SLE123

Week 8

Electric Forces and Fields

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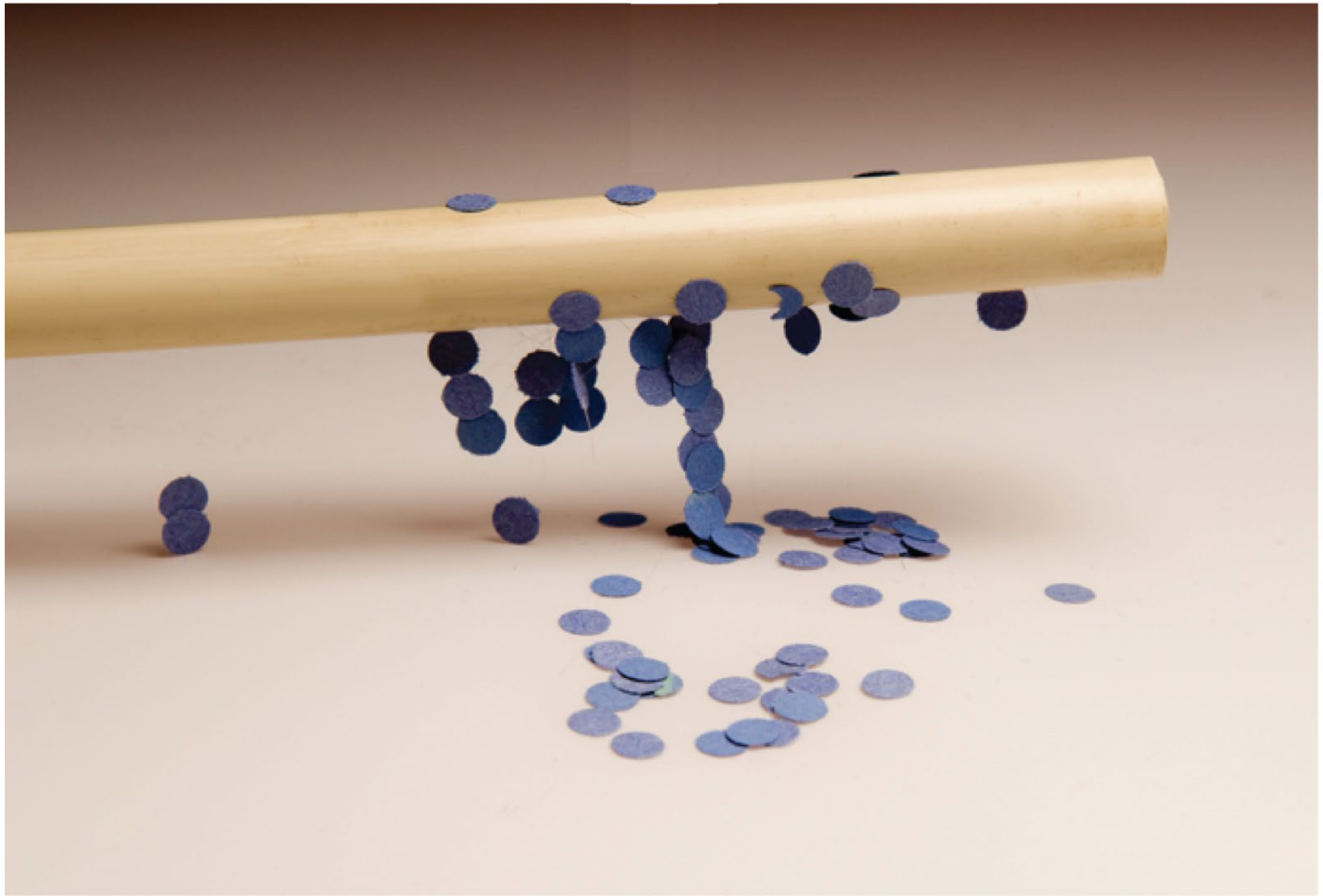
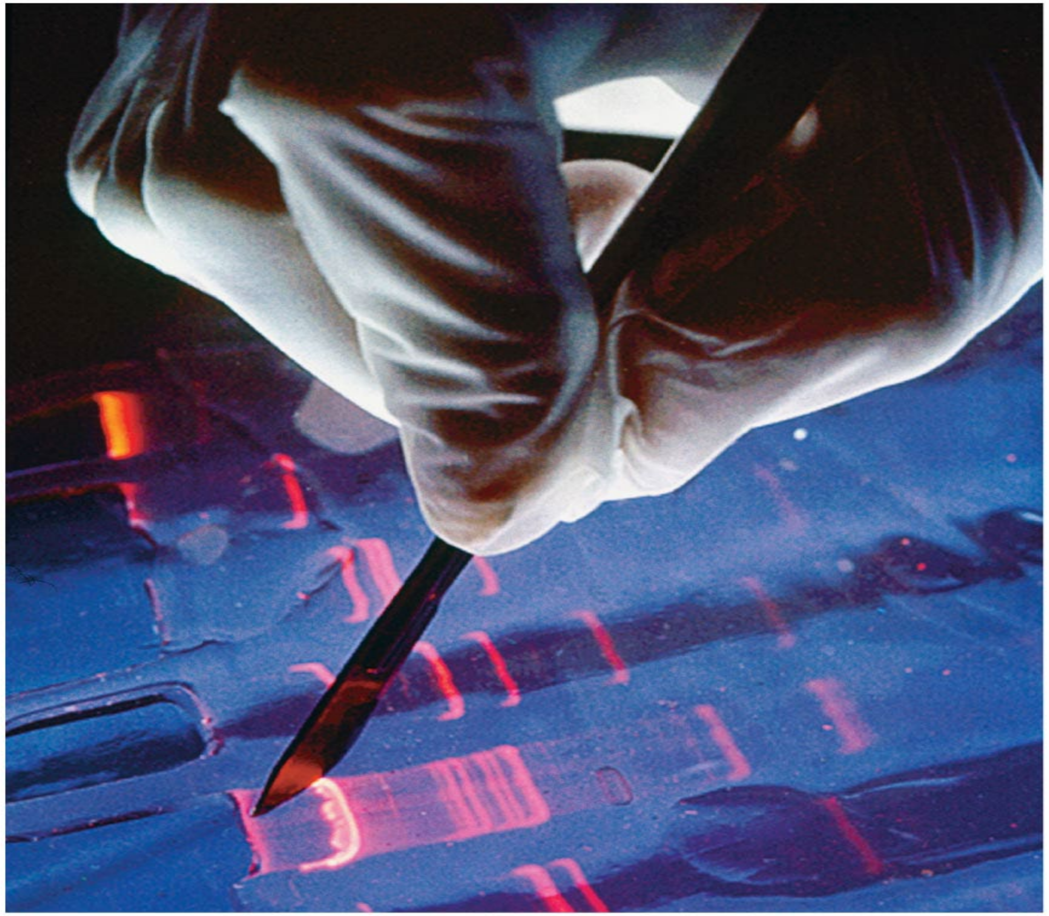
Electric Forces and Fields



College Physics, 11e
Raymond A. Serway; Chris Vuille

Topics

- Electric charge
- Conduction
- Insulation
- Induction
- Polarization
- Coulomb’s law
- Electric fields



In electrophoresis, what causes DNA fragments to migrate through the gel? How can an investigator adjust the migration rate?

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.

Forces in Electric Fields

The electric field inside this smoke detector exerts a force on charged smoke particles, moving them toward a detecting electrode.

You'll learn how electric fields exert forces and torques on charged particles.

Structure of Atom

- An atom has a dense, positively charged *nucleus*, containing positively charged *protons* and neutral *neutrons.*
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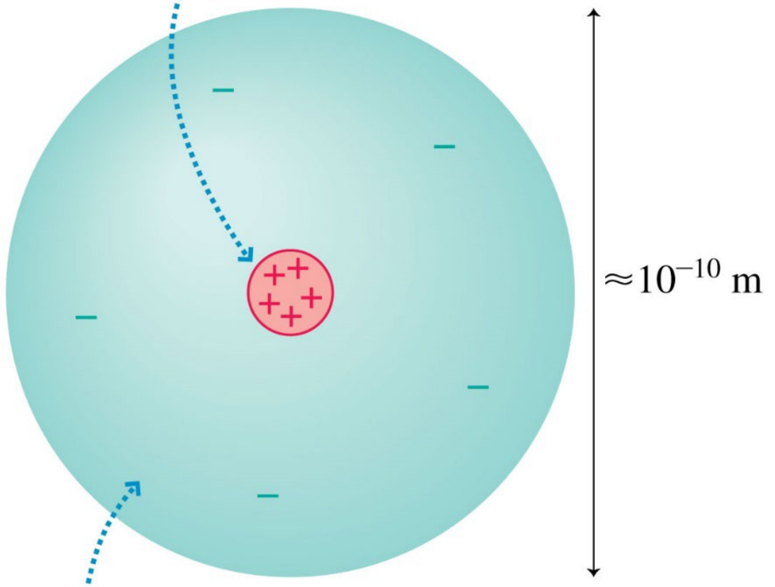
- The nucleus is surrounded by the much-less-massive orbiting negatively charged *electrons* that form an **electron cloud**.



Structure of Atom

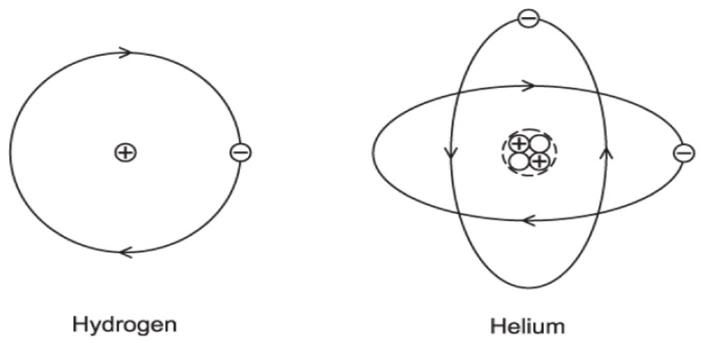


Figure 23.1

A (very) simple representation of the sub-atomic constituents of the two simplest atoms, hydrogen and helium. Hydrogen has a nucleus which consists of a single positively charged proton and has a single electron 'orbiting' this proton. Helium has two protons and two neutrons in its nucleus, and two electrons 'orbiting' this nucleus. Each *atom* has no net charge, despite being made of charged parts.

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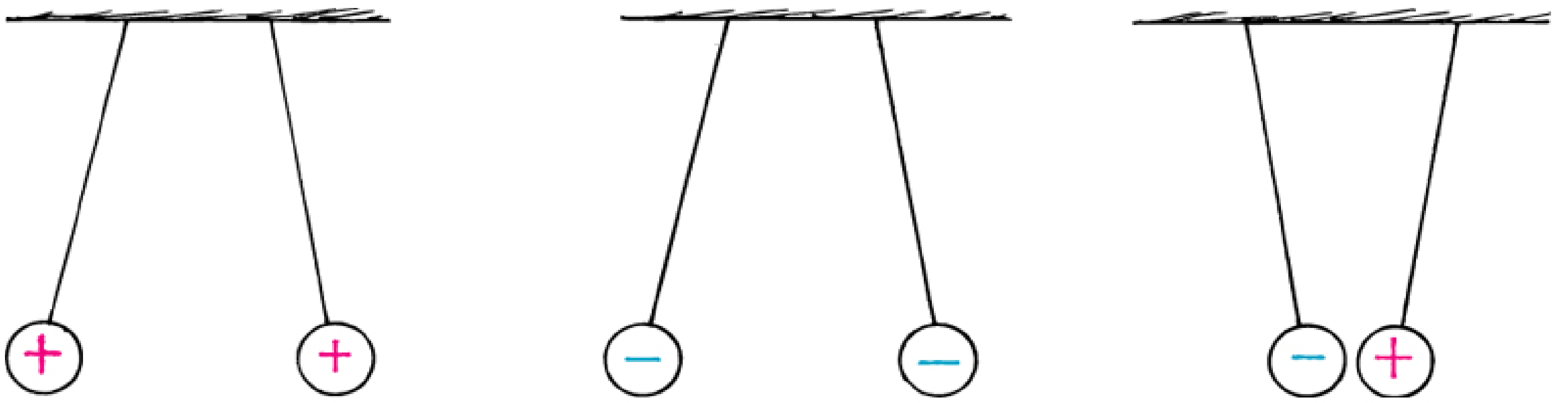
Charges



- Like charges repel, opposites attract
- In ordinary matter, the positive charge arises from protons, the negative charges from electrons.
- Protons and electrons have a strong attractive force (opposite charges).
- Electrons maintain a separation from the nucleus because of their wavelike properties (they require space)
- Protons, while repulsed by their like charges, are held together by strong nuclear forces

Conservation of Charge

- When something is charged, no electrons are created or destroyed, they are simply transferred from one object to another.

- Just as for atomic and nuclear reactions, charge is conserved for an event.

- Something that is negatively charged has an excess of electrons (more electrons than protons). Positive charge means there are fewer electrons than protons.

- It follows that charge on an object is always an integer multiple of the charge on an electron.

Charge by Rubbing

A variety of objects get charged by rubbing. From water droplets in clouds to spores.

Atoms are neutral and outer electrons are shed more easily than inner ones.

When two compounds are in contact (rubbed) one may give up electrons more readily than the other.

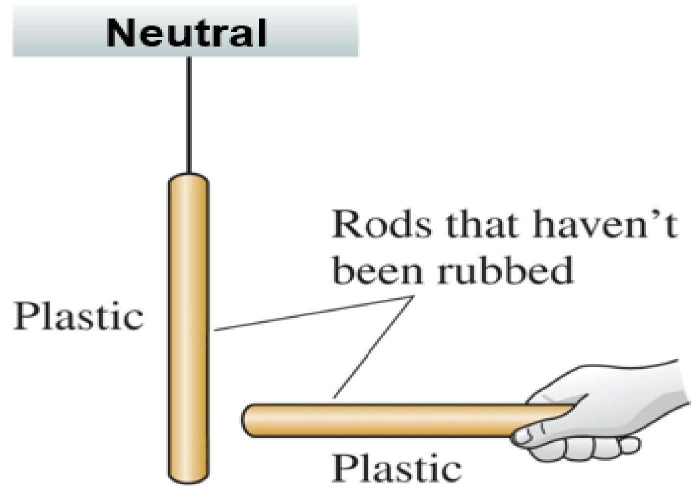
Charge by Rubbing

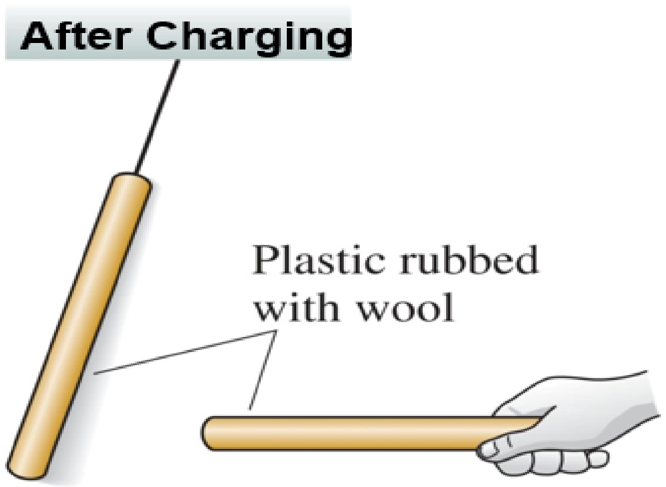
If the charge on the rod is negative after charging, what is the charge on the glove?

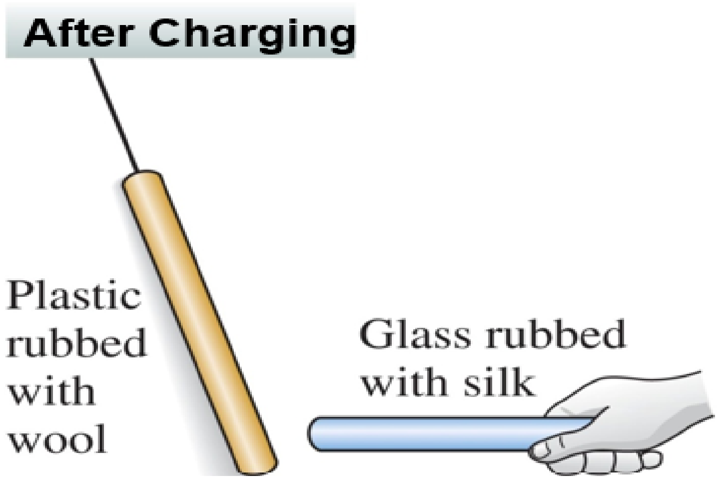
After charging, the net charge is zero.

Charge by Rubbing

Charge by Rubbing







- The **electric force** is the force between charged objects.
- Gravity is also a long-range force, but it is always attractive.
- The electric force can be repulsive and attractive.

Charge Model Part I

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

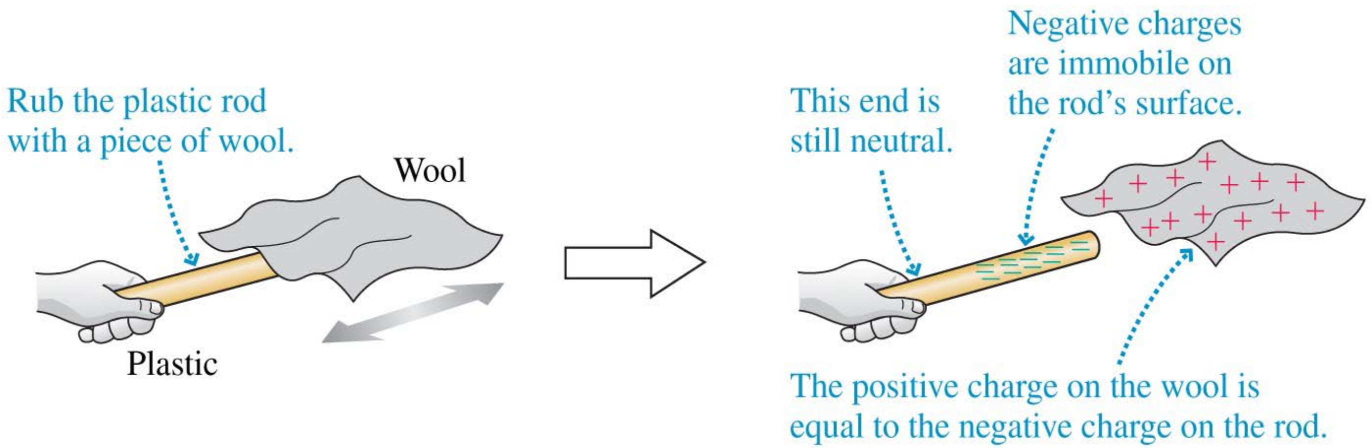
1. Frictional forces, such as rubbing, add something called **charge** to an object or remove it from the object. The process itself is called *charging*. More vigorous rubbing produces a larger quantity of charge.
2. There are two kinds of charge, positive and negative.
3. Two **like charges** (positive/positive or negative/negative) exert repulsive forces on each other. Two **opposite charges** (positive/negative), exert attractive forces on each other.
4. The force between two charges is a long-range force. The magnitude 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 positive and negative charge. The rubbing process somehow manages to separate the two.

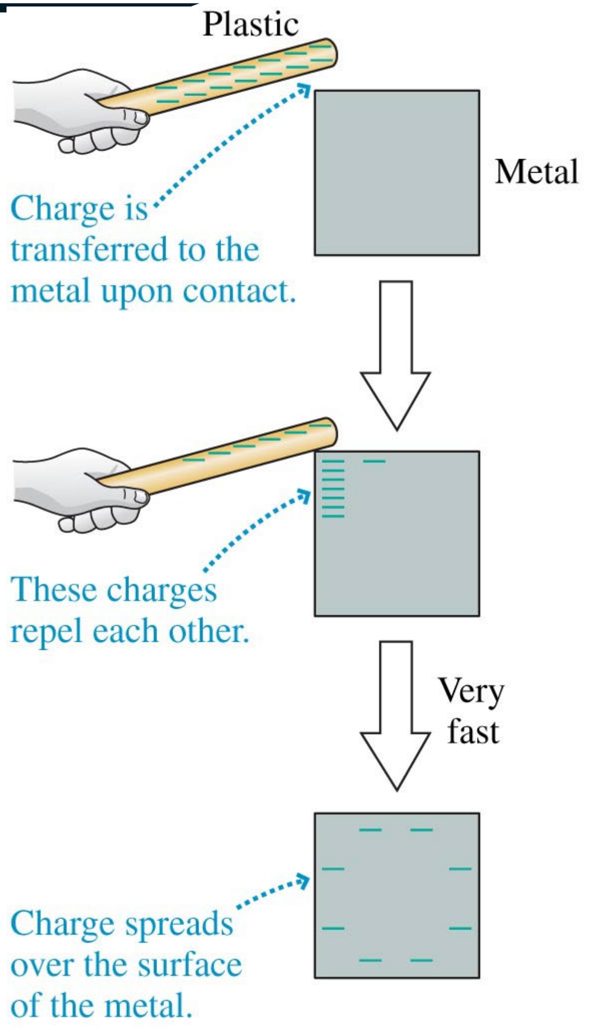
Charge Model Part II

Charge model, part II

6. There are two types of materials. Conductors are materials through or along which charge easily moves. Insulators are materials on or in which charges remain fixed in place.
7. Charge can be transferred from one object to another by contact.
8. Charge is conserved; it cannot be created or destroyed.

Visualising Charge





Charges on an insulator do not move.

Charges on a conductor adjust until there is no net force on any charge. We call this **electrostatic equilibrium**.

Visualising Charge

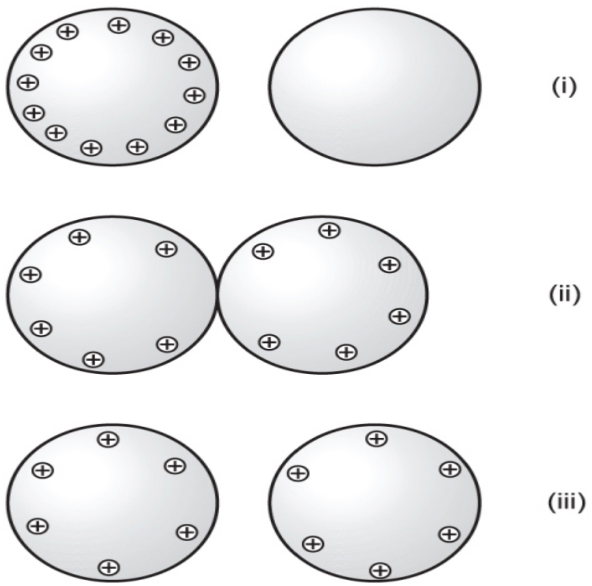


Figure 23.3

(i) A neutral conducting sphere (right) is brought close to an identical sphere with an excess positive charge (left). (ii) The two spheres are touched and the mobile charges redistribute over the surfaces of both, leaving both with an excess positive charge. (iii) The two spheres are separated, and each sphere has an excess positive charge of half the magnitude of the original excess charge on the left sphere.

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Electrostatic Induction

- There are a variety of methods of **charging** an object. One method is known as **induction**.

- In the **induction** process, a charged object is brought near but not touched to a neutral conducting object.

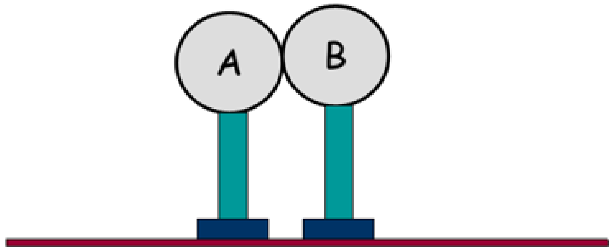
- The presence of a charged object near a neutral conductor will force (or **induce**) electrons within the conductor to move.

- Thus charge induction is a ***redistribution of electrical charge in an object***, caused by the influence of nearby charges.

Electrostatic Induction

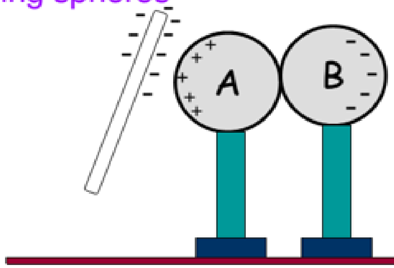
Charging by Induction (1)

- Two conducting spheres in contact



Charging by Induction (2)

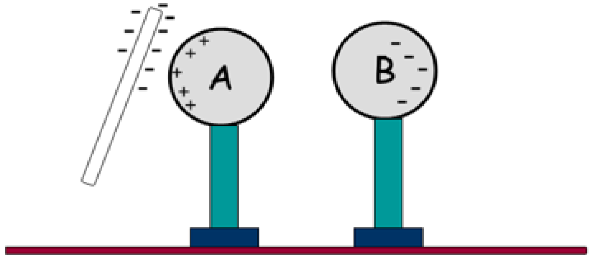
- A charged rod is brought close to A - but not touching
- This causes charges to separate within the two touching spheres



Charge is conserved

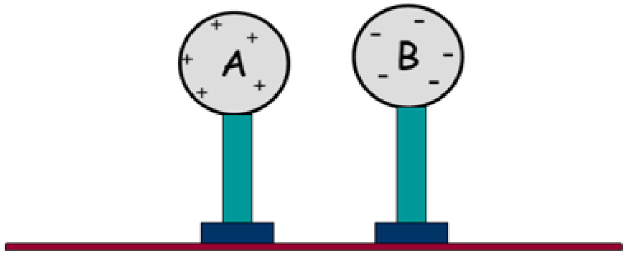
Charging by Induction (3)

- B is separated from A – so charges can't recombine



Charging by Induction (4)

- Each sphere is left with excess charge – which "distributes" over the surface to minimize repulsion.



Electrostatic Induction

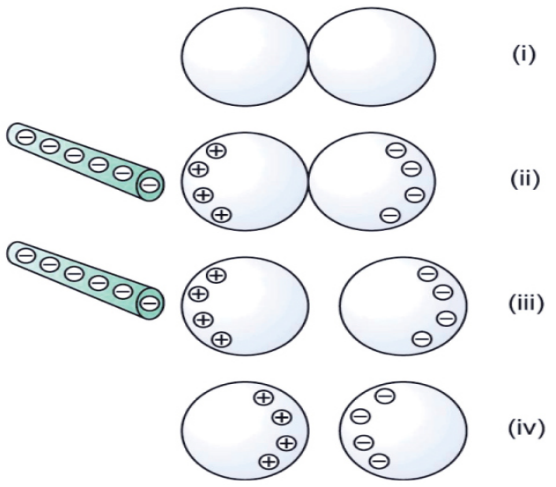


Figure 23.4

(i) Two identical uncharged conducting spheres are in contact with each other. (ii) A (negatively) charged object is brought close to the two spheres, but not so close that charge is transferred from the object to the spheres. This causes charges to separate within the two touching spheres. (iii) The two spheres are moved apart. As they are now no longer touching recombination of the separated charge is impossible. (iv) The charged object is removed and each of the conducting spheres finishes with an excess charge of equal magnitude but opposite sign.

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Conductors and Insulators

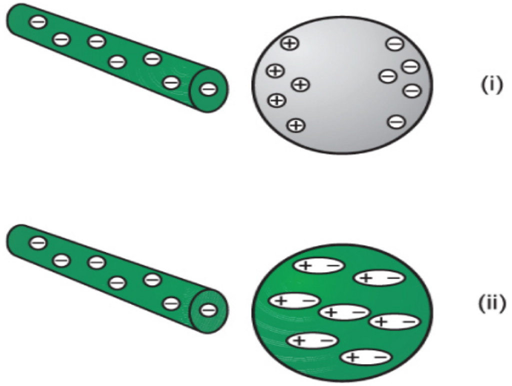

Figure 23.7

(i) Conductor: charges can move throughout the conductor and opposite charges accumulate on end of the conductor. (ii) Insulator: charges are still bound to a particular location in the insulator, but may spend more time on one side or other of a molecule.

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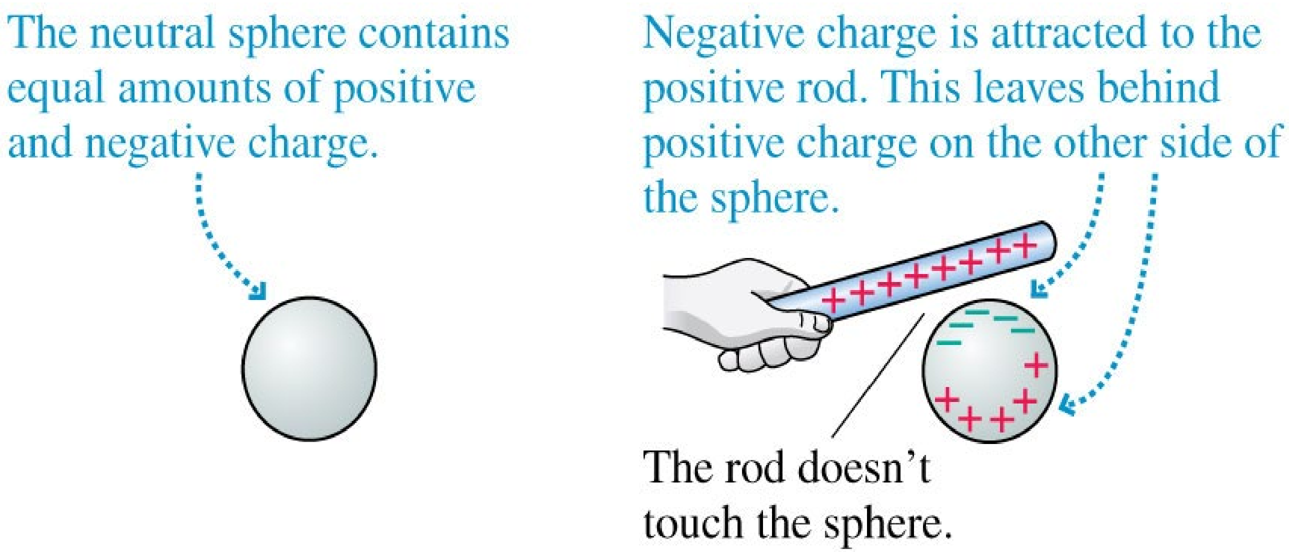
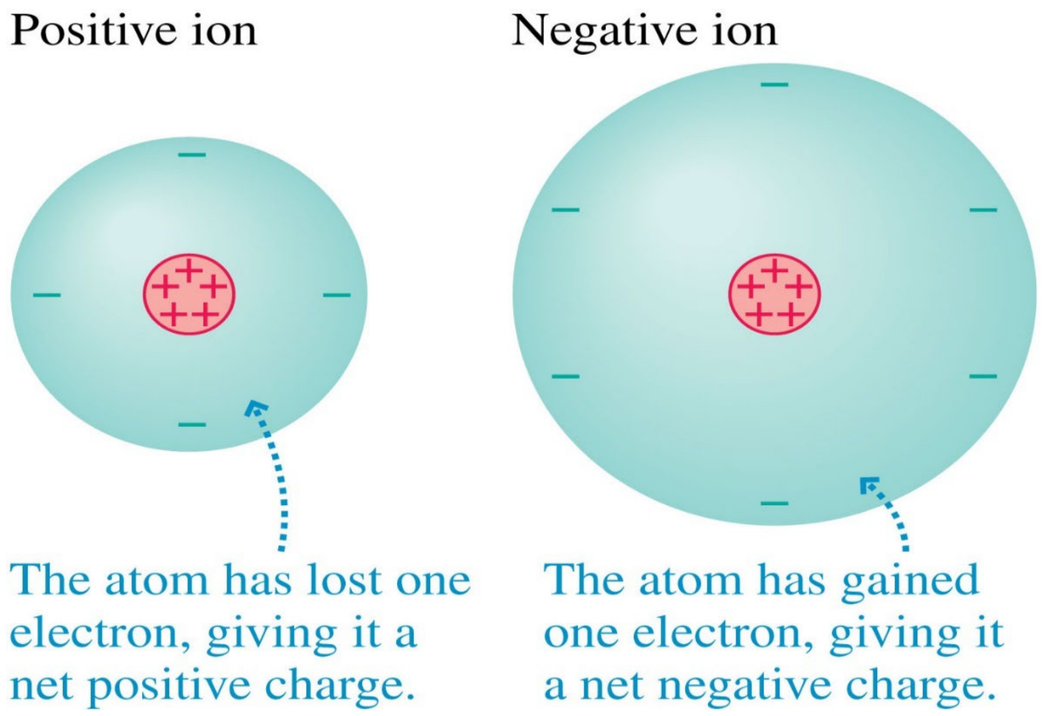
Polarisation

- **Charge polarization** is the slight separation of the positive and negative charges in a neutral object when a charged object is brought near.



An Atomic View of Charging

- **Ionization** is the process of removing an electron from the electron cloud of an atom.



Charge of an electron

The SI unit of charge is the Coulomb designated C .

A coulomb is the amount of charge carried by a current of one ampere in one second.

The smallest possible charges are those of the electron and proton for which $e = 1.6 \times 10^{-19}\ C$

e is the elementary unit of charge, a fundamental constant.

Example: How many electrons in a coulomb?

If N electrons make 1 coulomb of charge then:

$$N \times 1.6 \times 10^{-19} = 1\ C$$

$$N = 1/(1.6 \times 10^{-19}) = 6.25 \times 10^{18} \text{ electrons in } 1\ C.$$

Charged Particles in Biology

Dipoles in biology (An electric dipole is a separation of positive and negative charges.)

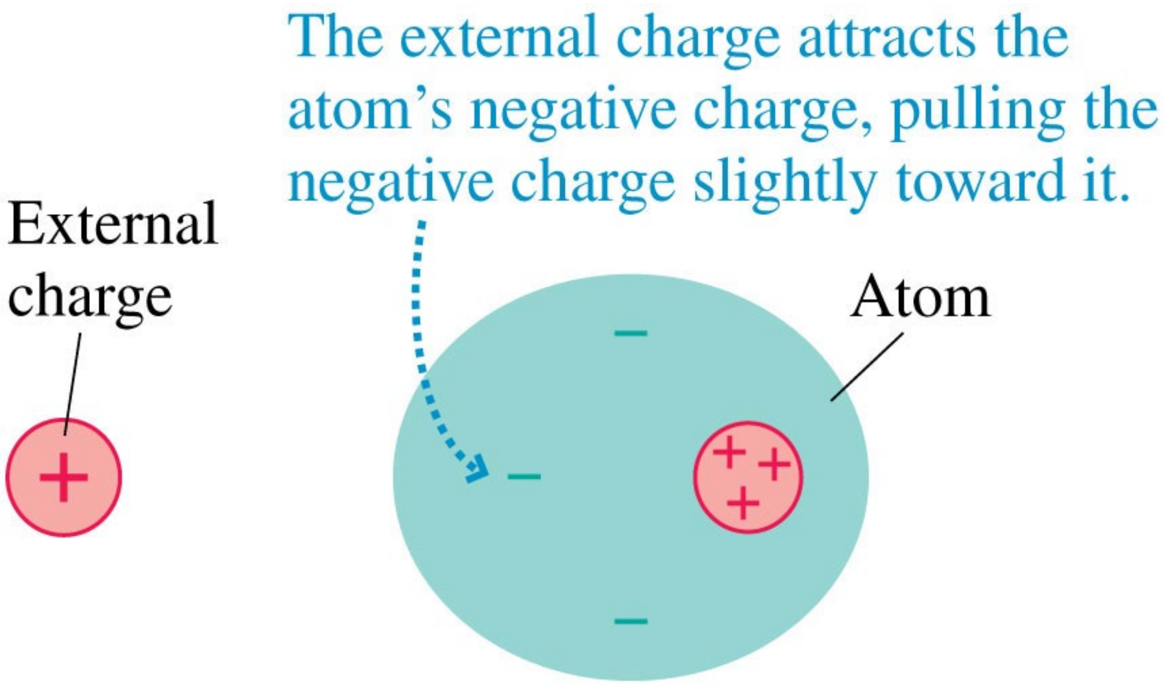
- water
- proteins
- amino acids
- nucleic acids
- lipids (sometimes! mainly non-polar)

Charged particles in biology

- Atoms – protons & electrons
- ions - atoms or groups of atoms that have lost or gained one or more electron *eg*, both Na^+ and K^+ used in transmission of nerve impulses; Ca^{2+} used in muscle contraction; H_2CO_3/HCO_3^- pair used to maintain blood as slightly basic in humans.
- proteins in aqueous solution
- amino acids in aqueous solution present as zwitterions
- nucleic acids - in their phosphate linking groups
- lipids - if they have carboxylate or phosphate groupings

Electric Dipoles

An **electric dipole** is two equal but opposite charges with a separation between them.



Coulomb's Law

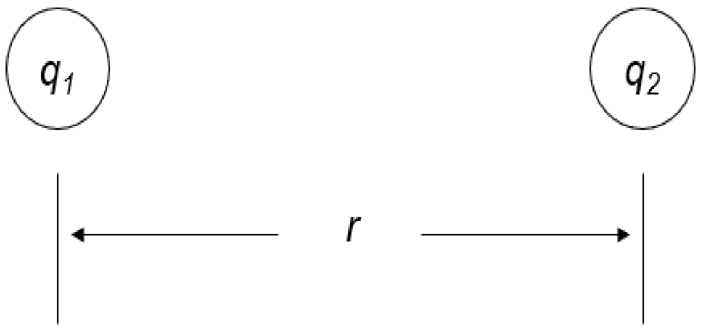
The force between two charges q_1 and q_2 at a distance d is

- proportional to each of the charges
- inversely proportional to the distance between them

$$F = K \frac{q_1 q_2}{r^2}$$

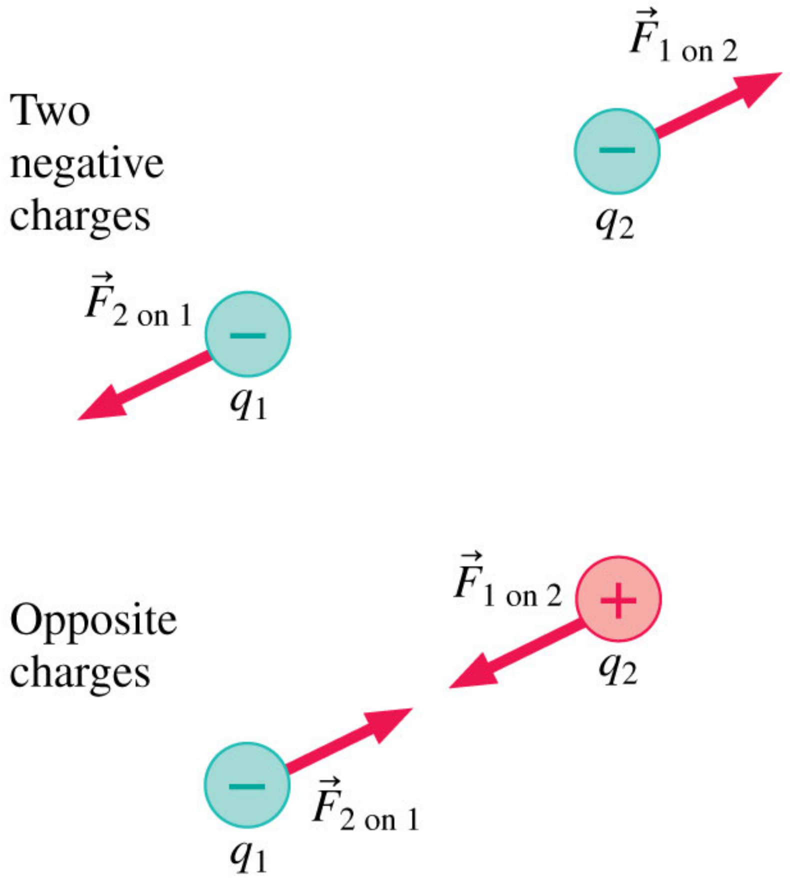
where :

$$K = 9 \times 10^9 \ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}} = \text{Coulomb's Constant}$$



Coulomb's Law

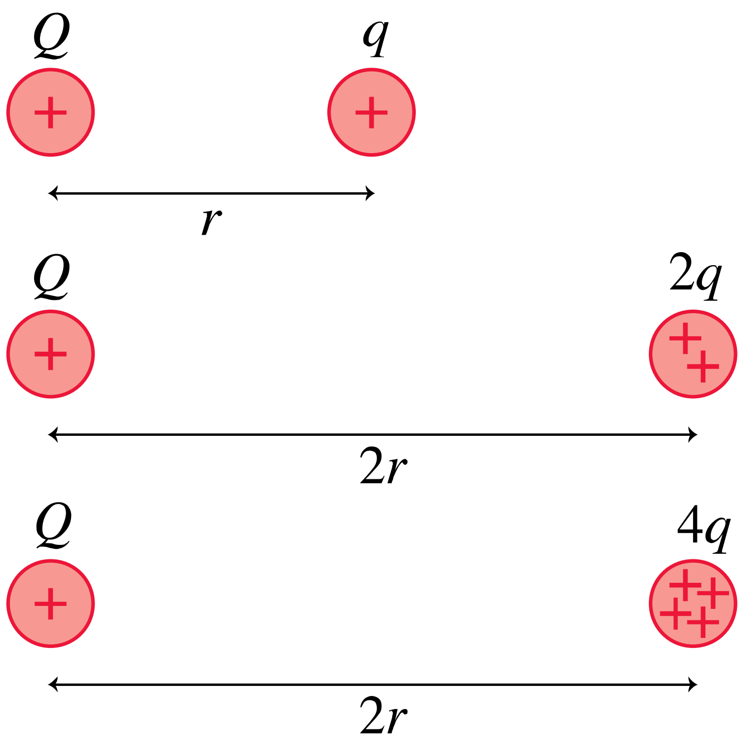
- Coulomb's law looks much like Newton's gravity except the charge *q* can be positive or negative, so the force can be attractive or repulsive.
- The direction of the force is determined by the second part of Coulomb's law.



Quick Check

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

  - q
  - $2q$
  - $4q$
  - q and $2q$ are tied
  - q and $4q$ are tied



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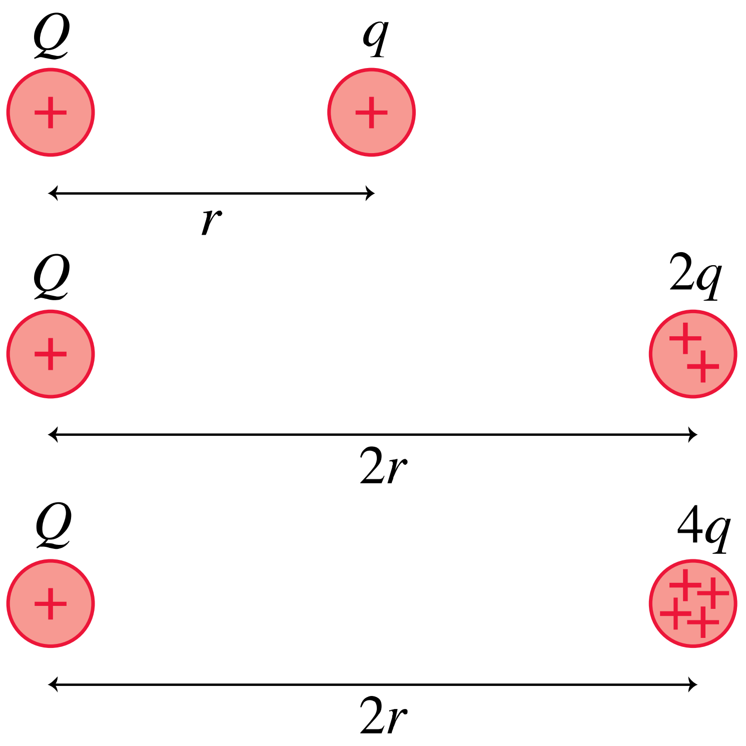
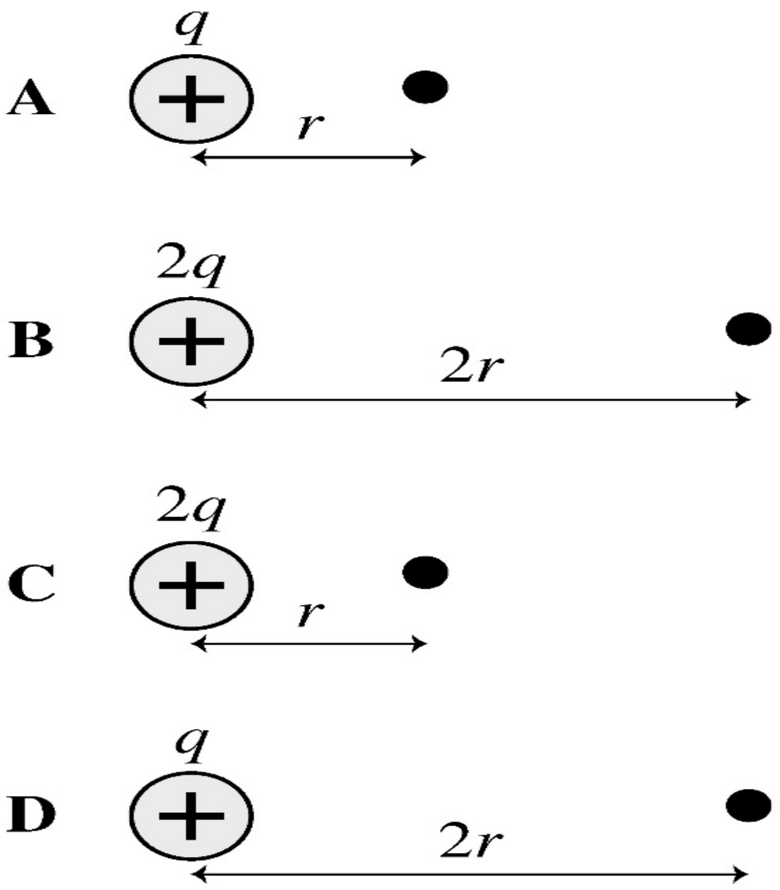


Quick Check

- In each of the following cases, an identical small, positive charge is placed at the black dot. In which case is the force on the small charge the largest?



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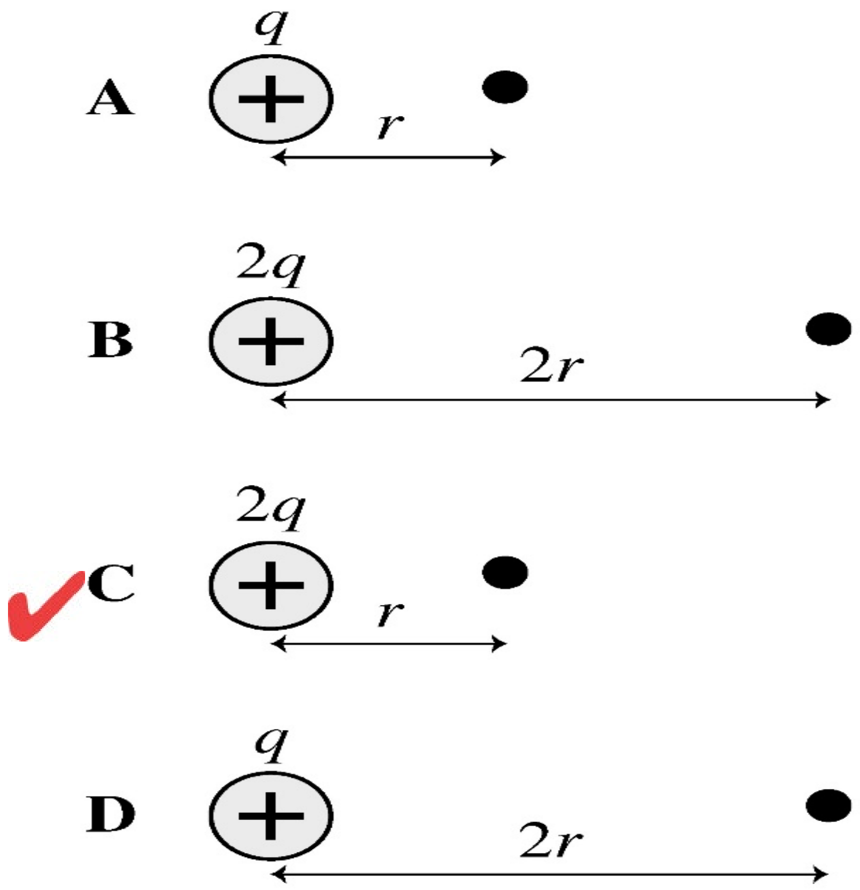


Problem

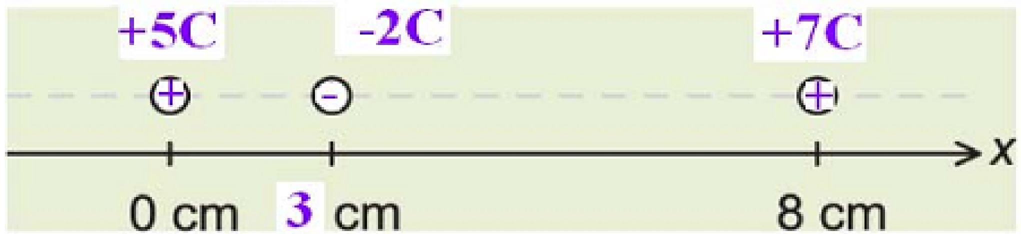


Figure 24.3

Three charges are arranged in a line.

What is net force on the -2C charge?

$$F_{\text{from}\,+5C\,\text{charge}} = K\frac{|+5C||-2C|}{(0.030\text{m})^2} = 9\times10^9\ \frac{(10)}{0.00090}\text{N} = 1\times10^{14}\text{N}$$

pointing to the left

$$F_{\text{from}\,+7C\,\text{charge}} = K\frac{||+7C||-2C||}{(0.050\text{m})^2} = 9\times10^9\ \frac{(14)}{0.0025}\text{N} = 5.04\times10^{13}\text{N}$$

pointing to the right

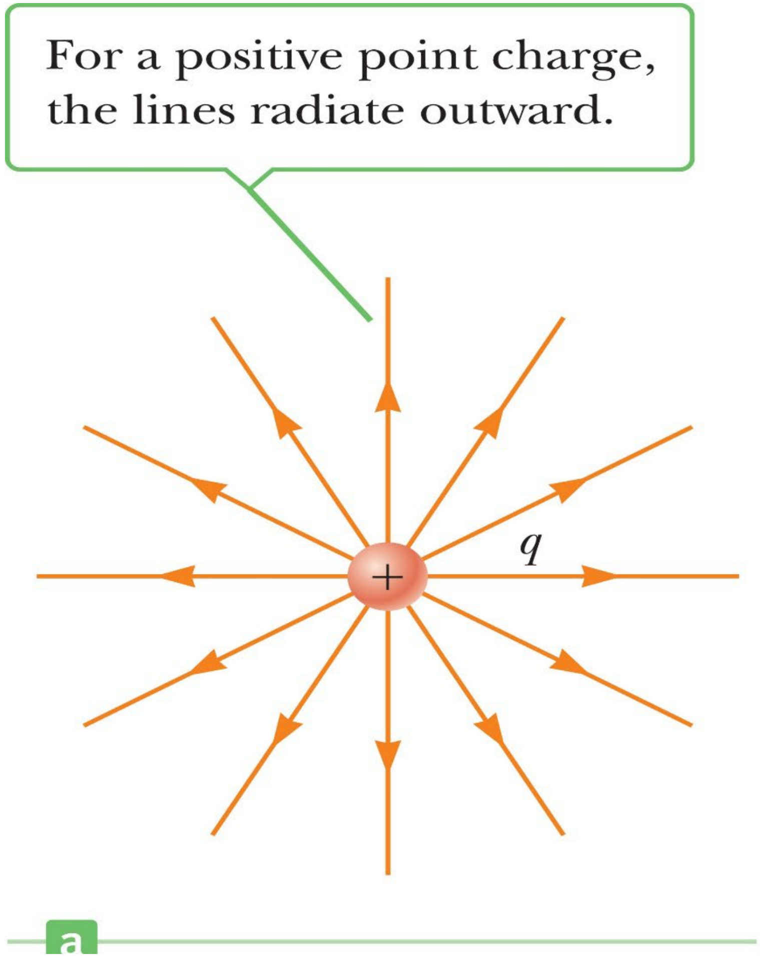
Net force is $(10-5.04)\times 10^{13}\text{N} \approx 5\times 10^{13}\text{N}$ to the left

The Concept of Electric Field

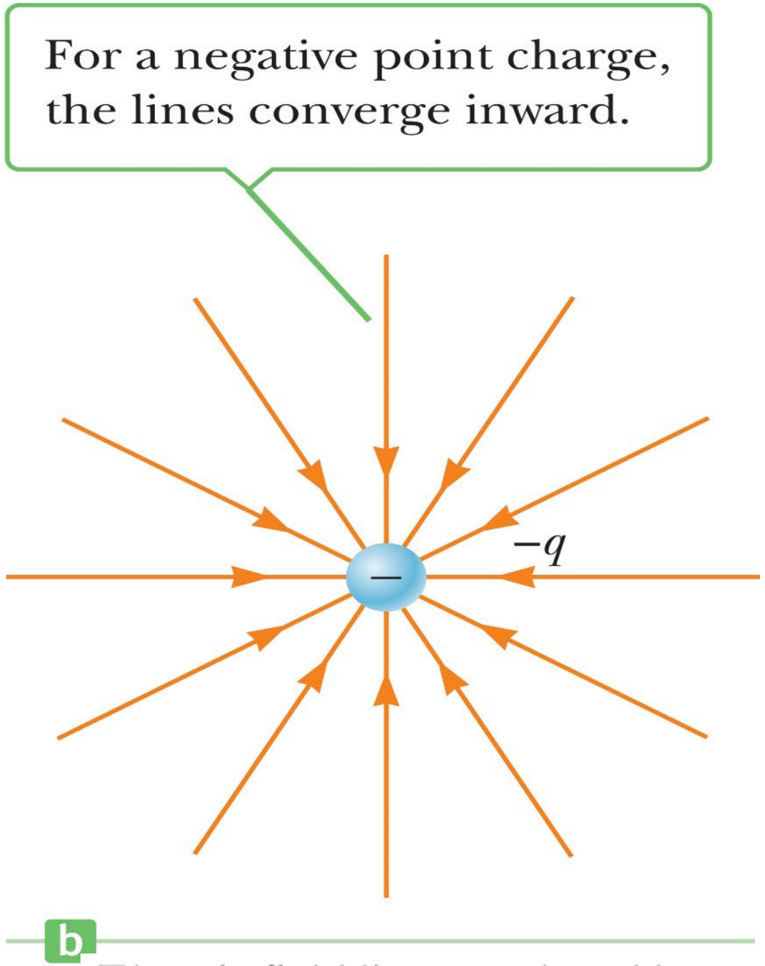
- The space around a charge is altered to create an **electric field.**
- The alteration of space around a mass is called the **gravitational field.**
- The alteration of space around a magnet is called the **magnetic field.**

An electric field is a region of influence which exists for some test charge which is produced by one or more other charges.

Electric Field Lines



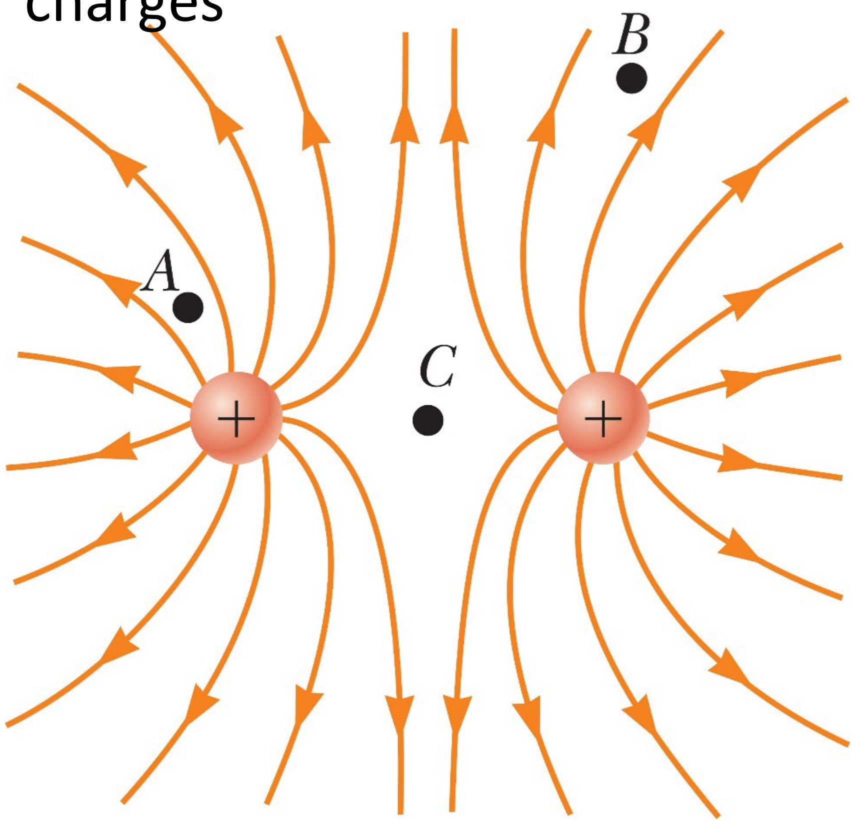
Electric field lines produced by an isolated positive point charge.



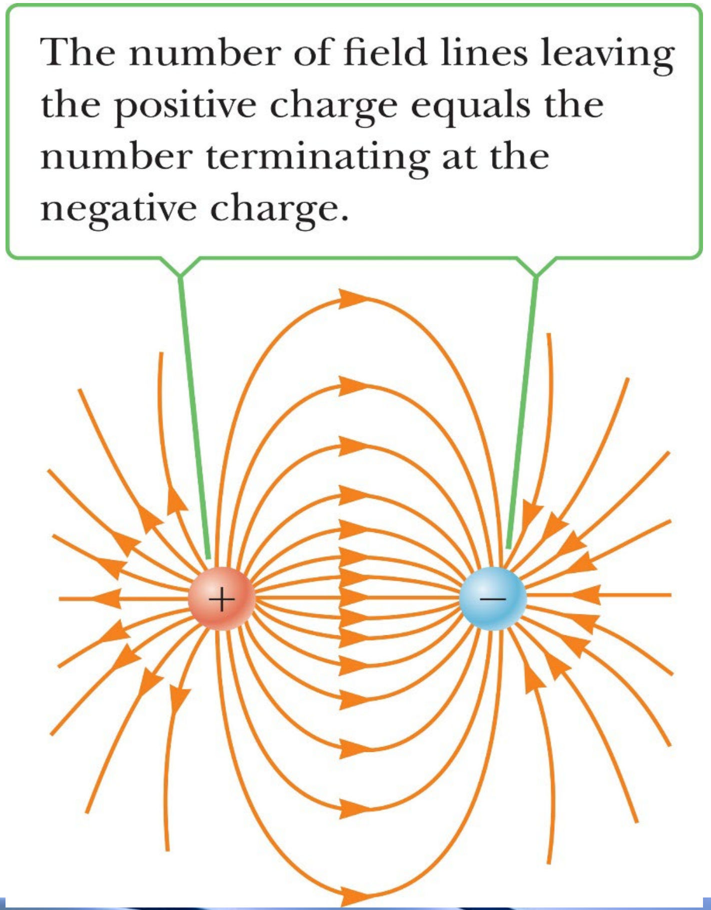
Electric field lines produced by an isolated negative point charge.

Electric Field Lines

Electric Field from two positive charges

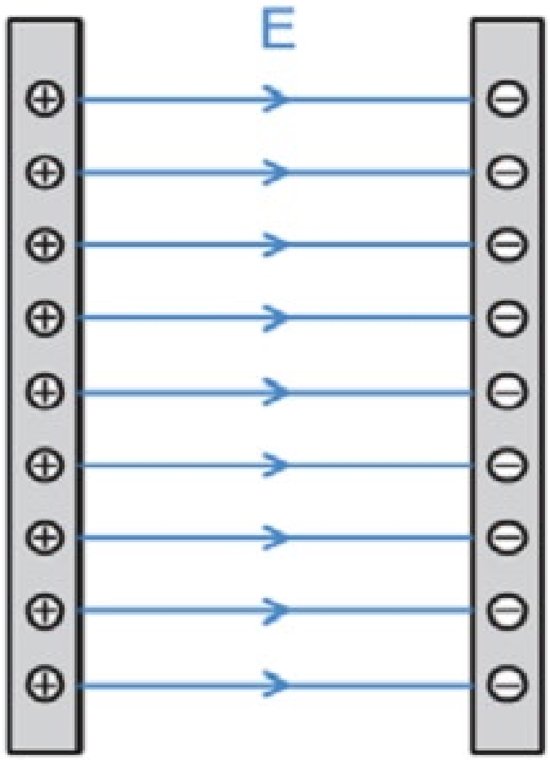


Electric Field from a positive charge and a negative charge



Electric Field Lines

Uniform electric field lines produced by parallel plates carrying uniformopposite charges. (Note that the non-uniform field formed at the fringes of the plate is not shown here.)



Electric Field Equation

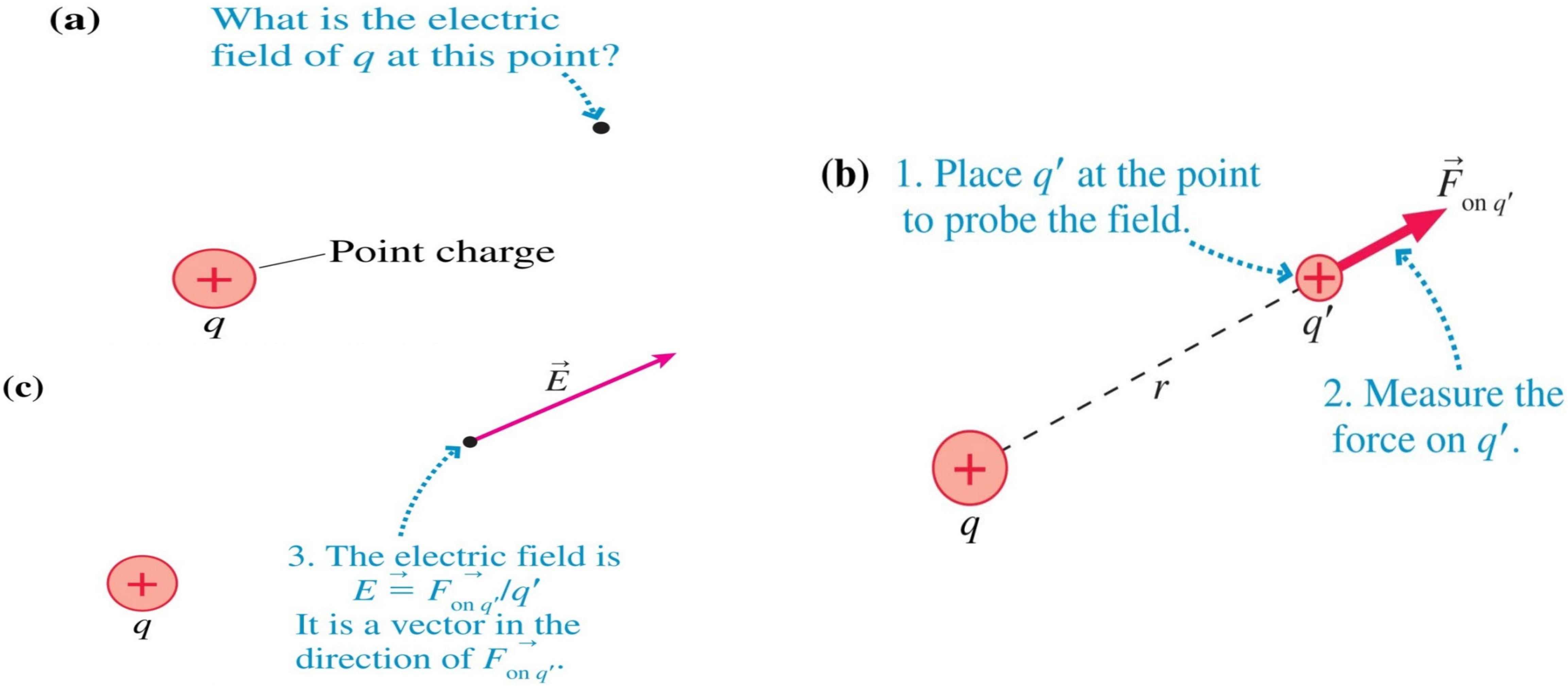
- We define the electric field *E* at the point (*x, y, z*) as

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

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

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

Electric Field of a Point Charge



Electric Field of a Point Charge

$$E = \frac{\text{force}}{\text{charge}} = \frac{F}{q}$$

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

Electric field of point charge q at a distance r

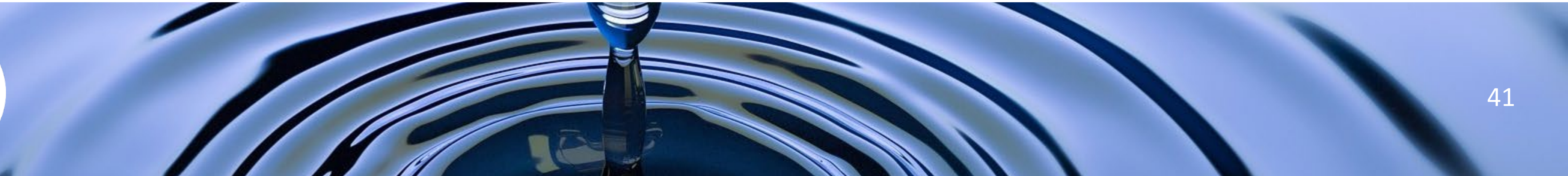
Acceleration of a Charged Particle due to an Electric Field,

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

The Field Model

TABLE 20.2 Typical electric field strengths

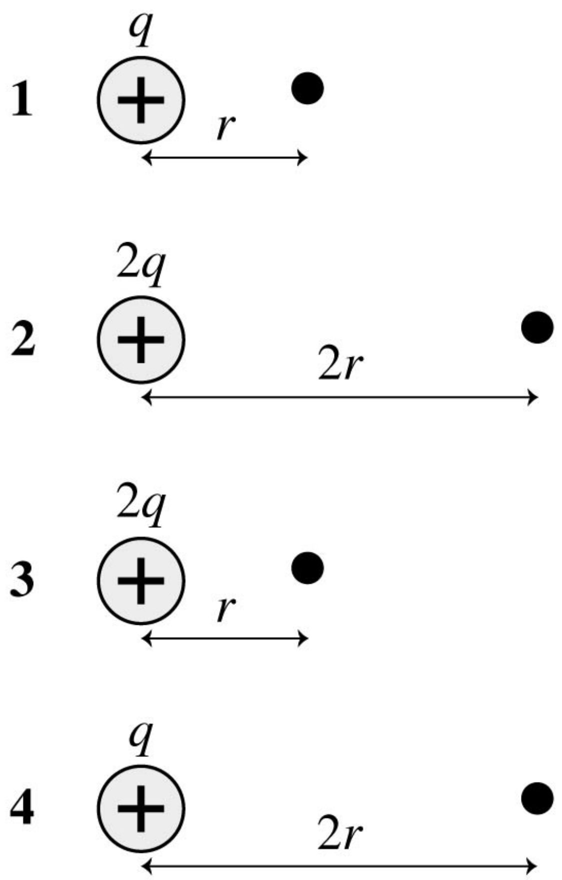
Field	Field strength (N/C)
Inside a current-carrying wire	10^{-2}
Earth's field, near the earth's surface	10^{2}
Near objects charged by rubbing	10^{3} to 10^{6}
Needed to cause a spark in air	10^{6}
Inside a cell membrane	10^{7}
Inside an atom	10^{11}



Quick Check

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

    - 3, 2, 1, 4
    - 3, 1, 2, 4
    - 1, 4, 2, 3
    - 1, 2, 3, 4



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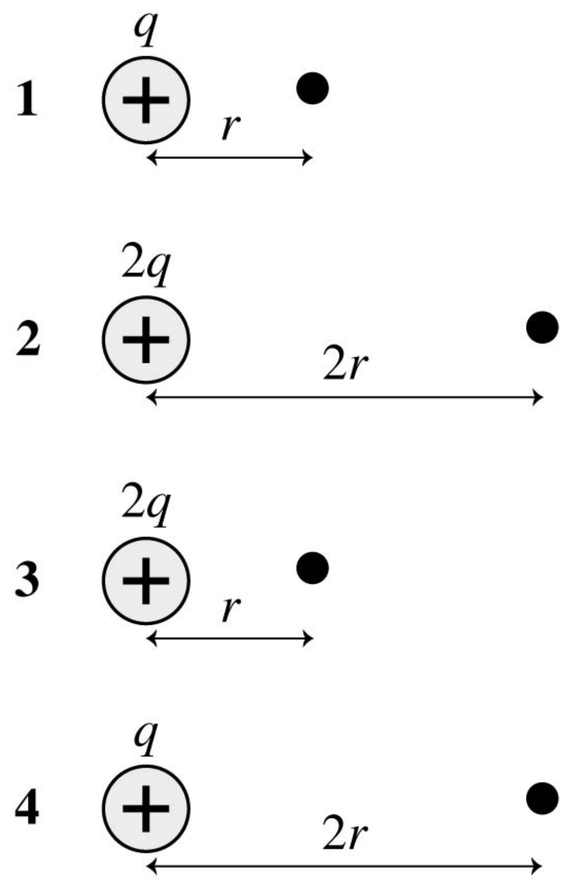
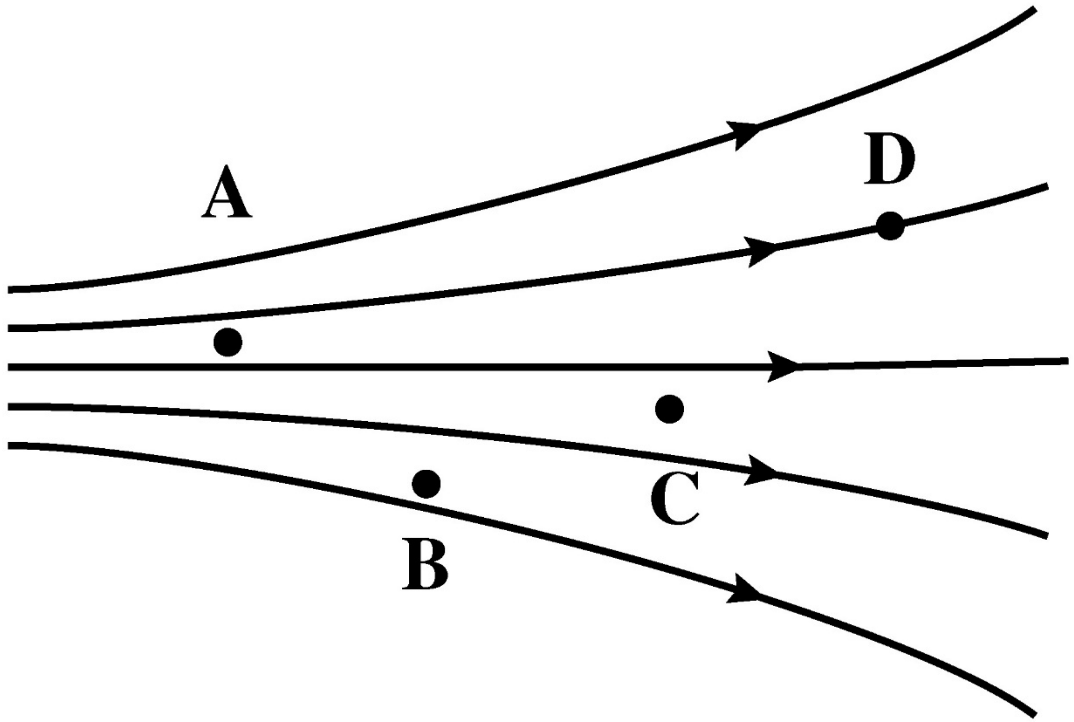


Quick Check

- A set of electric field lines is directed as shown. At which of the noted points is the magnitude of the field the greatest?



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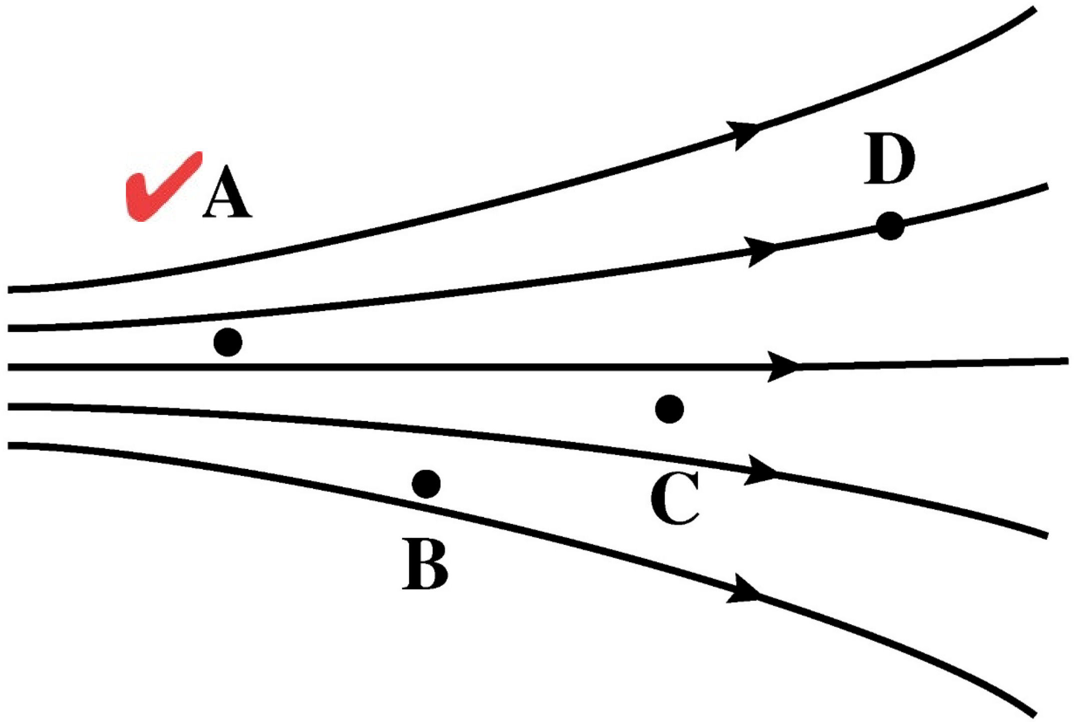
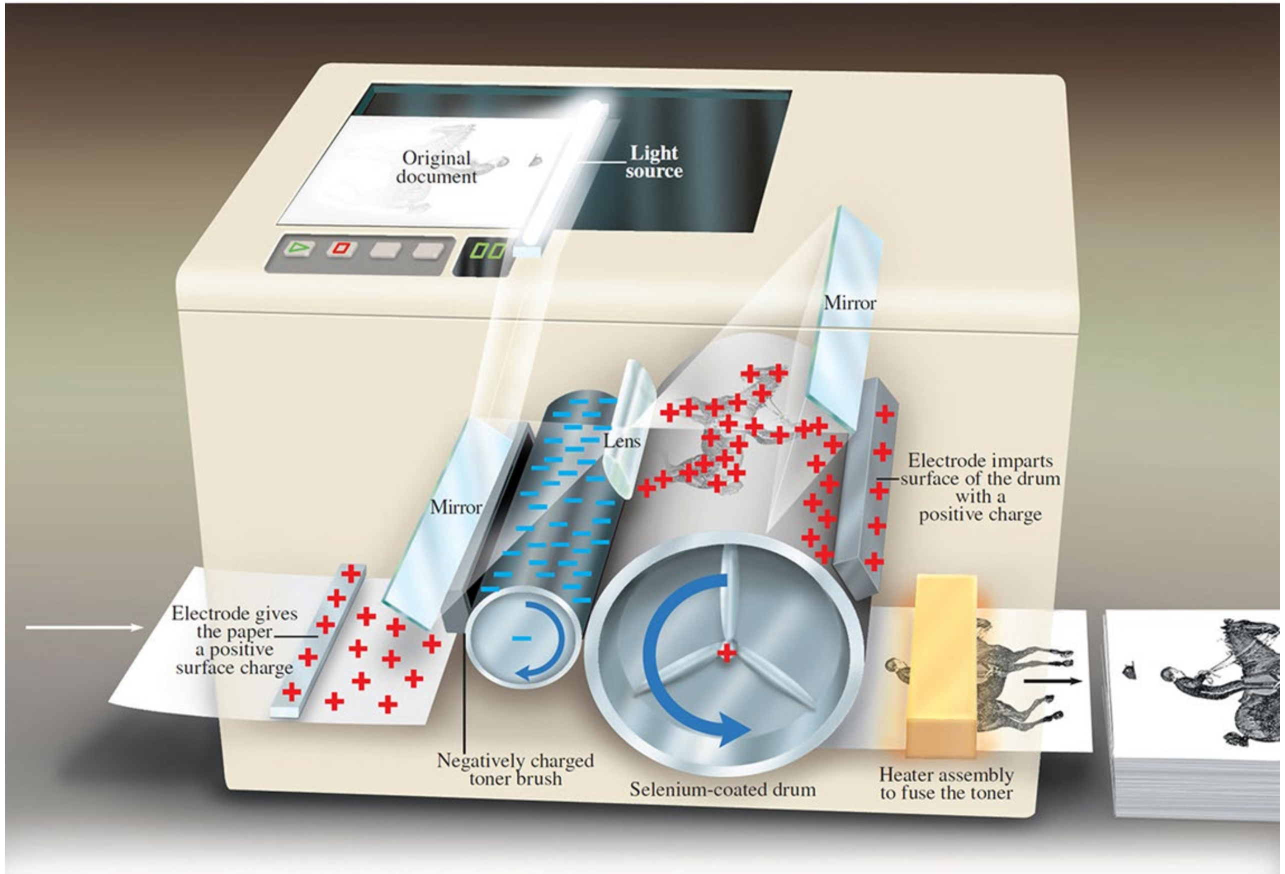


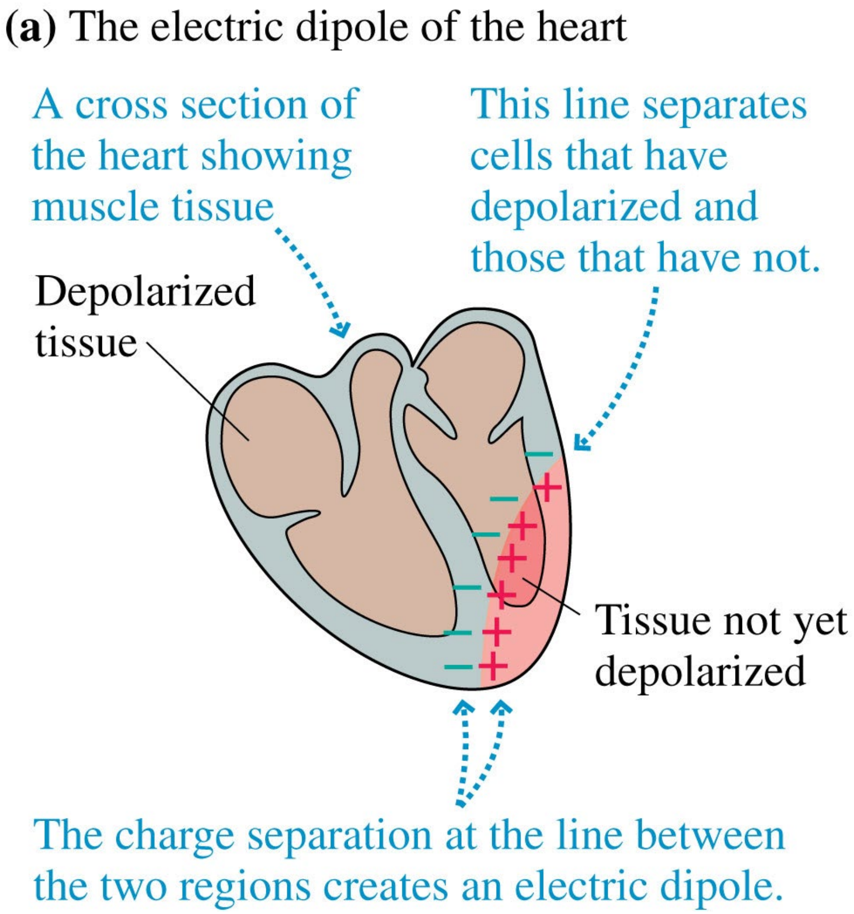
Applications of Electric Fields



The electrostatic photocopier works by depositing a pattern of positive charge on a non-conducting drum. Dry toner particles are attracted to the drum in the desired pattern. Then the drum is rolled across the paper and with the application of heat, sticks the ink to the paper in the required pattern.

Electric Field of the Heart

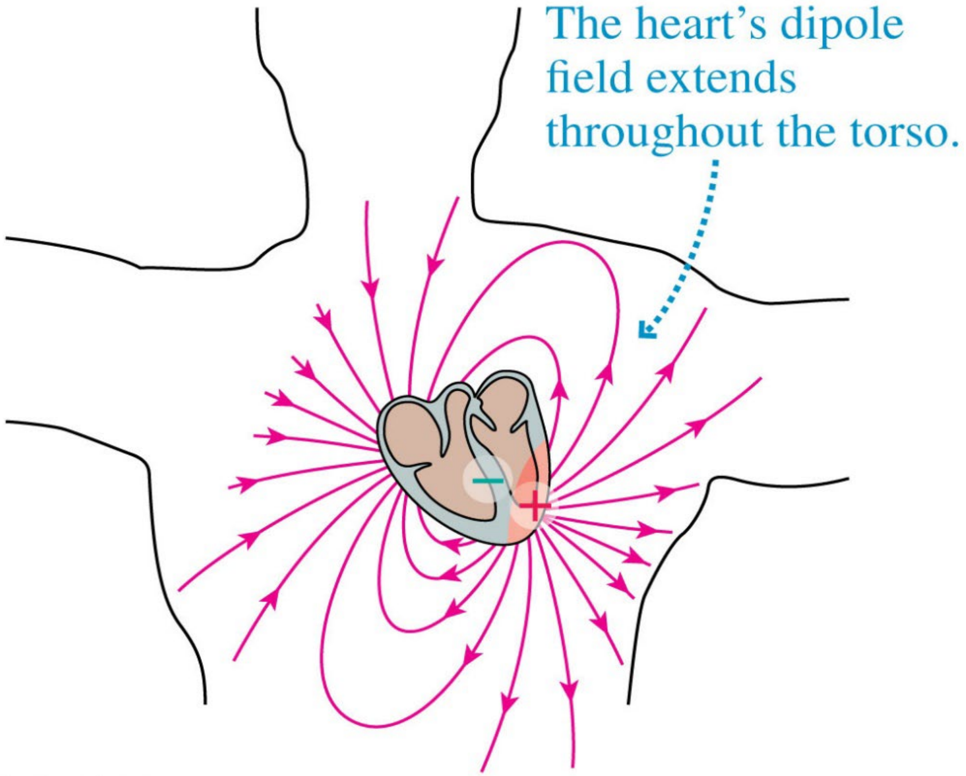
- The surface of the heart is positive on one side of the boundary between tissue that is polarized and tissue that is not yet depolarized, negative on the other.
- The heart is a large electric dipole. The orientation and strength of the dipole change during each beat of the heart.



Electric Field of the Heart

- The dipole electric field generated by the heart extends throughout the torso.
- An *electrocardiogram* measures the changing field of the heart as it beats.
- The measurements can be used to diagnose the operation of the heart.

(b) The field of the heart in the body



Electric Field Applications

Returning to Gel electrophoresis

The DNA strands - or protein fragments - will possess a charge because of their side chains

DNA fragments will all have negatively charged phosphate groups; but with the proteins fragments it will depend on whether they have more negatively charged side-chain groups or more positively charged ones.)

The mixture is placed on a gel - which is placed between parallel pales, and then an electric field is applied.

The large portions of molecules will move towards an oppositely-charged plate with an initial force depending upon their charge. But they will then suffer drag in the gel - with the larger heavier fragments being slowed down the most

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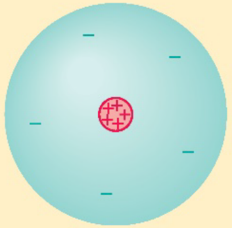
Summary

GENERAL PRINCIPLES

Charge

There are two kinds of charges, called **positive** and **negative.**

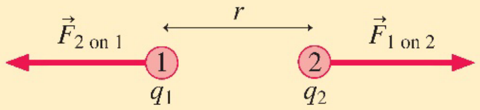


- Atoms consist of a nucleus containing positively charged protons surrounded by a cloud of negatively charged electrons.
- The **fundamental charge** e is the magnitude of the charge on an electron or proton: $e = 1.60 \times 10^{-19}$ C.
- Matter with equal amounts of positive and negative charge is **neutral.**
- Charge is conserved; it can't be created or destroyed.

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 $K = 8.99 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$ 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).

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