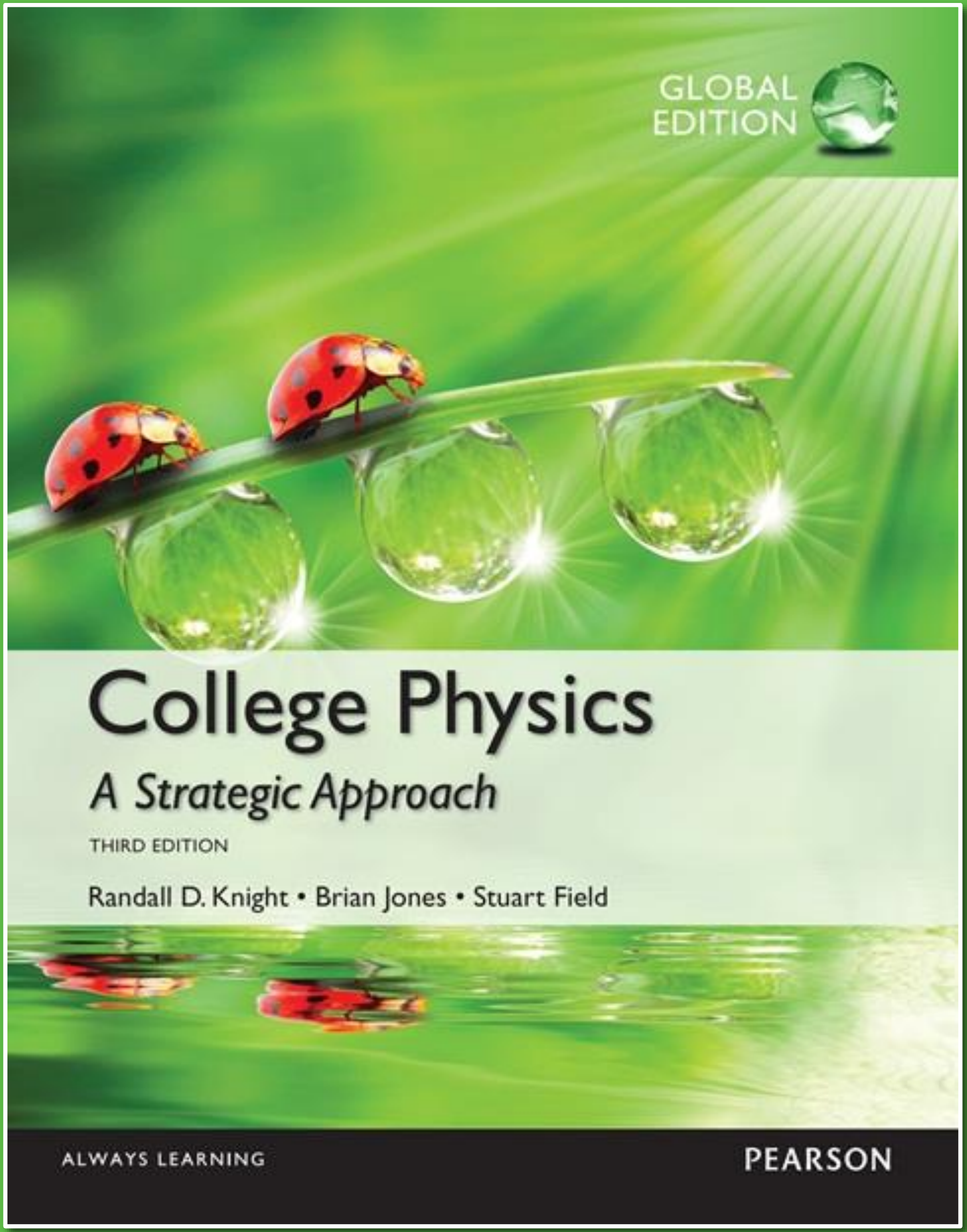

Lecture Presentation

Chapter 20

Electric Fields and Forces

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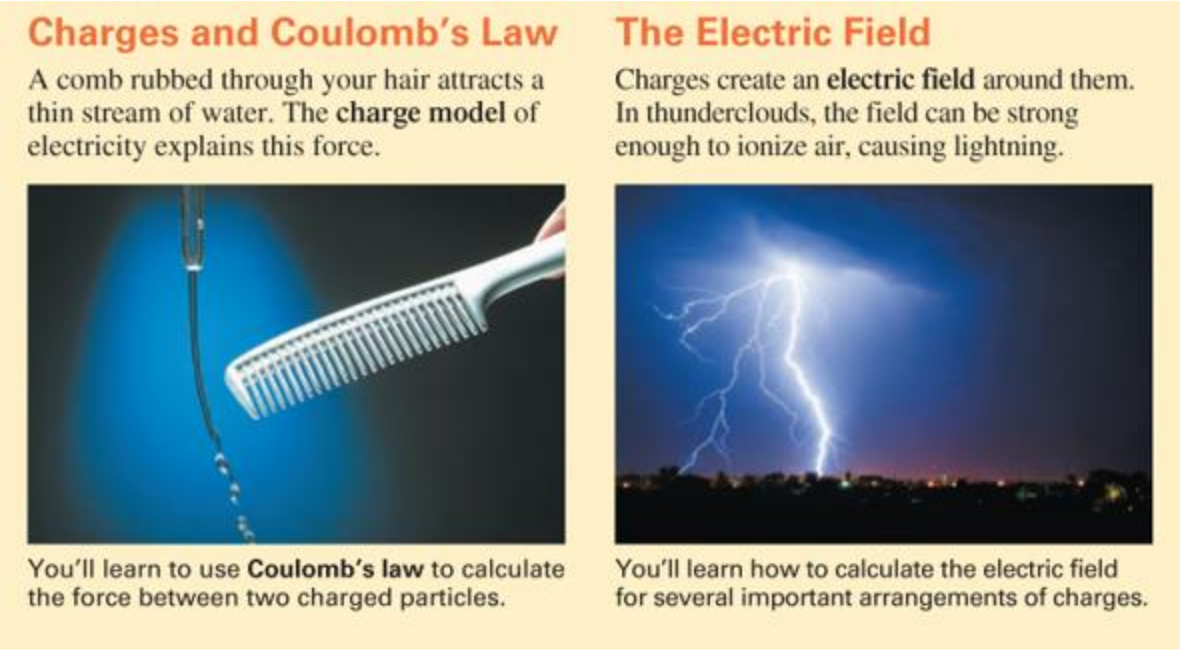
Chapter 20 Electric fields and forces

Section 20.1 Charges and Forces
Section 20.2 Charges, Atoms, and Molecules
Section 20.3 Coulomb’s Law
Section 20.4 The Concept of the Electric Field
Section 20.5 Applications of the Electric Field
Section 20.7 Forces and Torques in Electric Fields

Chapter 20 Preview
Looking Ahead



Charges and Coulomb's Law

A comb rubbed through your hair attracts a thin stream of water. The **charge model** of electricity explains this force.

You'll learn to use **Coulomb's law** to calculate the force between two charged particles.

The Electric Field

Charges create an **electric field** around them. In thunderclouds, the field can be strong enough to ionize air, causing lightning.

You'll learn how to calculate the electric field for several important arrangements of charges.

Chapter Goal: To develop a basic understanding of electric phenomena in terms of charges, forces, and fields.

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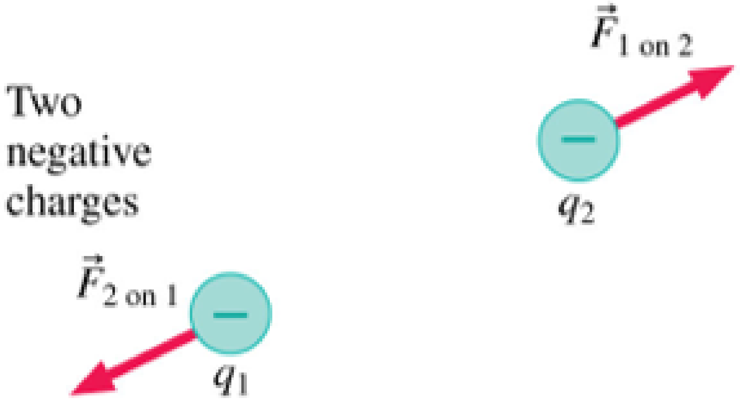
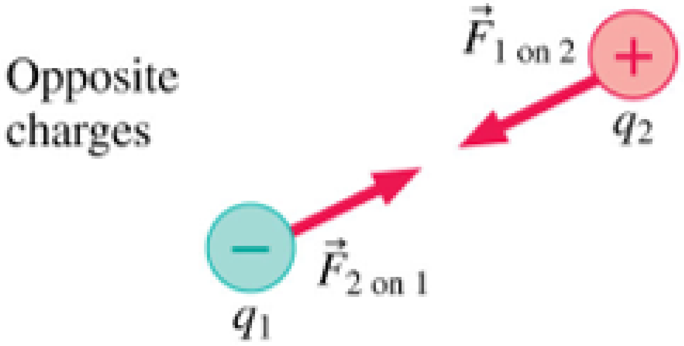
Electric Charge and Force:

- Electrons and protons are the basic charges in ordinary matter.
- The **electric force** is the force between charged objects.
- The electric force can be repulsive and attractive.
- Charges of the same kind repel each other.
- Charges of different kinds attract each other.





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Charge Conservation

- Charge is represented by the symbol q. The SI unit is a **coulomb** (C).
- The fundamental charge (e) is the magnitude of the charge of an electron or proton:

$$e = 1.60 \times 10^{-19}\ \text{C}$$

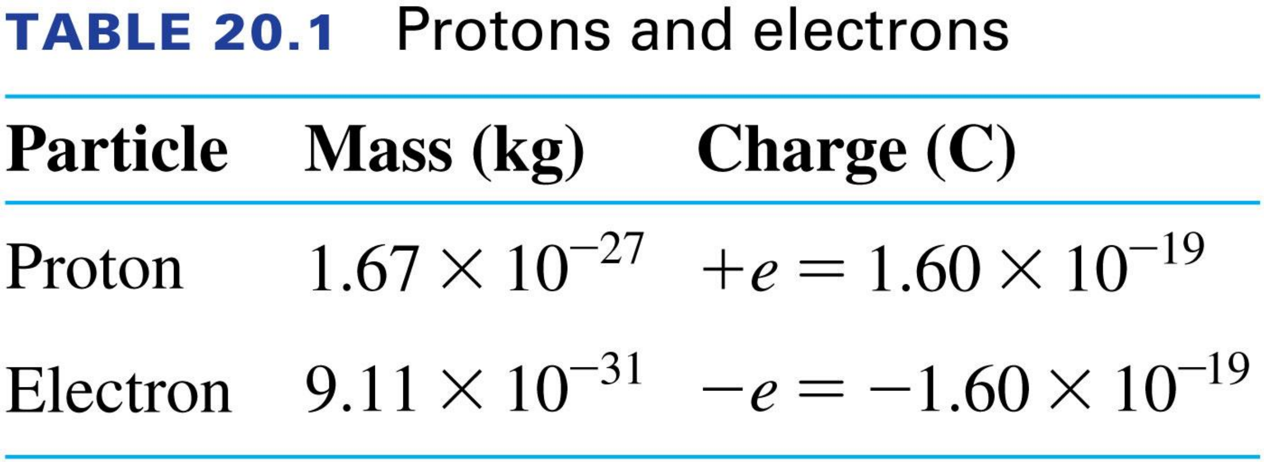

TABLE 20.1 Protons and electrons

Particle	Mass (kg)	Charge (C)
Proton	1.67×10^{-27}	$+e = 1.60 \times 10^{-19}$
Electron	9.11×10^{-31}	$-e = -1.60 \times 10^{-19}$

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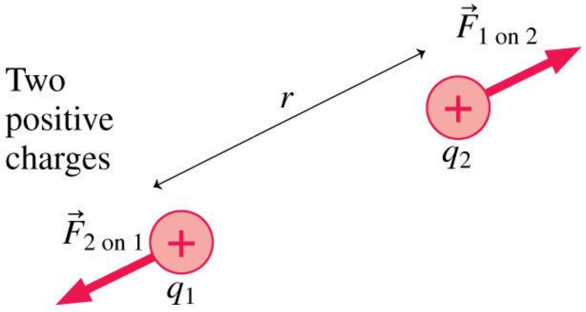
Coulomb’s Law

- Coulomb’s law describes the force between two charged particles.
- The magnitude of the electric force F between charges q_1 and q_2 separated by a distance r is given by

$$F_{1\,\text{on}\,2} = F_{2\,\text{on}\,1} = \frac{K|q_1||q_2|}{r^2}$$



where the charges are in coulombs (C), and $K = 8.99 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$ is called the **electrostatic constant.** These forces are an action/reaction pair, equal in magnitude and opposite in direction. It is customary to round K to $9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$ for all but extremely precise calculations, and we will do so.

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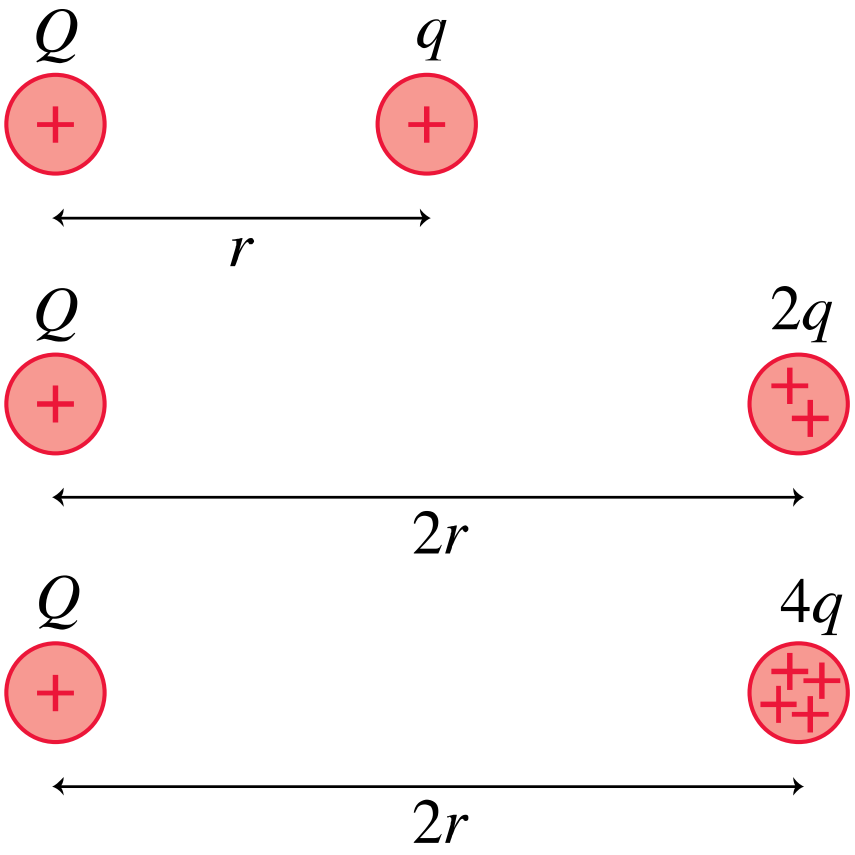
QuickCheck 20.10

Which of the three right-hand charges experiences the largest force?

A. q
B. $2q$
C. $4q$
D. q and $2q$ are tied
E. q and $4q$ are tied



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Example Problem

Point charge A has a charge of –1.0 nC, and point charge B has a charge of 4.0 nC. They are separated by 1.0 cm. What are the magnitude and direction of the electric forces on charges A and B?

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Example Problem

Point charge A has a charge of –1.0 nC, and point charge B has a charge of 4.0 nC. They are separated by 1.0 cm. What are the magnitude and direction of the electric forces on charges A and B?

Answer: The forces are equal and opposite. The magnitude is given by Coulomb's law: F = kq1q2/r^2 where q1 = -1 nC, q2 = 4 nC and r = 0.01 m. The force on each charge is thus 3.6E-4 N. The force is attractive so the force on each charge is directed toward the other charge.

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Using Coulomb's Law

- Coulomb's law is a force law, and forces are vectors.
- **Electric forces, like other forces, can be superimposed.**
- The *net* electric force on charge *j* due to all other charges is the sum of the individuals forces due to each charge:

$$\vec{F}_{\text{net}} = \vec{F}_{1\,\text{on}\,j} + \vec{F}_{2\,\text{on}\,j} + \vec{F}_{3\,\text{on}\,j} + \cdots$$

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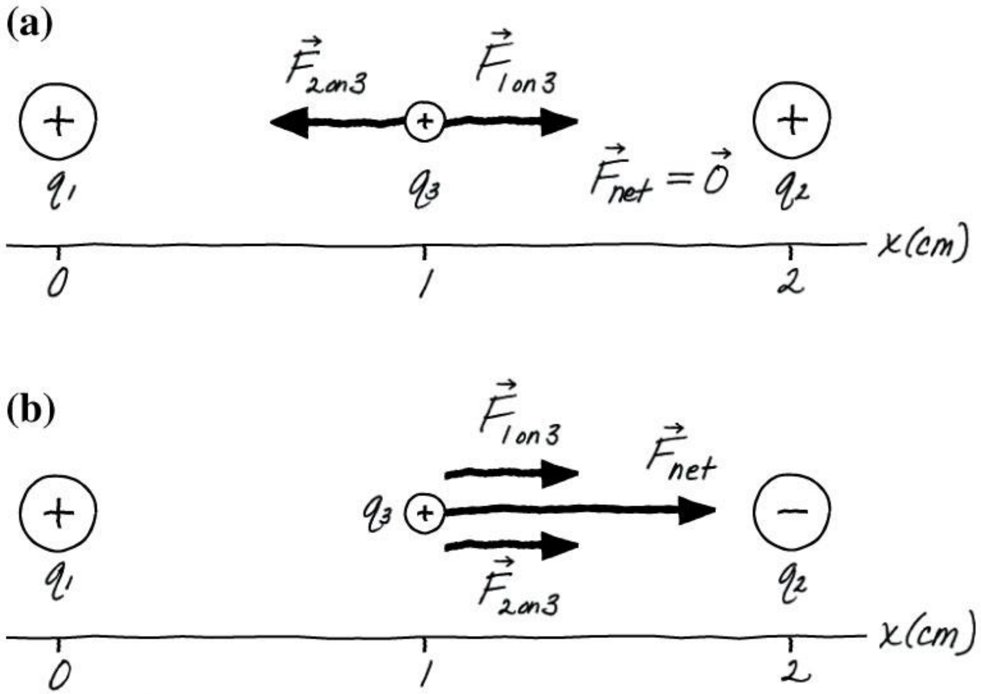
Example 20.3 Adding electric forces in one dimension

Two +10 nC charged particles are 2.0 cm apart on the *x*-axis. What is the net force on a +1.0 nC charge midway between them? What is the net force if the charged particle on the right is replaced by a -10 nC charge?



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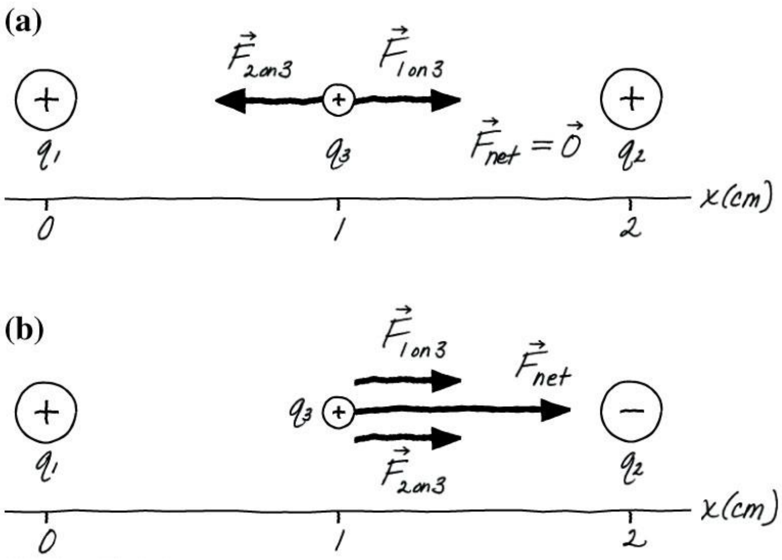
Example 20.3 Adding electric forces in one dimension (cont.)

PREPARE We proceed using the steps of Problem-Solving Strategy 20.1. We model the charged particles as point charges. The visual overview of the Figure establishes a coordinate system and shows the forces $\vec{F}_{1\text{ on }3}$ and $\vec{F}_{2\text{ on }3}$. The Figure (a) shows a +10 nC charge on the right;

The Figure (b) shows a –10 nC charge.



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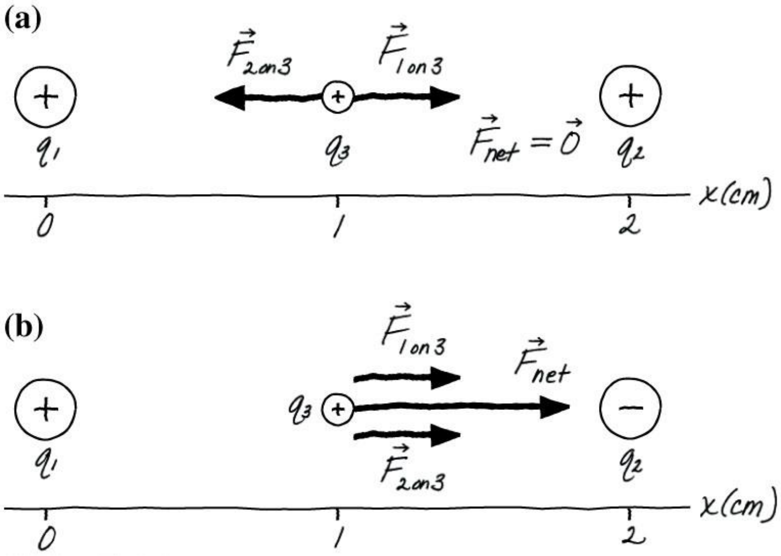
Example 20.3 Adding electric forces in one dimension (cont.)

SOLVE Electric forces are vectors, and the net force on q_3 is the *vector* sum $\vec{F}_{\text{net}} = \vec{F}_{1\text{ on }3} + \vec{F}_{2\text{ on }3}$. Charges q_1 and q_2 each exert a repulsive force on q_3, but these forces are equal in magnitude and opposite in direction. Consequently, $\vec{F}_{\text{net}} = \vec{0}$. The situation changes if q_2 is negative, as in Figure (b). In this case, the two forces are equal in magnitude but in the *same* direction, so $\vec{F}_{\text{net}} = 2\vec{F}_{1\text{ on }3}$. The magnitude of the force is given by Coulomb's law.



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Example 20.3 Adding electric forces in one dimension (cont.)

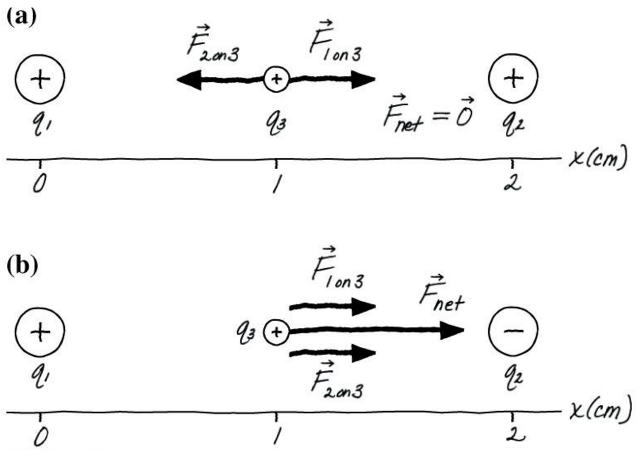
The force due to q_1 is

$$F_{1\,\text{on}\,3} = \frac{K|q_1||q_3|}{r_{13}^2}$$

$$= \frac{(9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(10 \times 10^{-9}\ \text{C})(1.0 \times 10^{-9}\ \text{C})}{(0.010\ \text{m})^2}$$

$$= 9.0 \times 10^{-4}\ \text{N}$$

There is an equal force due to q_2, so the net force on the 1.0 nC charge is $\vec{F}_{\text{net}} = (1.8 \times 10^{-3}$ N, to the right).



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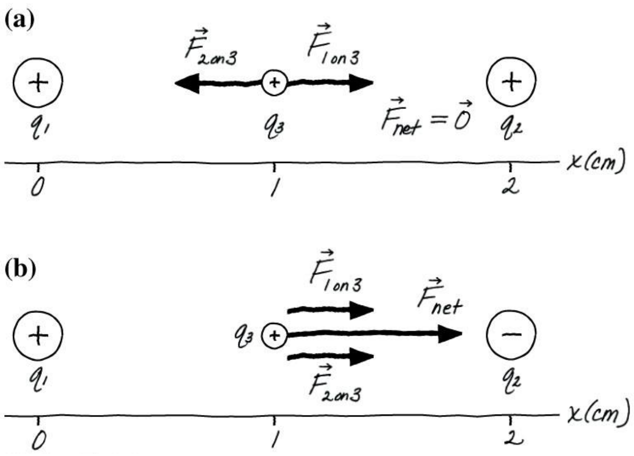
Example 20.3 Adding electric forces in one dimension (cont.)

ASSESS This example illustrates the important idea that electric forces are *vectors*. An important part of assessing our answer is to see if it is "reasonable." In the second case, the net force on the charge is approximately 1 mN. Generally, charges of a few nC separated by a few cm experience forces in the range from a fraction of a mN to several mN. With this guideline, the answer appears to be reasonable.



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Reading Question 20.3

Coulomb's law describes

A. The electric field due to a point charge.
B. The force between two point charges.
C. The electric field due to a charged rod.
D. The electric potential of a point charge.

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Section 20.4 The Concept of the Electric Field

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The Electric Field

- At every point in space, the electric field due to an arrangement of stationary point charges is a vector of magnitude equal to the force per unit charge at that location.

- The direction of the electric field equal to the direction of the force that a positive point charge would experience if placed at that location.

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Electric Field of a Point Charge

- We define the electric field $\vec{E}$ at the point (x, y, z) as

$$\vec{E} \text{ at } (x, y, z) = \frac{\vec{F}_{\text{on } q} \text{ at } (x, y, z)}{q}$$

Electric field at a point defined by the force on charge q

- The unit of E is N/C.

- The electric field due to multiple charges is the vector sum of the electric field due to each of the charges.

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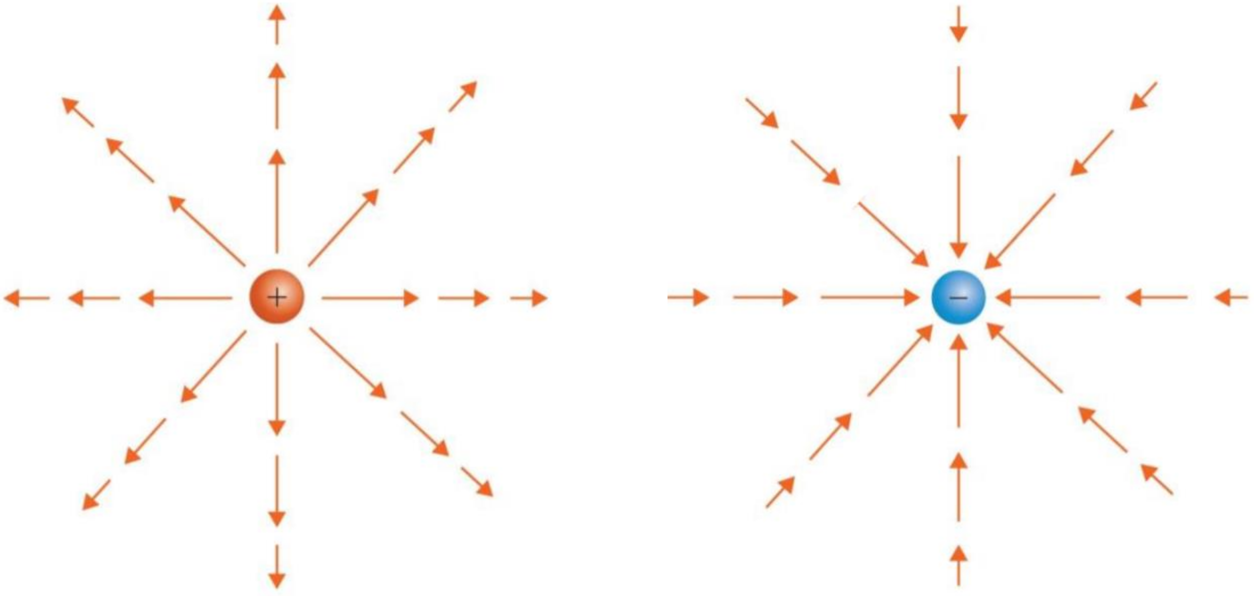
Electric Field of a Point Charge

- The electric field of a stationary point charge is radial.

$$\vec{E} = \left(\frac{K|q|}{r^2}, \begin{bmatrix} \text{away from } q \text{ if } q > 0 \\ \text{toward } q \text{ if } q < 0 \end{bmatrix} \right)$$

Electric field of point charge q at a distance r from the charge



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Example 20.6 Finding the electric field of a proton

The electron in a hydrogen atom orbits the proton at a radius of 0.053 nm. What is the electric field due to the proton at the position of the electron?

SOLVE The proton's charge is $q = e$. At the distance of the electron, the magnitude of the field is

$$E = \frac{Ke}{r^2} = \frac{(9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})(1.60 \times 10^{-19}\ \mathrm{C})}{(5.3 \times 10^{-11}\ \mathrm{m})^2}$$

$$= 5.1 \times 10^{11}\ \mathrm{N/C}$$

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Example 20.6 Finding the electric field of a proton (cont.)

Because the proton is positive, the electric field is directed away from the proton:

$$E = (5.1 \times 10^{11}\ \text{N/C, outward from the proton})$$

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QuickCheck 20.18

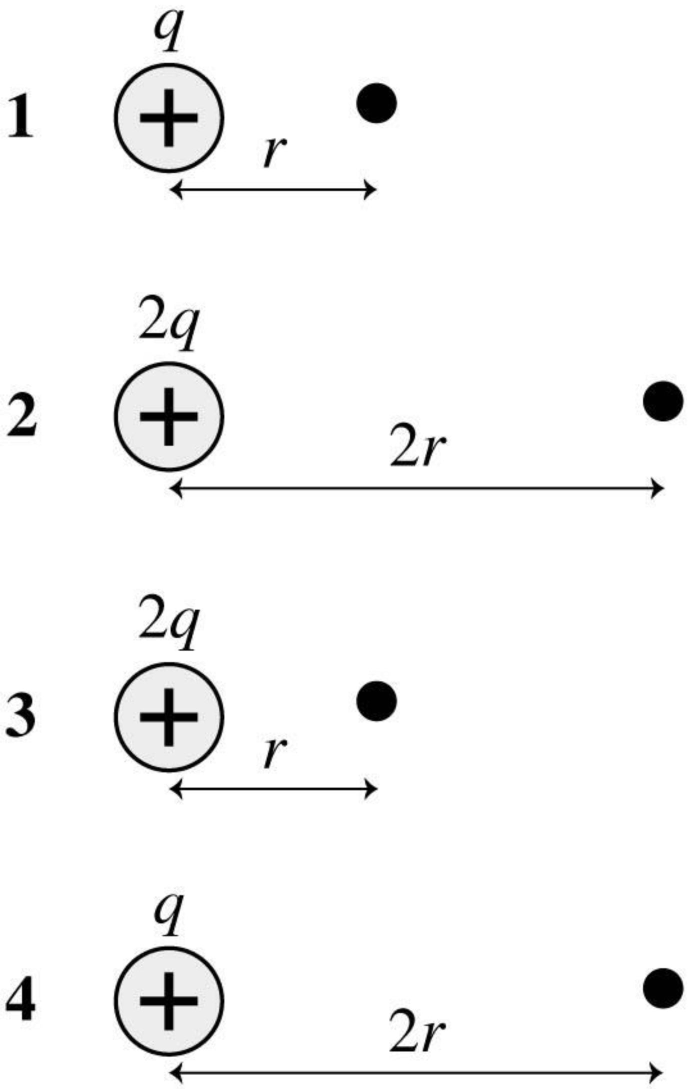
Rank in order, from largest to smallest, the magnitudes of the electric field at the black dot.

A. 3, 2, 1, 4

B. 3, 1, 4, 2

C. 1, 4, 2, 3

D. 3, 1, 2, 4



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Example Problem

A small bead, sitting at the origin, has a charge of +10 nC. At the point (3.0 cm, 4.0 cm), what is the magnitude and direction of the electric field due to this bead?

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Example Problem

A small bead, sitting at the origin, has a charge of +10 nC. At the point (3.0 cm, 4.0 cm), what is the magnitude and direction of the electric field due to this bead?

Answer: the distance of the point from the charge is sqrt(0.03^2+0.04^2) = 0.05 m. The electric field is given by kq/r^2 where r = 0.05, k = 9E9 (SI) and q = 1E-8. So E = 36000 V/m. The direction is away from the bead (an angle of atan(4/3)=53 degrees above the horizontal, and to the right).

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Section 20.5 Applications of the Electric Field

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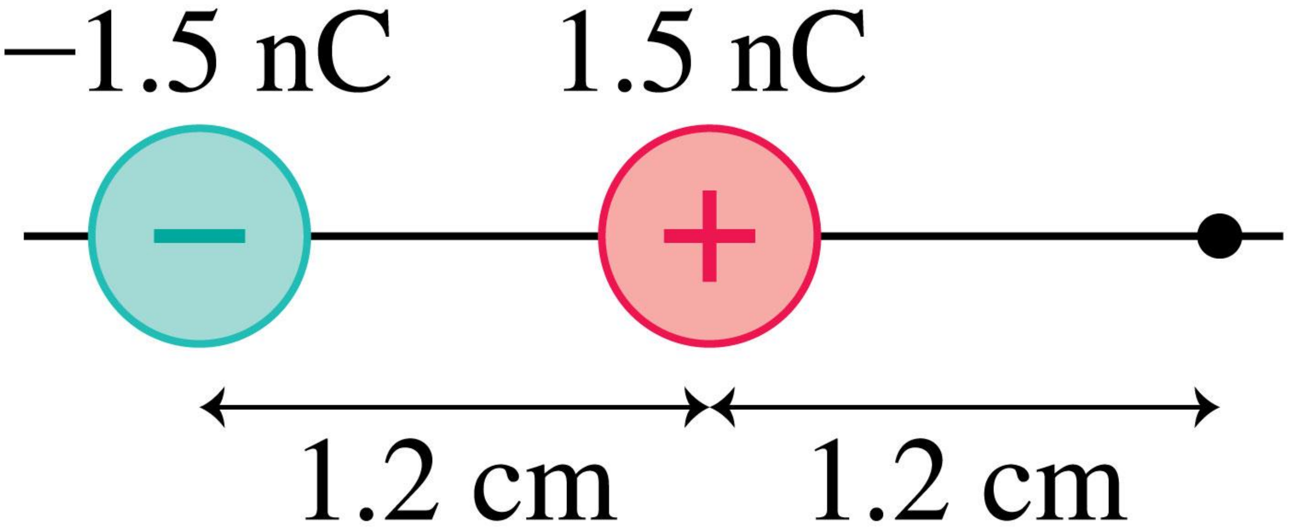
Example 20.7 Finding the field near a dipole

A dipole consists of a positive and negative charge separated by 1.2 cm, as shown in the FIGURE. What is the electric field strength along the line connecting the charges at a point 1.2 cm to the right of the positive charge?



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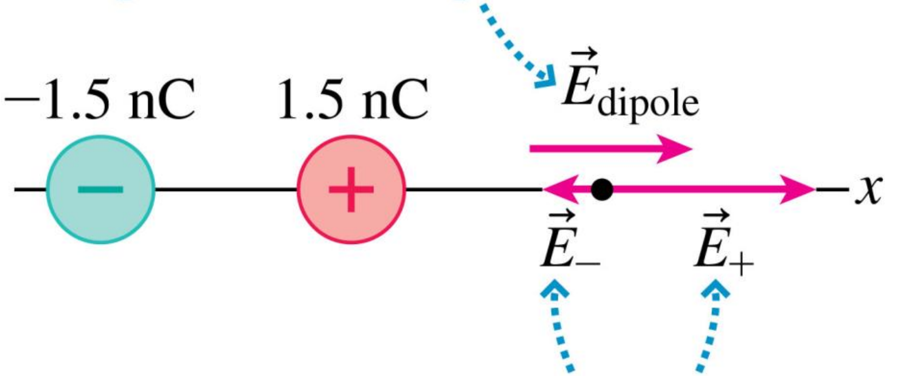
Example 20.7 Finding the field near a dipole (cont.)

PREPARE We define the *x*-axis to be along the line connecting the two charges, as in the FIGURE.

The dipole has no net charge, but it does have a net electric field. The point at which we calculate the field is 1.2 cm from the positive charge and 2.4 cm from the negative charge.



The dipole electric field at this point is in the positive *x*-direction.

$E_- < E_+$ because the + charge is closer.

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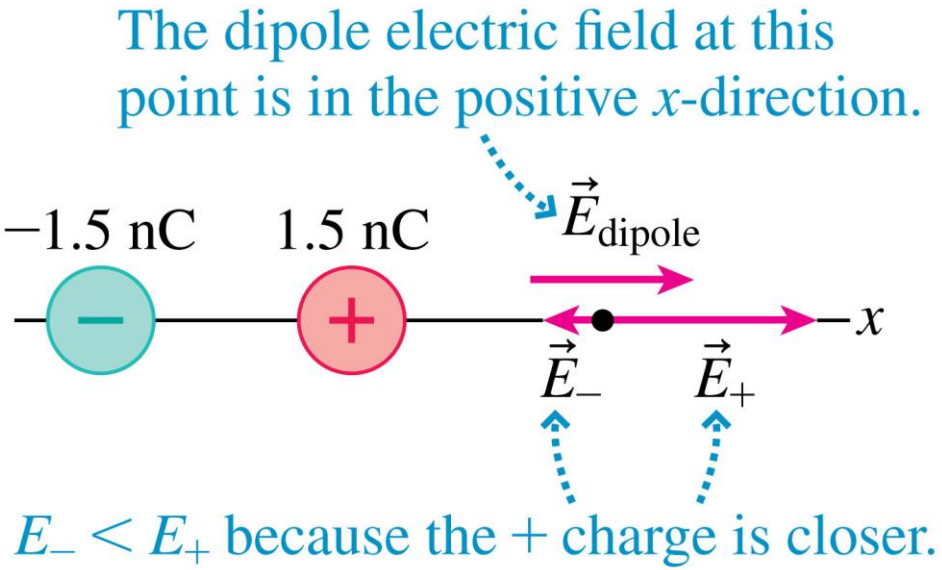
Example 20.7 Finding the field near a dipole (cont.)

Thus the electric field of the positive charge will be larger, as shown in the Figure. The net electric field of the dipole is the vector sum of these two fields, so the electric field of the dipole at this point is in the positive *x*-direction.



The dipole electric field at this point is in the positive *x*-direction.

$E_- < E_+$ because the $+$ charge is closer.

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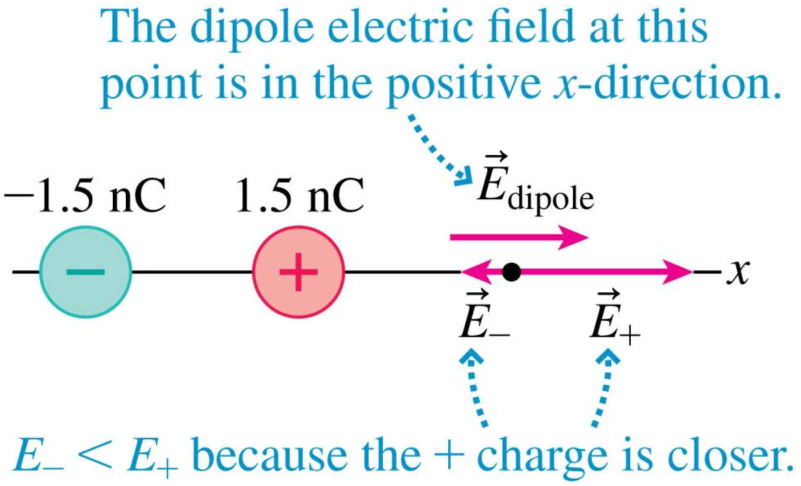
Example 20.7 Finding the field near a dipole (cont.)

SOLVE The magnitudes of the fields of the two charges are given, so the magnitude of the dipole field is


The dipole electric field at this point is in the positive x-direction.

$E_- < E_+$ because the + charge is closer.

$$E_{\text{dipole}} = E_+ - E_-$$

$$= \frac{\left(9.0 \times 10^9 \,\frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.5 \times 10^{-9}\ \text{C})}{(0.012\ \text{m})^2} - \frac{\left(9.0 \times 10^9 \,\frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.5 \times 10^{-9}\ \text{C})}{(0.024\ \text{m})^2}$$

$$= 7.0 \times 10^4\ \text{N/C}$$

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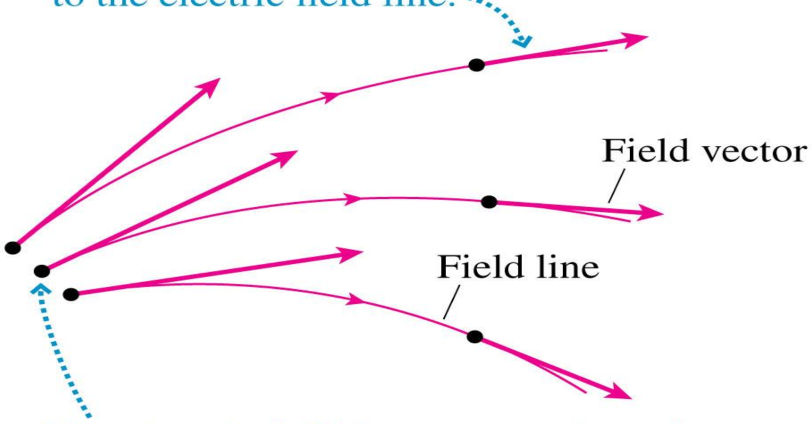
Relation between E and electric field lines

- The electric field vector $\underline{\vec{E}}$ is tangent to the electric field line at each point.

- Field lines cannot cross.

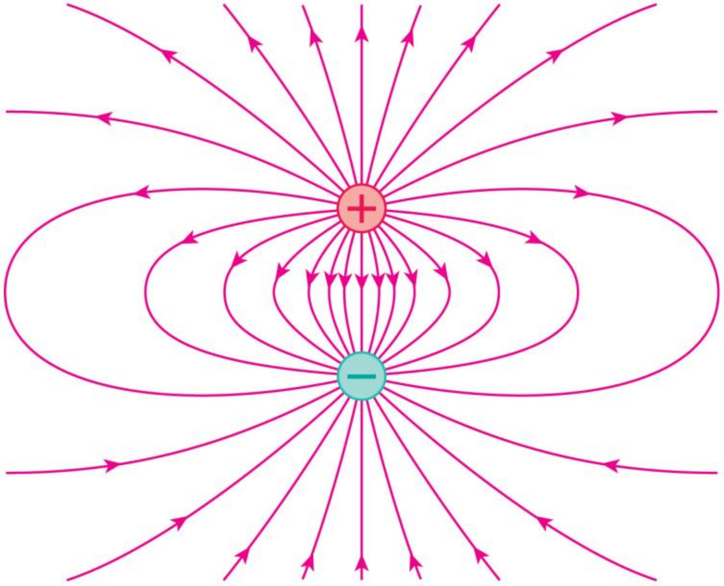
- Field lines start on a positive charge and end on a negative charge.

(a) Relationship between field vectors and field lines



The electric field vector is tangent to the electric field line.

The electric field is stronger where the electric field vectors are longer and where the electric field lines are closer together.



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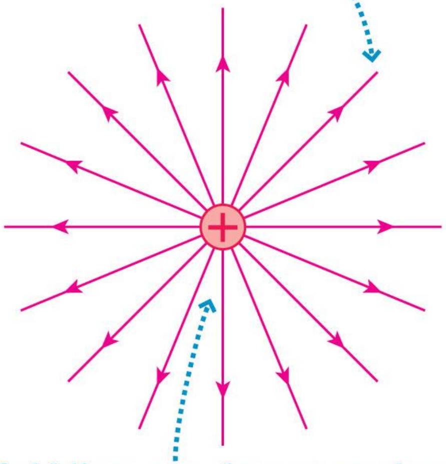
Electric Field Lines

- The number of lines per unit area through a surface ⊥ to the lines is proportional to the strength of the electric field at that region.

That means, if field lines are closed together → electric field is strong
field lines are far apart → electric field is weak

(b) Field lines of a positive point charge



The field is directed away from the positive charge, so the field lines are directed radially outward.

The field lines are closest together near the charge, where the field strength is greatest.

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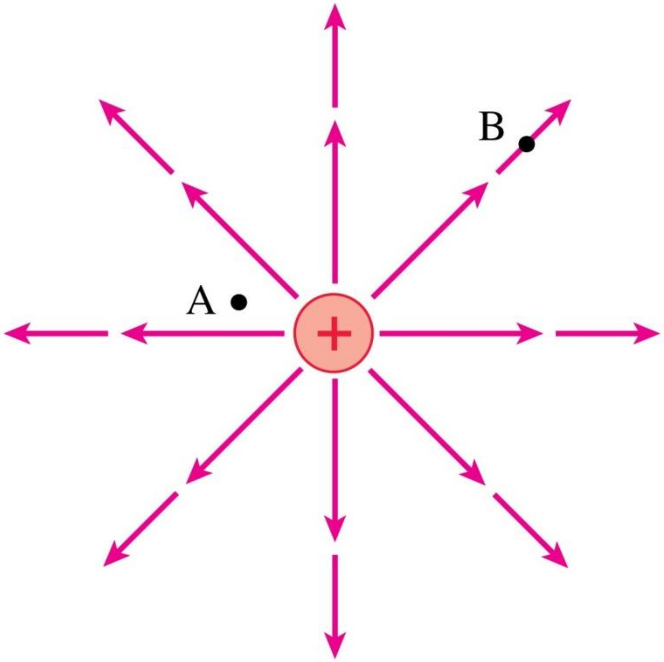
QuickCheck 20.17

At which point is the electric field stronger?

A. Point A
B. Point B
C. Not enough information to tell



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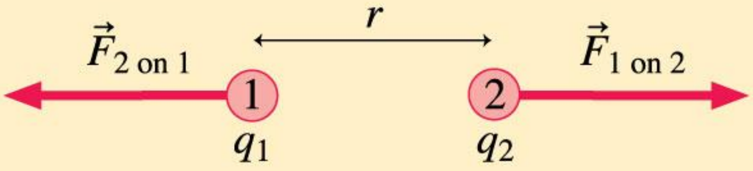
Summary: General Principles

Coulomb's Law

The forces between two charged particles q_1 and q_2 separated by distance r are

$$F_{1\,\text{on}\,2} = F_{2\,\text{on}\,1} = \frac{K|q_1||q_2|}{r^2}$$



where $K = 9 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$ is the **electrostatic constant.** These forces are an action/reaction pair directed along the line joining the particles.

- The forces are repulsive for two like charges, attractive for two opposite charges.
- The net force on a charge is the vector sum of the forces from all other charges.
- The unit of charge is the coulomb (C).

Text: p. 691

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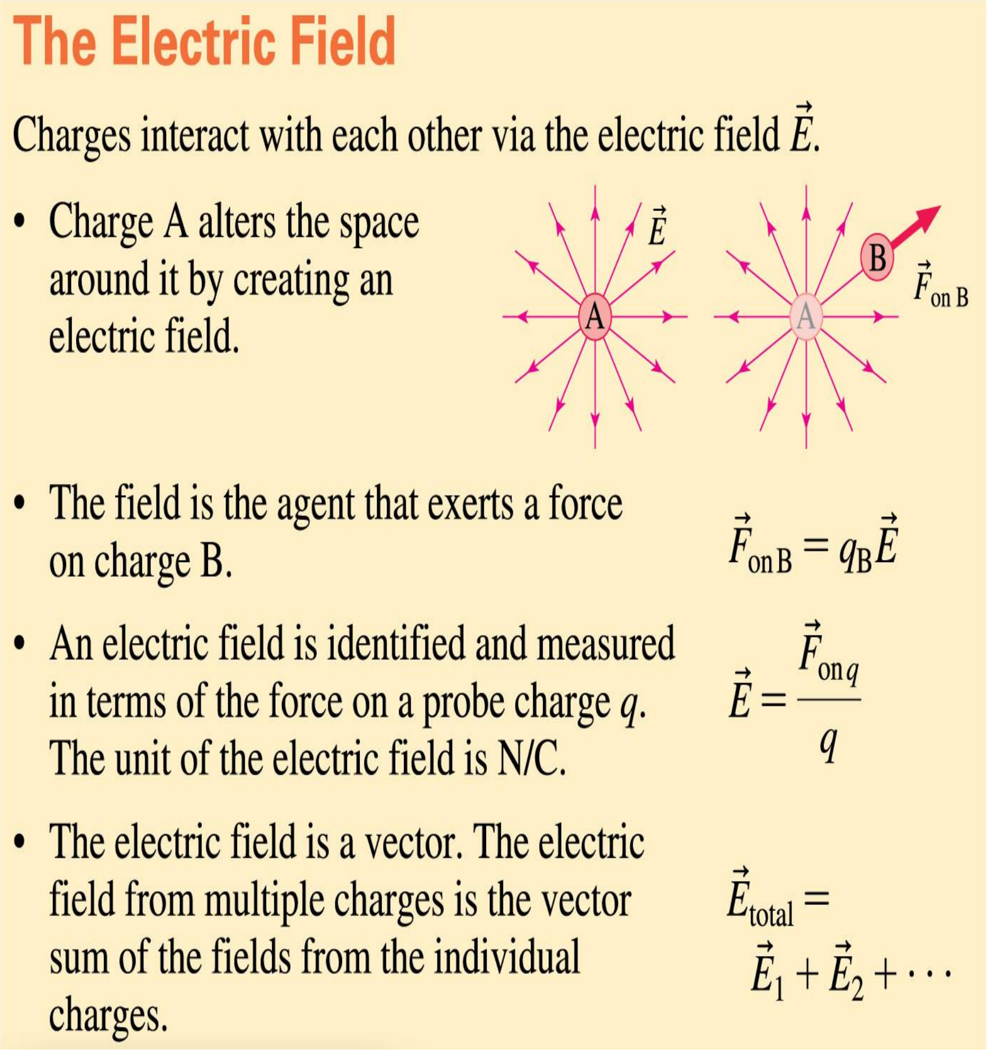
Summary: Important Concepts



The Electric Field

Charges interact with each other via the electric field $\vec{E}$.

- Charge A alters the space around it by creating an electric field.

- The field is the agent that exerts a force on charge B.

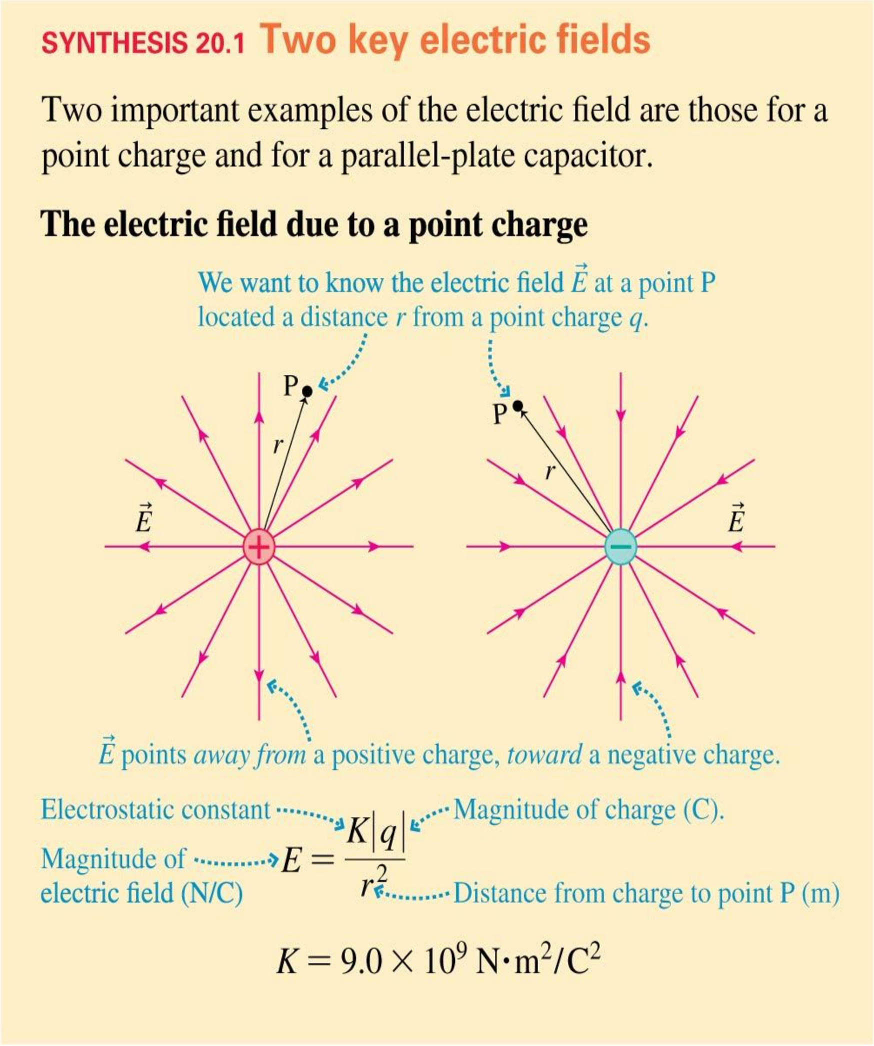
$$\vec{F}_{\text{on B}} = q_B\vec{E}$$

- An electric field is identified and measured in terms of the force on a probe charge q. The unit of the electric field is N/C.

$$\vec{E} = \frac{\vec{F}_{\text{on } q}}{q}$$

- The electric field is a vector. The electric field from multiple charges is the vector sum of the fields from the individual charges.

$$\vec{E}_{\text{total}} = \vec{E}_1 + \vec{E}_2 + \cdots$$



SYNTHESIS 20.1 Two key electric fields

Two important examples of the electric field are those for a point charge and for a parallel-plate capacitor.

The electric field due to a point charge

We want to know the electric field $\vec{E}$ at a point P located a distance r from a point charge q.

$\vec{E}$ points *away from* a positive charge, *toward* a negative charge.

Electrostatic constant

Magnitude of charge (C).

Magnitude of electric field (N/C)

$$E = \frac{K|q|}{r^2}$$

Distance from charge to point P (m)

$$K = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$$

Text: p. 691

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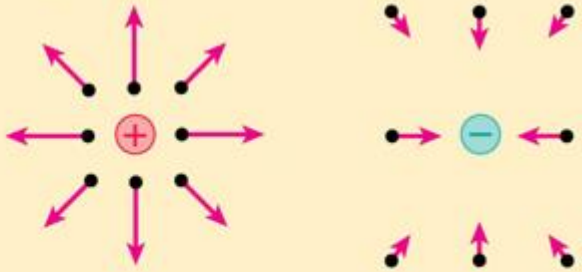
Summary: Important Concepts

Visualizing the electric field

The electric field exists at all points in space.

- An electric field vector shows the field at only one point, the point at the tail of the vector.
- A **field diagram** shows field vectors at several points.



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