tension, the electrical force, and the weight.

Solve for |*q*|

If the charge of the spheres is not given, you cannot determine the sign of *q*, only that they both have same sign.



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Electric Field – Introduction

The electric force is a field force.

Field forces can act through space.

- The effect is produced even with no physical contact between objects.

Faraday developed the concept of a field in terms of electric fields.

Electric Field – Definition

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**, enters this electric field, an electric force acts on it.

Electric Field – Definition, cont

The electric field 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 acting on a positive test charge, q_o, placed at that point divided by the test charge:

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

Electric Field, Notes

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

The existence of an electric field is a property of the source charge.

- The presence of the test charge is not necessary for the field to exist.

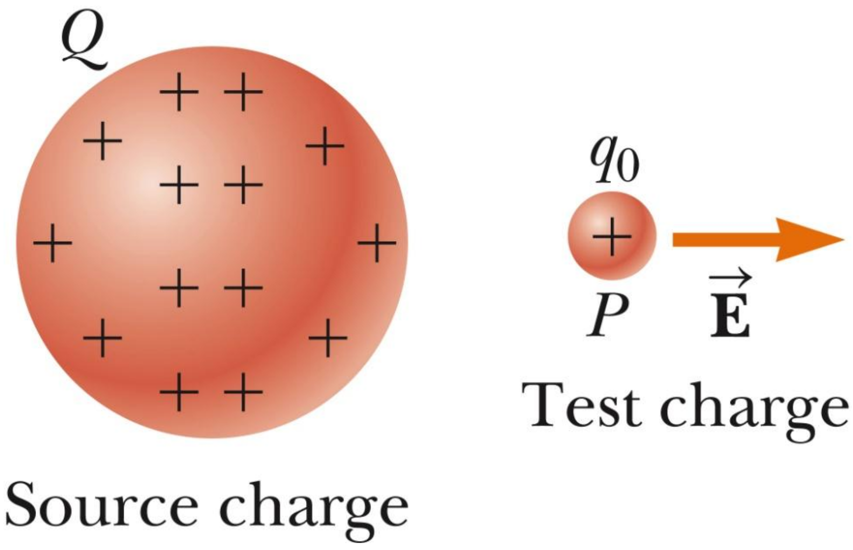
The test charge serves as a detector of the field.

Electric Field Notes, Final

The direction of $\vec{\mathbf{E}}$ is that of the force on a positive test charge.

The SI units of $\vec{\mathbf{E}}$ are N/C.

We can also say that an electric field exists at a point if a test charge at that point experiences an electric force.



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

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

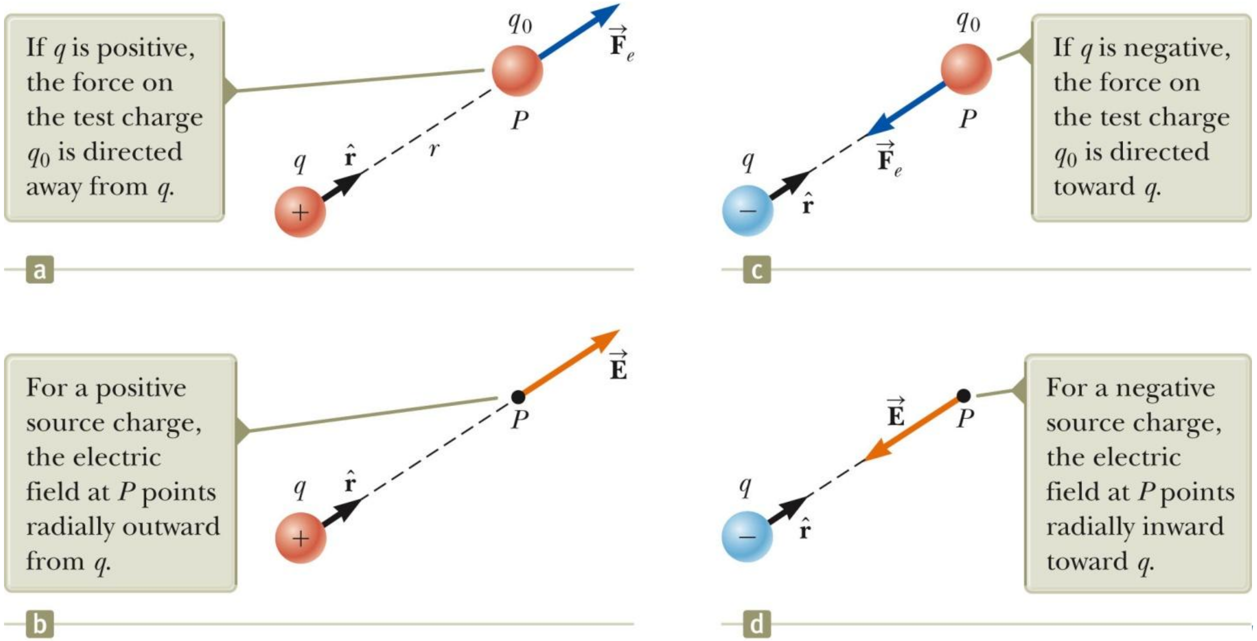
More About Electric Field Direction

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.



Electric Fields from Multiple Charges

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.

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

Electric Field Lines

Field lines give us a means of representing the electric field pictorially.

The electric field vector is tangent to the electric field line at each point.

- The line has a direction that is the same as that of the electric field vector.

The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region.

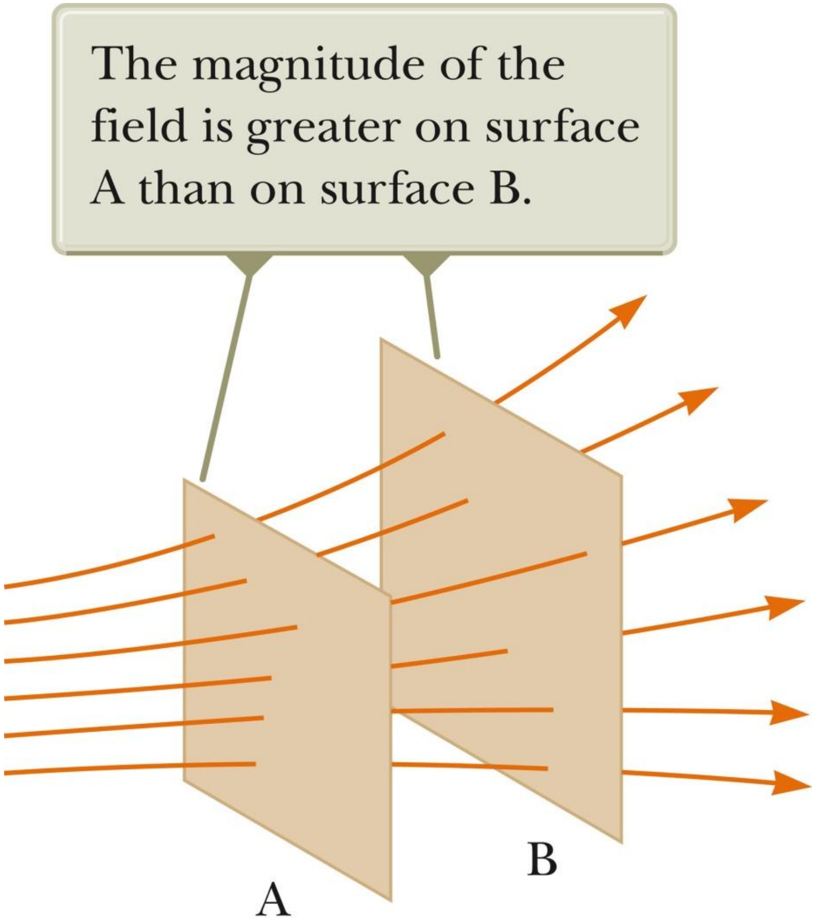
Electric Field Lines, General

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.



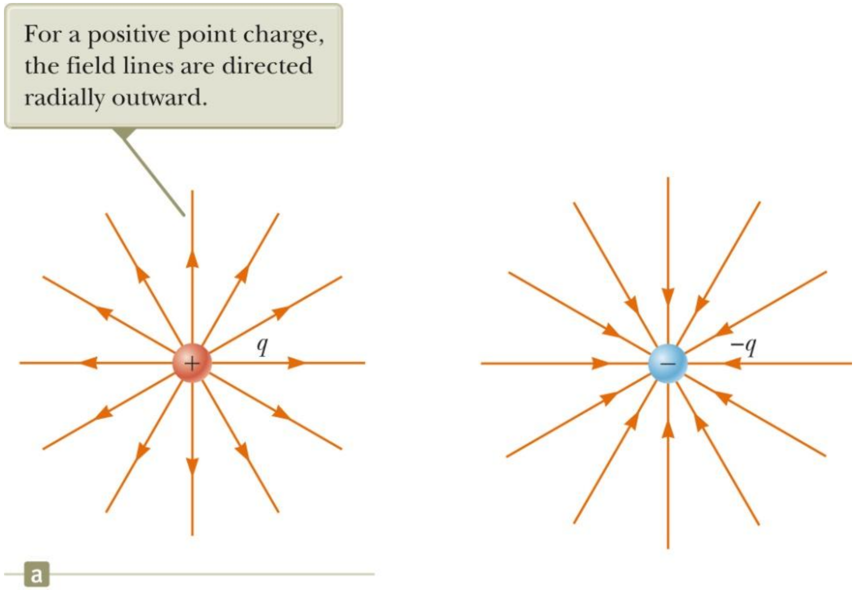
Electric Field Lines, Positive Point Charge

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.

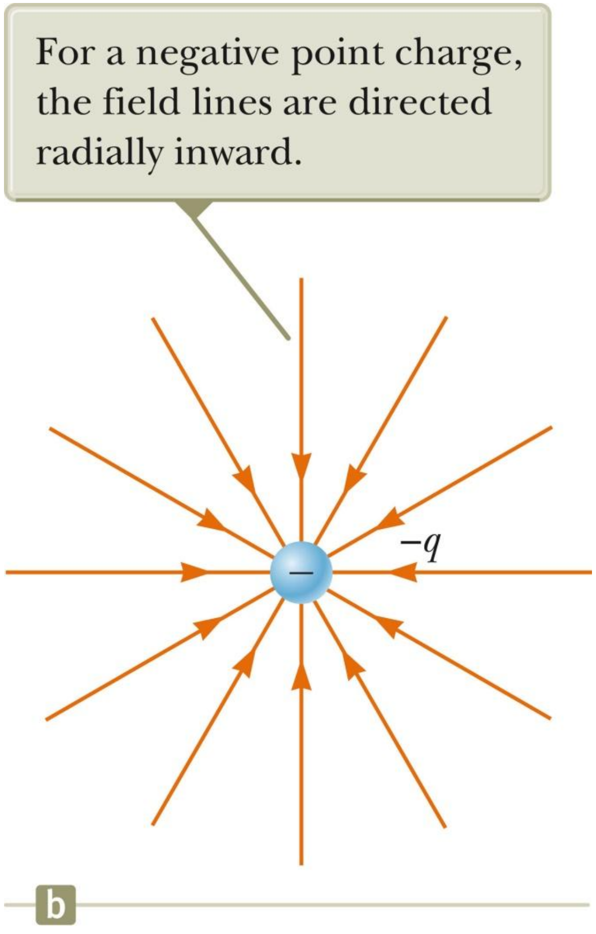


Electric Field Lines, Negative Point Charge

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.

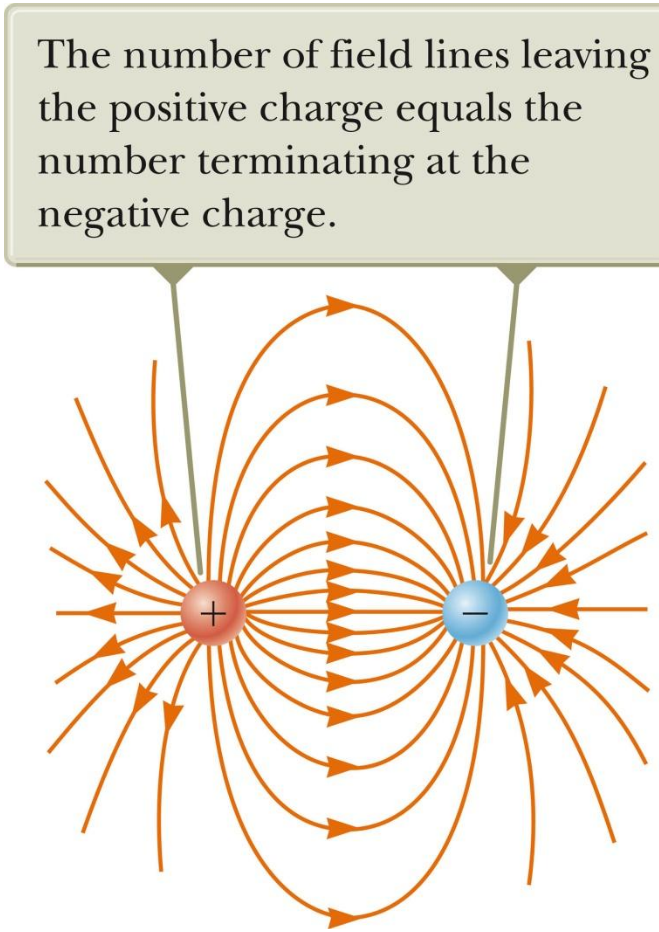
No two field lines can cross.

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.



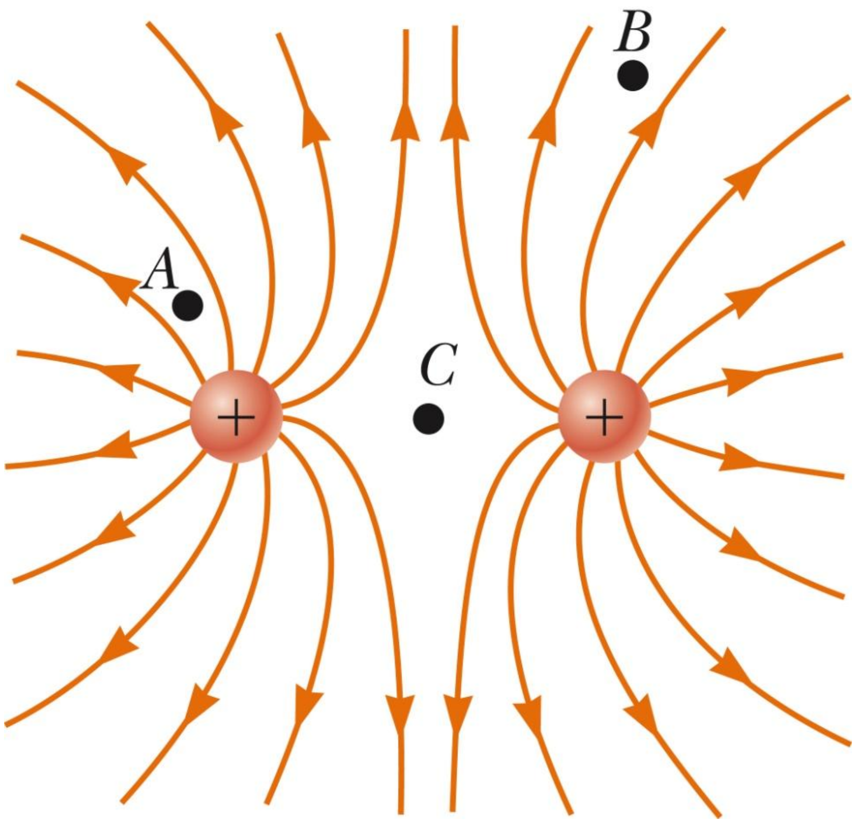
Electric Field Lines – Like Charges

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.

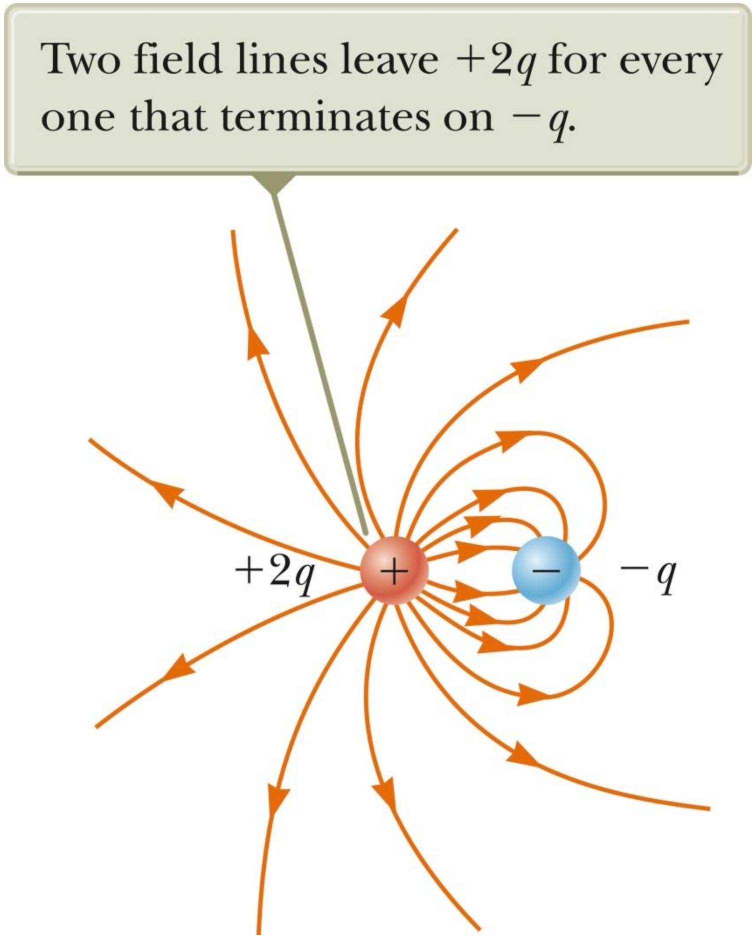


Electric Field Lines, Unequal Charges

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*.



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.

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.