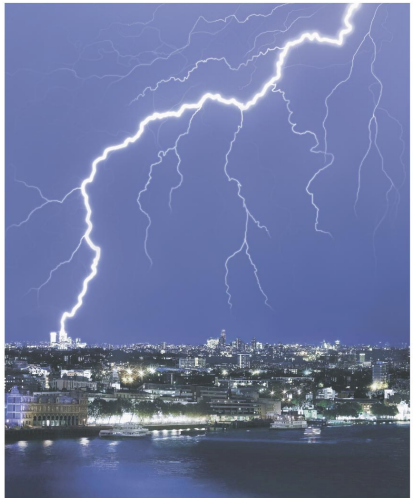
Chapter 26. Electric Charges and Forces

The electric force is one of the fundamental forces of nature. Controlled electricity is the cornerstone of our modern, technological society.

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



Chapter 26. Electric Charges and Forces

Topics:

- Developing a Charge Model
- Charge
- Insulators and Conductors
- Coulomb's Law
- The Field Model

Chapter 26. Reading Quizzes

What is the SI unit of charge?

A. Coulomb
B. Faraday
C. Ampere
D. Ohm
E. Volt

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A. Charged plasma
B. Charge sphere
C. Electric ether
D. Electric field
E. Electrophoresys

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If a negative charged rod is held near a neutral metal ball, the ball is attracted to the rod. This happens

A. because of magnetic effects.
B. because the ball tries to pull the rod's electrons over to it.
C. because the rod polarizes the metal.
D. because the rod and the ball have opposite charges.

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D. because the rod and the ball have opposite charges.

The electric field of a charge is defined by the force on

A. an electron.
B. a proton.
C. a source charge.
D. a test charge.

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Chapter 26. Basic Content and Examples

Charge Model, Part I

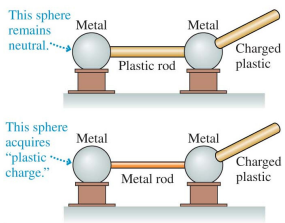
Charge model, part I The basic postulates of our model are:

1. Frictional forces, such as rubbing, add something called **charge** to an object or remove it from the object. The process itself is called *charging*. More vigorous rubbing produces a larger quantity of charge.
2. There are two and only two kinds of charge. For now we will call these "plastic charge" and "glass charge." Other objects can sometimes be charged by rubbing, but the charge they receive is either "plastic charge" or "glass charge."

Charge Model, Part I

3. Two **like charges** (plastic/plastic or glass/glass) exert repulsive forces on each other. Two **opposite charges** (plastic/glass) attract each other.
4. The force between two charges is a long-range force. The size of the force increases as the quantity of charge increases and decreases as the distance between the charges increases.
5. *Neutral* objects have an *equal mixture* of both "plastic charge" and "glass charge." The rubbing process somehow manages to separate the two.

Discovering electricity III



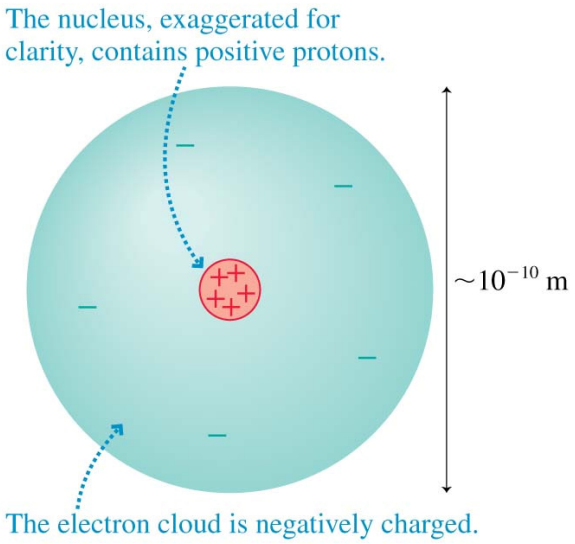
Experiment 11

Place two metal spheres close together with a plastic rod connecting them. Charge a second plastic rod, by rubbing, and touch it to one of the metal spheres. Afterward, the metal sphere that was touched picks up small pieces of paper and repels a charged, hanging plastic rod. The other metal sphere does neither.

Experiment 12

Repeat Experiment 11 with a metal rod connecting the two metal spheres. Touch one metal sphere with a charged plastic rod. Afterward, *both* metal spheres pick up small pieces of paper and repel a charged, hanging plastic rod.

FIGURE 26.1 An atom.



Atoms and Electricity

- An atom consists of a very small and dense *nucleus* surrounded by much less massive orbiting *electrons.*
- The nucleus is a composite structure consisting of *protons,* positively charged particles, and neutral *neutrons.*
- The atom is held together by the attractive electric force between the positive nucleus and the negative electrons.
- Electrons and protons have charges of opposite sign but *exactly* equal magnitude.
- This atomic-level unit of charge, called the **fundamental unit of charge, *e*.**

Charge quantization

TABLE 26.1 Protons and electrons

Particle	Mass (kg)	Charge
Proton	1.67×10^{-27}	$+e$
Electron	9.11×10^{-31}	$-e$

- A macroscopic object has net charge

$$q = N_p e - N_e e = (N_p - N_e)e$$

- Where N_p and N_e are the number of protons and electrons contained in the object.
- The process of removing an electron from the electron cloud of an atom is called **ionization.**
- An atom that is missing an electron is called a *positive ion.* Its *net* charge is $q = +e$.

FIGURE 26.2 Positive and negative ions.

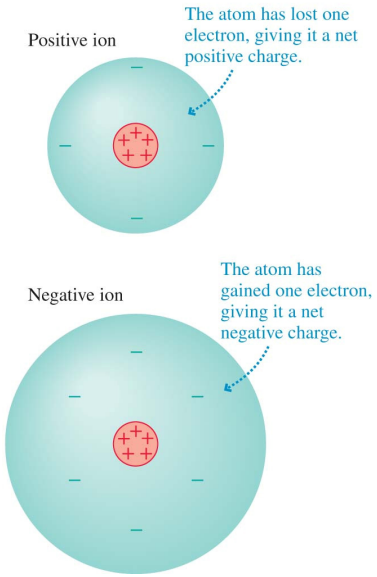
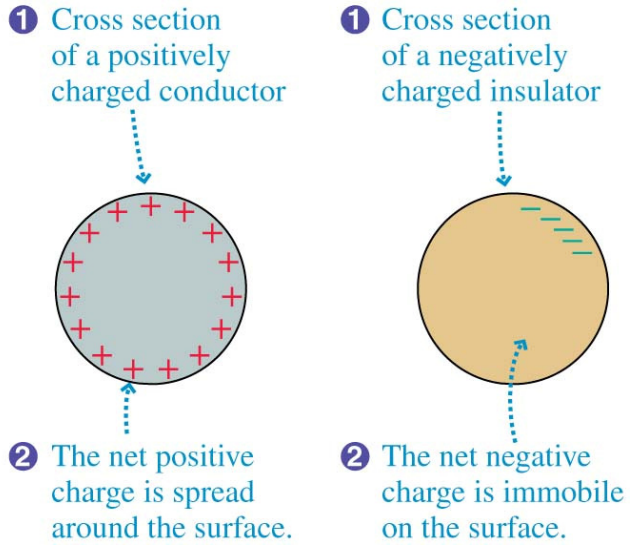
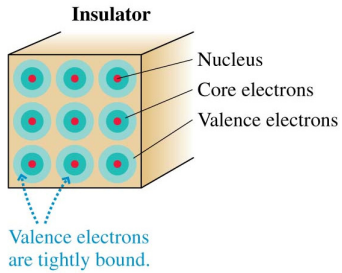


FIGURE 26.4 Charge diagrams.



Insulators

- The electrons in the insulator are all tightly bound to the positive nuclei and not free to move around.
- Charging an insulator by friction leaves patches of molecular ions on the surface, but these patches are immobile.



Conductors

- In metals, the outer atomic electrons are only weakly bound to the nuclei.
- These outer electrons become detached from their parent nuclei and are free to wander about through the entire solid.
- The solid *as a whole* remains electrically neutral, but the electrons are now like a negatively charged liquid permeating an array of positively charged **ion cores.**

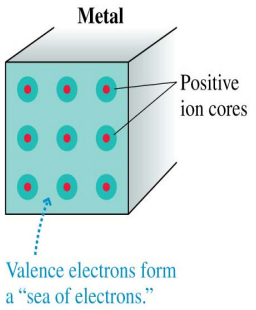


FIGURE 26.7 A conductor is charged by contact with a charged plastic rod.

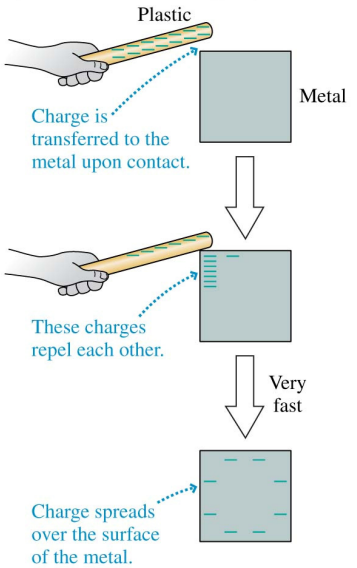
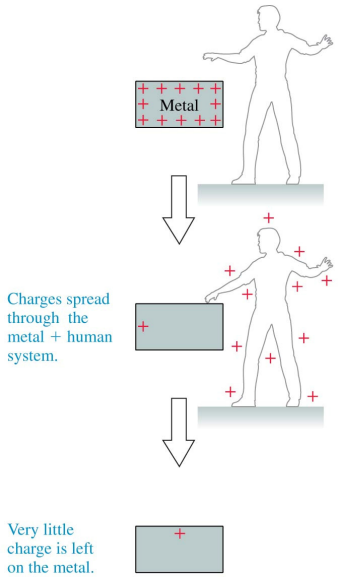
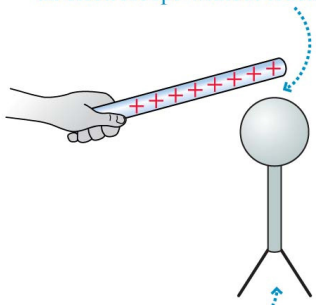


FIGURE 26.10 Touching a charged metal discharges it.



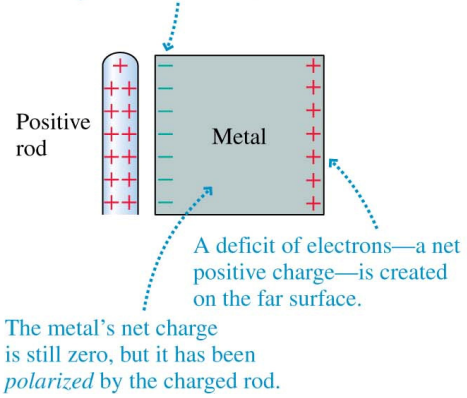
Charge Polarization

FIGURE 26.11 A charged rod held close to an electroscope causes the leaves to repel each other.



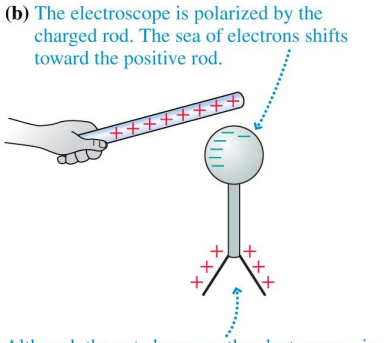
Charge Polarization

FIGURE 26.12 A charged rod polarizes a metal.



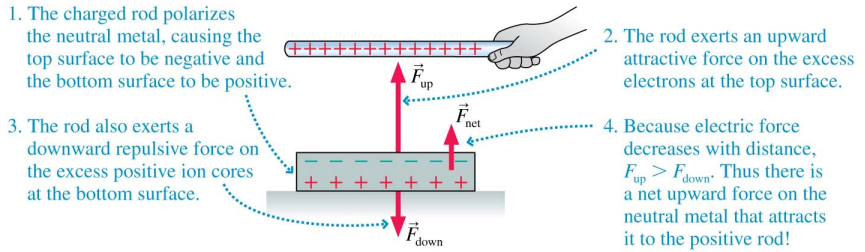
Charge Polarization

FIGURE 26.12 A charged rod polarizes a metal.



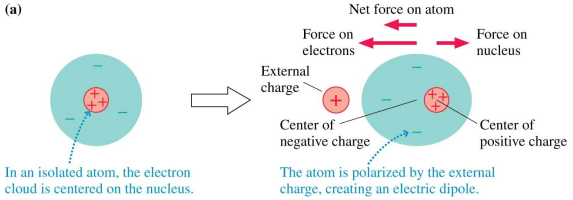
Polarization Force

FIGURE 26.13 The polarization force on a neutral piece of metal is due to the slight charge separation.



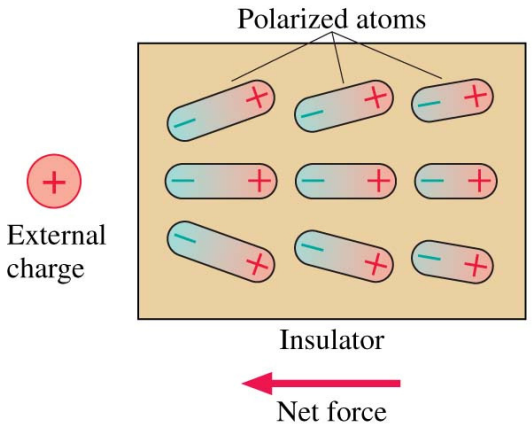
The Electric Dipole

FIGURE 26.14 A neutral atom is polarized by an external charge, forming an *electric dipole*.

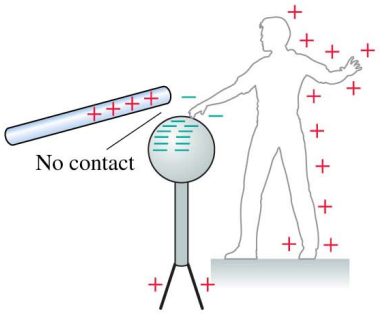


The Electric Dipole

FIGURE 26.15 The atoms in an insulator are polarized by an external charge.

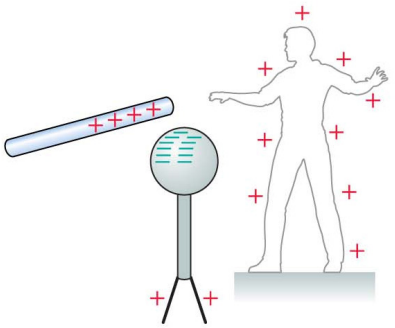


Charging by Induction, Step 1



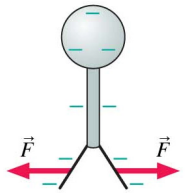
1. The charged rod polarizes the electroscope + person conductor. The leaves repel slightly due to polarization, but overall the electrosc has an excess of electrons and the pe has a deficit of electrons.

Charging by Induction, Step 2



2. The negative charge on the electroscope is isolated when contact is broken.

Charging by Induction, Step 3



3. When the rod is removed, the leaves first collapse as the polarization vanishes, then repel as the excess negative charge spreads out. The electroscope has been *negatively* charged.

Coulomb's law:

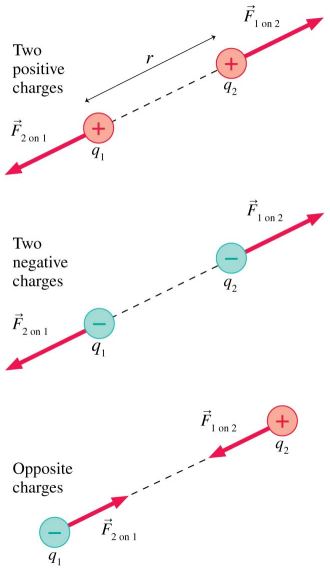
1. If two charged particles having charges q_1 and q_2 are a distance r apart, the particles exert forces on each other of magnitude

$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2} \qquad (26.2)$$

where K is called the **electrostatic constant.** These forces are an action/reaction pair, equal in magnitude and opposite in direction.
2. The forces are directed along the line joining the two particles. The forces are *repulsive* for two like charges and *attractive* for two opposite charges.

In SI units $K = 8.99 \times 10^9$ N m^2/C^2.

FIGURE 26.17 Attractive and repulsive forces between charges.



The Electric Field

We begin our investigation of electric fields by postulating a **field model** that describes how charges interact:

1.Some charges, which we will call the **source charges,** alter the space around them by creating an *electric field.*

2.A separate charge *in* the electric field experiences a force exerted *by the field.*

Suppose probe charge q experiences an electric force $F_{\text{on }q}$ due to other cha

$$\vec{E}(x, y, z) \equiv \frac{F_{\text{on }q} \text{ at } (x, y, z)}{q}$$

The units of the electric field are N/C. The magnitude E of the electric field is called the **electric field strength.**

The Electric Field of a Point Charge

The electric field at distance r from a point charge q is

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r} \qquad \text{(electric field of a point charge)}$$

where the unit vector for r points away from the charge to the point at which we want to know the field.
This unit vector expresses the idea "away from q".

FIGURE 26.28 The electric field of a positive charge.

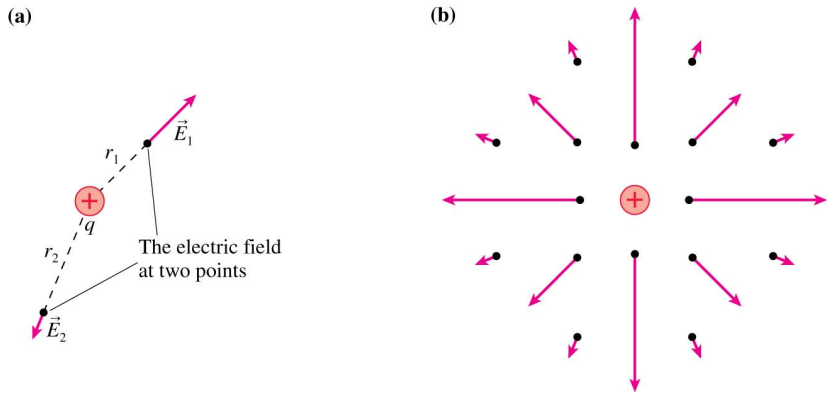
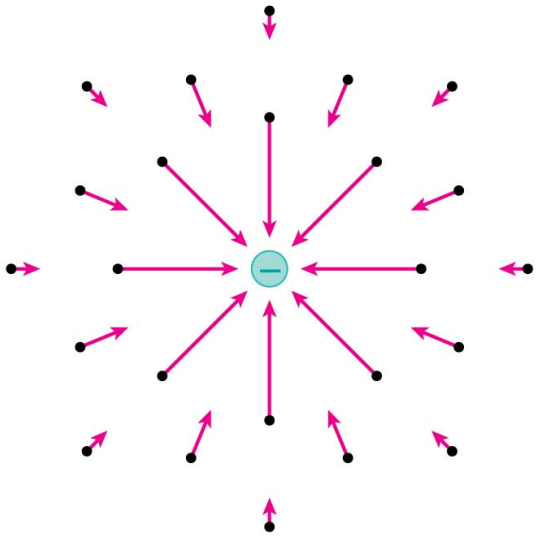


FIGURE 26.30 The electric field of a negative point charge.



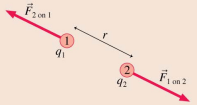
Chapter 26. Summary Slides

General Principles

Coulomb's Law

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

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



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 sum of the forces from all other charges.
- The unit of charge is the coulomb (C).
- The electrostatic constant is $K = 9.0 \times 10^9\ \text{N m}^2/\text{C}^2$.

Important Concepts

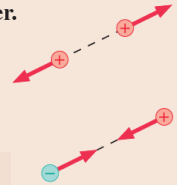
The Charge Model

There are two kinds of charge, positive and negative.

- Fundamental charges are protons and electrons, with charge $\pm e$ where $e = 1.60 \times 10^{-19}$ C.
- Objects are charged by adding or removing electrons.
- The amount of charge is $q = (N_p - N_e)e$.
- An object with an equal number of protons and electrons is neutral, meaning no *net* charge.

Charged objects exert electric forces on each other.

- Like charges repel, opposite charges attract.
- The force increases as the charge increases.
- The force decreases as the distance increases.



Important Concepts

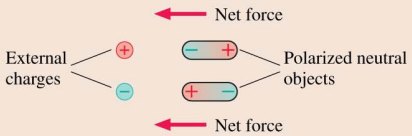
The Charge Model

There are two types of material, insulators and conductors.

- Charge remains fixed in or on an insulator.
- Charge moves easily through or along conductors.
- Charge is transferred by contact between objects.

Charged objects attract neutral objects.

- Charge polarizes metal by shifting the electron sea.
- Charge polarizes atoms, creating electric dipoles.
- The polarization force is always an attractive force.



Important Concepts

The Field Model

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. The force on charge q_B is $\vec{F}_{\text{on B}} = q_B\vec{E}$.

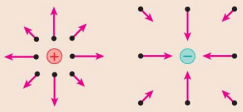
An electric field is identified and measured in terms of the force on a **probe charge** q:

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

Important Concepts

The Field Model

- The electric field exists at all points in space.
- An electric field vector shows the field only at one point, the point at the tail of the vector.

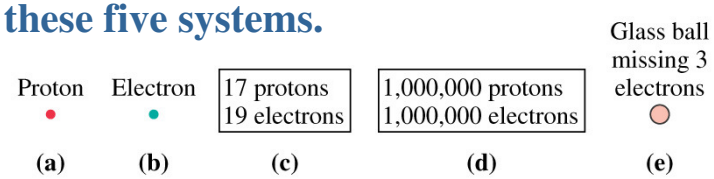


The electric field of a **point charge** is

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$$

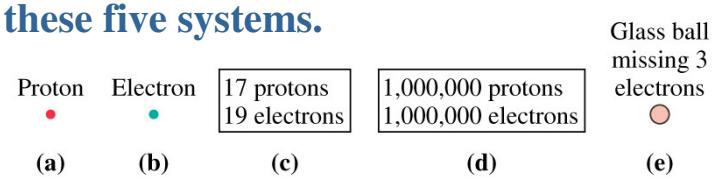
Chapter 26. Questions

Rank in order, from most positive to most negative, the charges q_a to q_e of these five systems.



A. $q_a = q_b > q_e > q_c > q_d$
B. $q_a > q_e > q_d > q_c > q_b$
C. $q_e > q_a > q_d > q_b > q_c$
D. $q_d > q_c > q_e > q_a = q_b$
E. $q_d > q_c > q_e > q_a > q_b$

Rank in order, from most positive to most negative, the charges q_a to q_e of these five systems.



A. $q_a = q_b > q_e > q_c > q_d$
B. $q_a > q_e > q_d > q_c > q_b$
✔ **C. $q_e > q_a > q_d > q_b > q_c$**
D. $q_d > q_c > q_e > q_a = q_b$
E. $q_d > q_c > q_e > q_a > q_b$

An electroscope is positively charged by *touching* it with a positive glass rod. The electroscope leaves spread apart and the glass rod is removed. Then a negatively charged plastic rod is brought close to the top of the electroscope, but it doesn't touch. What happens to the leaves?

A. The leaves get closer together.
B. The leaves spread further apart.
C. The leaves don't move.
D. One leaf moves higher, the other lower.

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C. The leaves don't move.
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Charges A and B exert repulsive forces on each other. $q_A = 4q_B$. Which statement is true?

A. $F_{\text{A on B}} > F_{\text{B on A}}$
B. $F_{\text{A on B}} < F_{\text{B on A}}$
C. $F_{\text{A on B}} = F_{\text{B on A}}$

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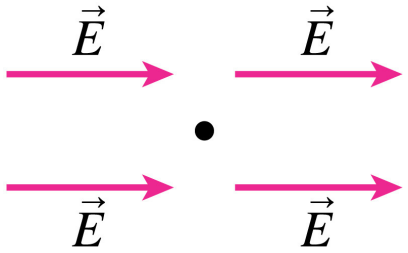
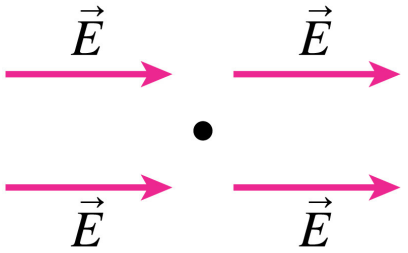
✔ **C. $F_{\text{A on B}} = F_{\text{B on A}}$**

An electron is placed at the position marked by the dot. The force on the electron is



A. to the right.
B. to the left.
C. zero.
D. There's not enough information to tell.

An electron is placed at the position marked by the dot. The force on the electron is



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