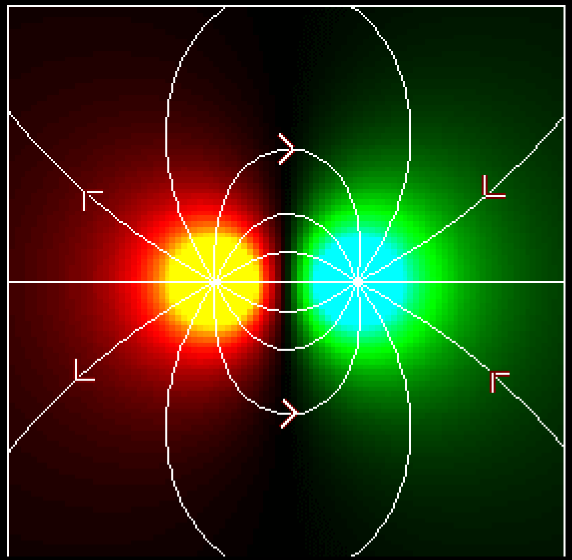
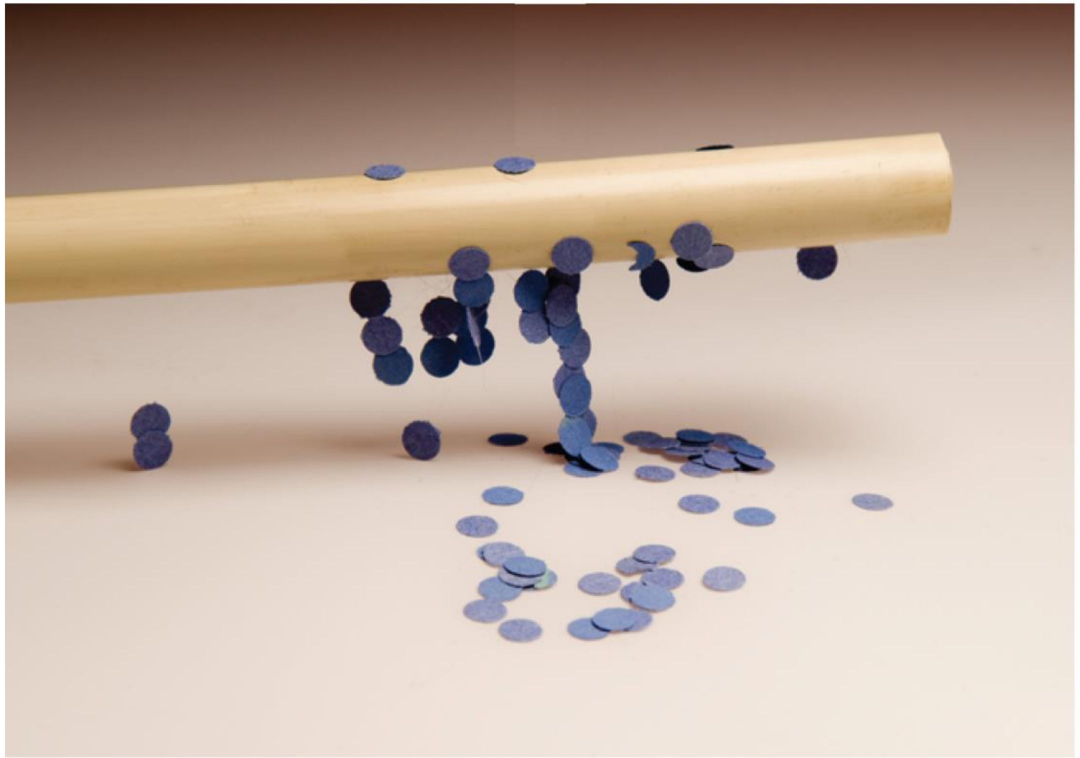
AP Physics

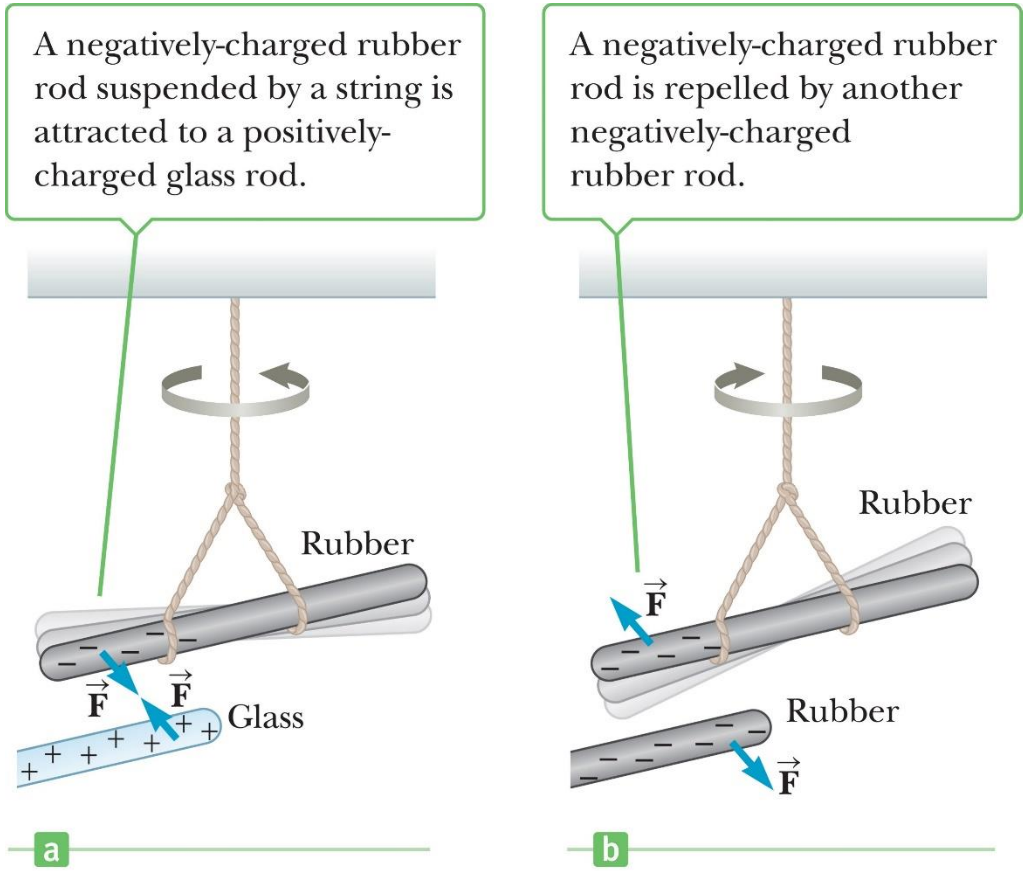
Chapter 15: Electric Forces and Fields



Properties of Electric Charges

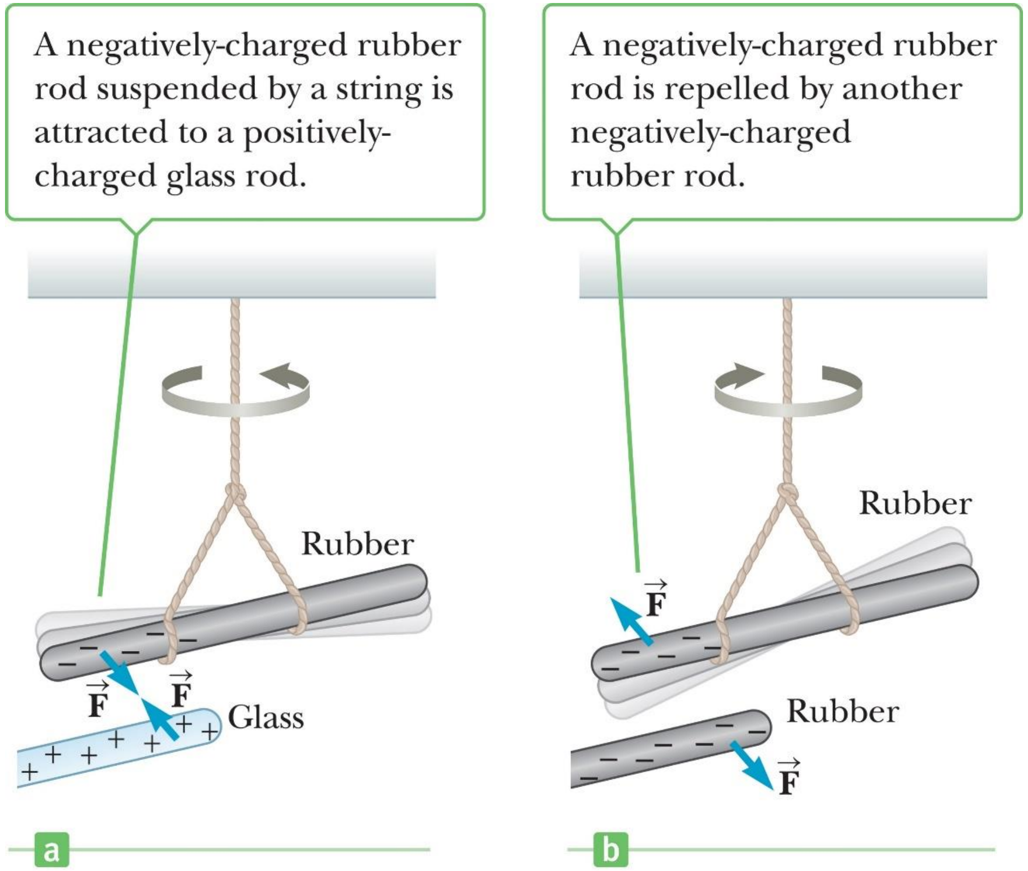


Properties of Electric Charges



- Like charges repel each other.

Properties of Electric Charges



- Like charges repel each other.

Properties of Electric Charges

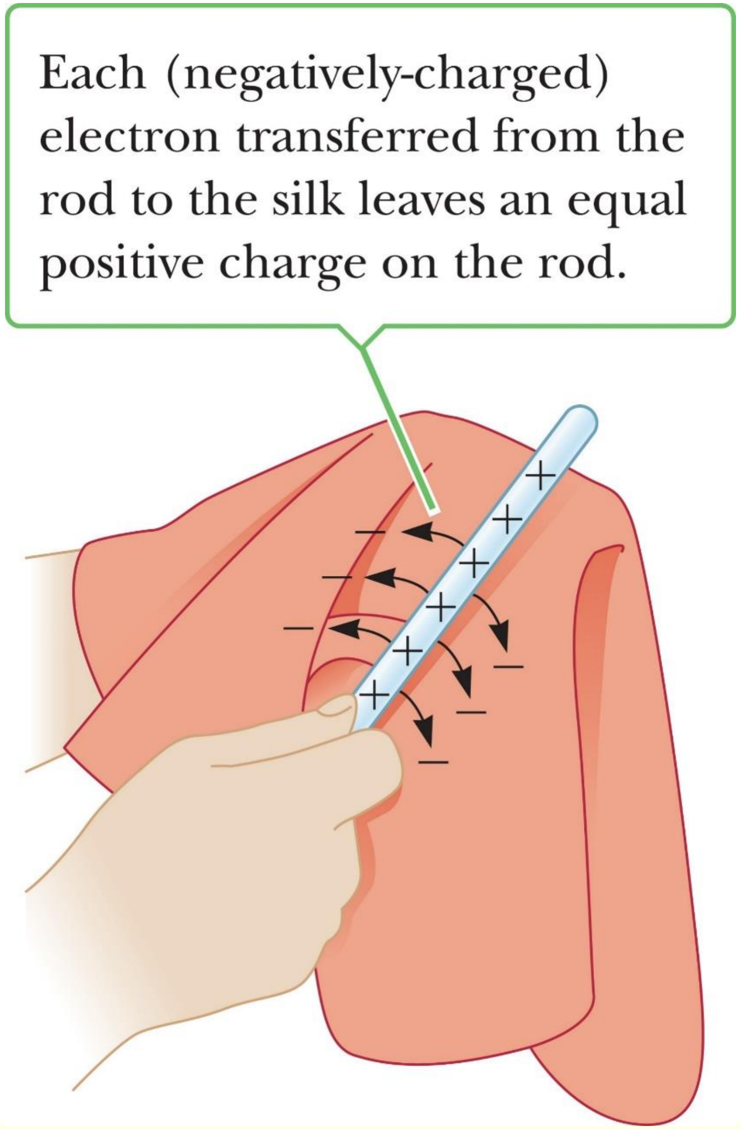
- Charge is simply the build up of extra electrons on a surface.
- A surface with extra electrons is considered negatively charged.
- A surface with a lack of electrons is considered positively charged.

Properties of Electric Charges

- Nature has two carriers of charges
- Electrons that are negatively charged
- Protons that are positively charged
- All matter in it’s “natural” state is neutrally charged, meaning it has the same number of protons and electrons.

Properties of Electric Charges

- When a glass rod is rubbed against silk the glass rod transfers electrons to the silk making the rod positively charged.
- The silk on the other hand is negatively charged.
- The rod and the silk gain charges in discrete increments. Meaning if the rod gets a +3 charge then the silk will receive a -3 charge.



Properties of Electric Charges

After a glass rod is rubbed against a silk cloth, the glass rod has a charge of +5 and the silk cloth has a charge of –7. What could the original charges of the glass rod and silk cloth have been?

1. +2, –5
2. 0, –2
3. +5, 0
4. 0, –5

Properties of Electric Charges

- Charge is quantized (Units: Coulomb)

- The charge of a single proton and a single electron is given by a constant.

- e = 1.60219 x 10^{-19} C *(charge of a single electron/proton)*

- This means that everything that is charged in nature must have a charge that is an integer multiple of e. Never a fraction.

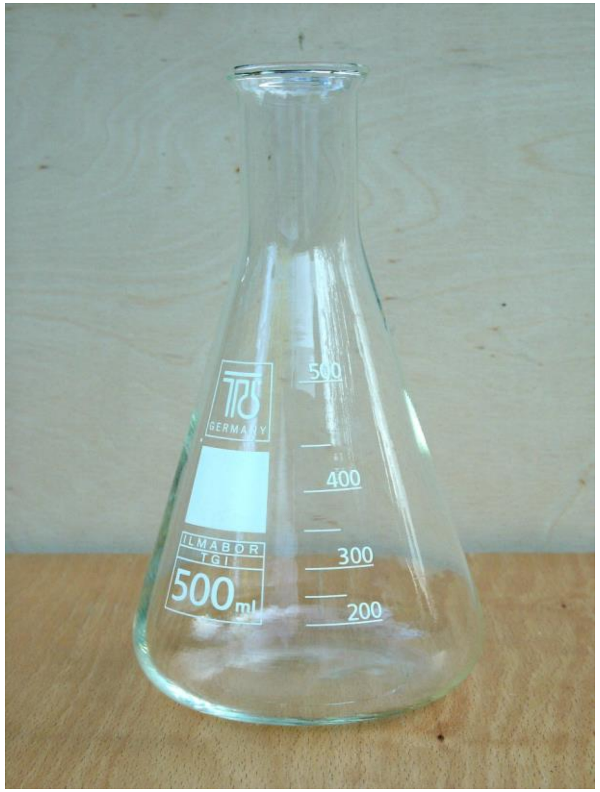
- Charge = $\pm ne$

Conductors and Insulators

- Electric charges can move freely through a **conductor** in the presence of an electric field.

- In an **insulator** electric charges cannot move freely throughout the material. They can only build up on a surface.

Conductors and Insulators



Insulator

Conductor

Conductors and Insulators

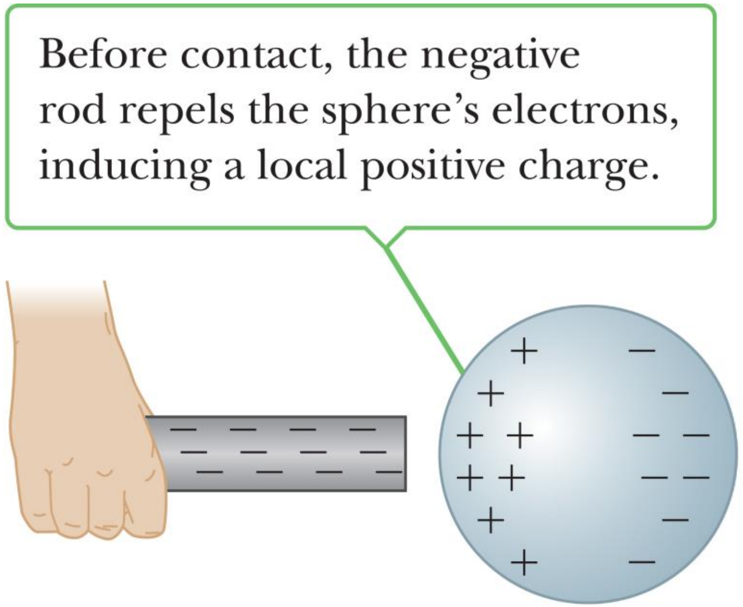
Let's say I wanted to build up charge in a copper wire. When I take the copper wire in my hand and rub it against wool or silk, the charge flows freely throughout the copper wire into my hand and down into the ground through my body. Thus no charge can be built up. What can I do to make sure the copper wire builds up charge by blocking the discharge through my body?

Conductors and Insulators

- The third class of material is known as semi conductors.

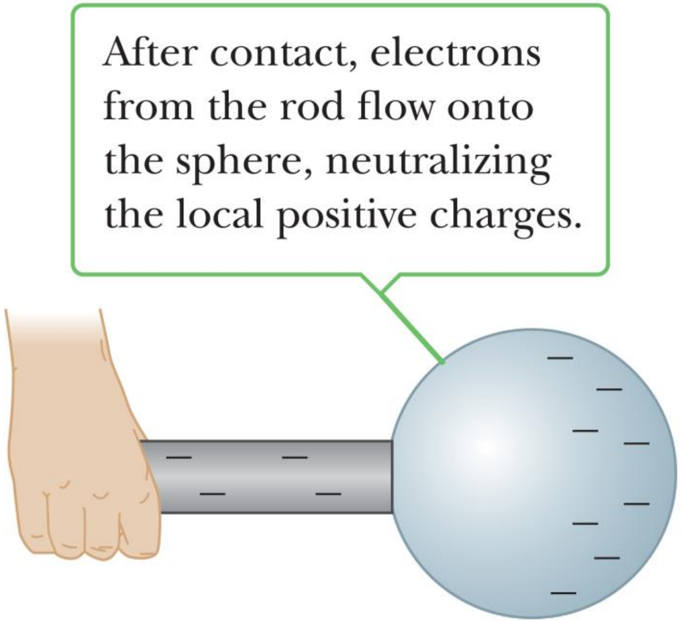
- They have properties of both conductors and insulators but we will not be discussing why this is for the purpose of this class.

Charging by Conduction



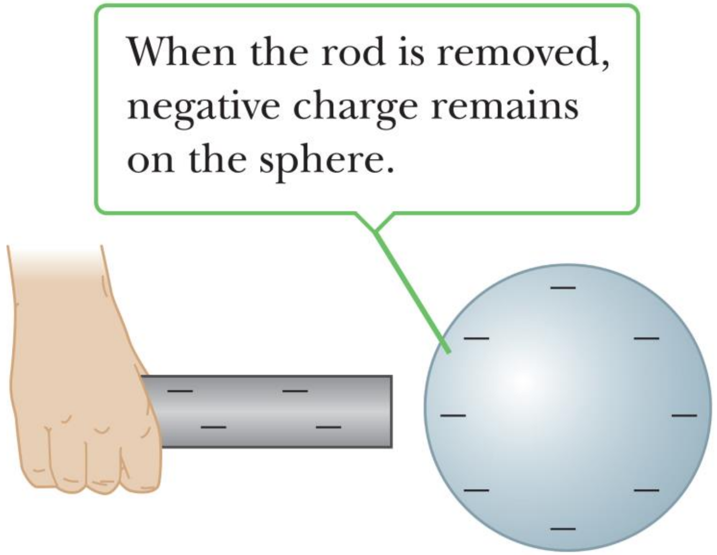
- When a negatively charged rod is brought into contact with a neutral sphere the electrons in the sphere are repelled creating a positive charge on one side of the sphere.

Charging by Conduction



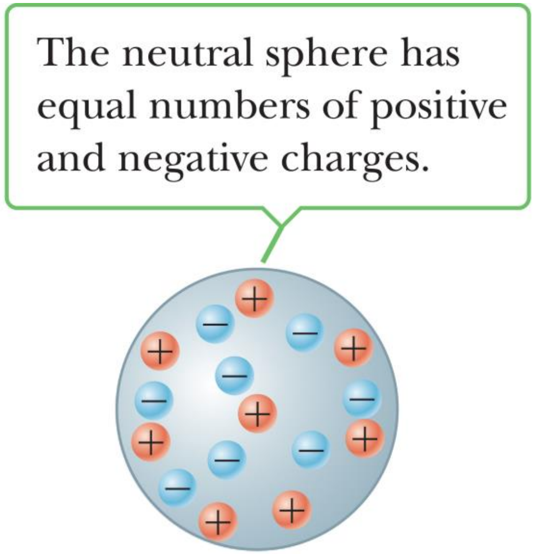
- Upon contact the excess electrons from the rod travel into the sphere neutralizing the positive charges.

Charging by Conduction



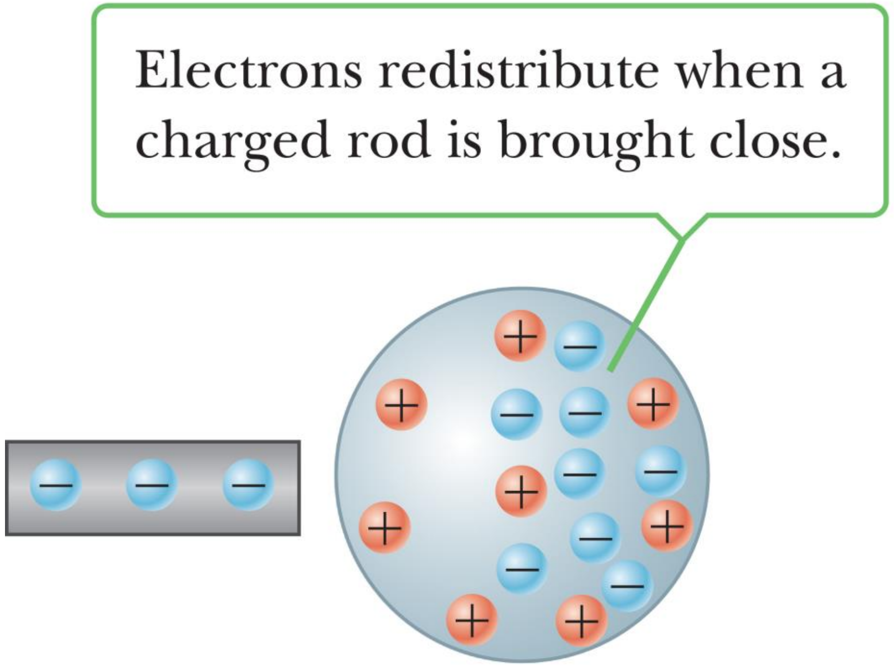
- When the rod is removed our sphere becomes overall negatively charged.

Charging by Induction



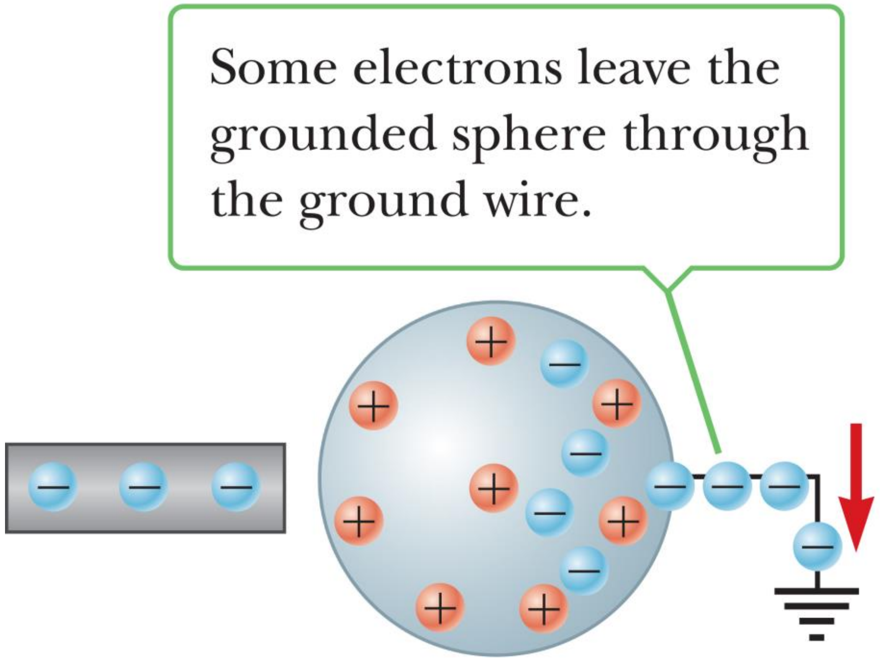
- This is a method to charge materials without touching them.
- In this scenario we have a neutral sphere.

Charging by Induction



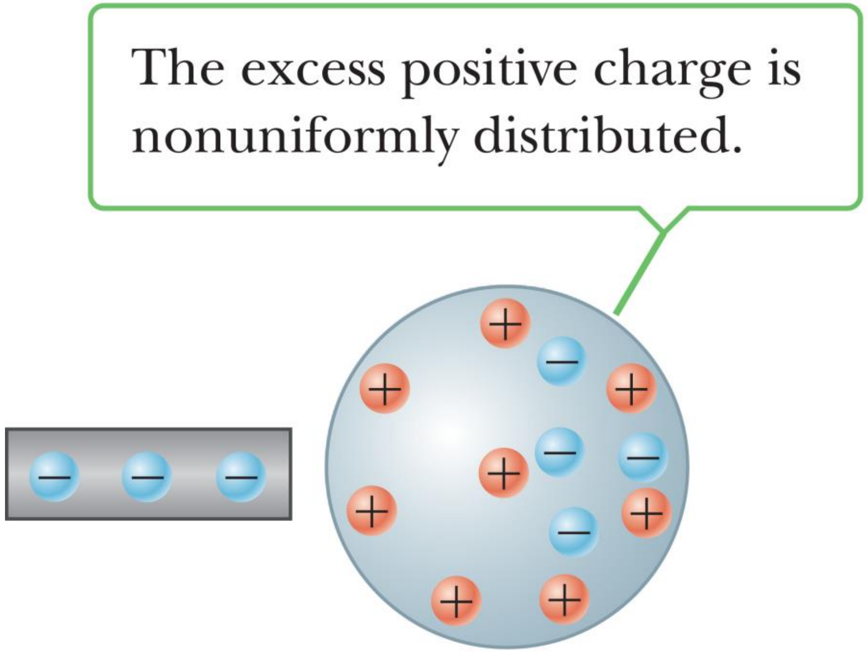
- When a charged rod is brought close to the sphere the charges redistribute in the sphere similar to last scenario.

Charging by Induction



- Attaching a wire/ground onto the sphere allows the build up of electrons to leave the sphere.

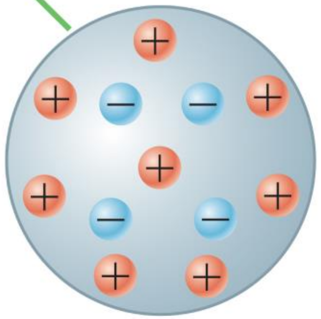
Charging by Induction



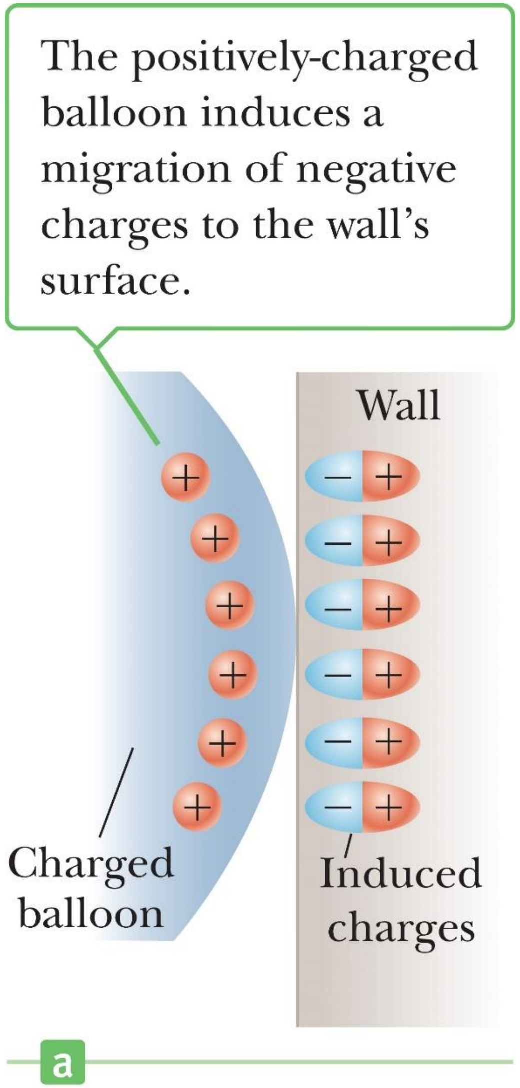
- We can then remove the ground and the sphere is now positively charged.

Charging by Induction

The remaining electrons redistribute uniformly, and there is a net uniform distribution of positive charge on the sphere's surface.



Charging by Induction



- When we think of atoms the positive charged is in the center of the atom and the negative charge is on the outside.
- However when in the presence of a field the charge distribution becomes split into a positive pole and a negative pole.
- This is called **polarization**.

Charging by Induction

A suspended object A is attracted to a neutral wall. It's also attracted to a positively-charged object B. Which of the following is true about object A?

1. It is uncharged.
2. It has a negative charge.
3. It has a positive charge.
4. It may be either charged or uncharged.

Coulomb's Law

Properties of Electric Force:

1. Directed along a line joining the two particles and inversely proportional to the square of the separation distance
2. Proportional to the product of the magnitudes of the charges of the two particles
3. Attractive if the charges are of opposite sign and repulsive if the charges have the same sign

$$F = k_e \frac{|q_1||q_2|}{r^2} \qquad k_e = 8.9875 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$$

Coulomb's Law

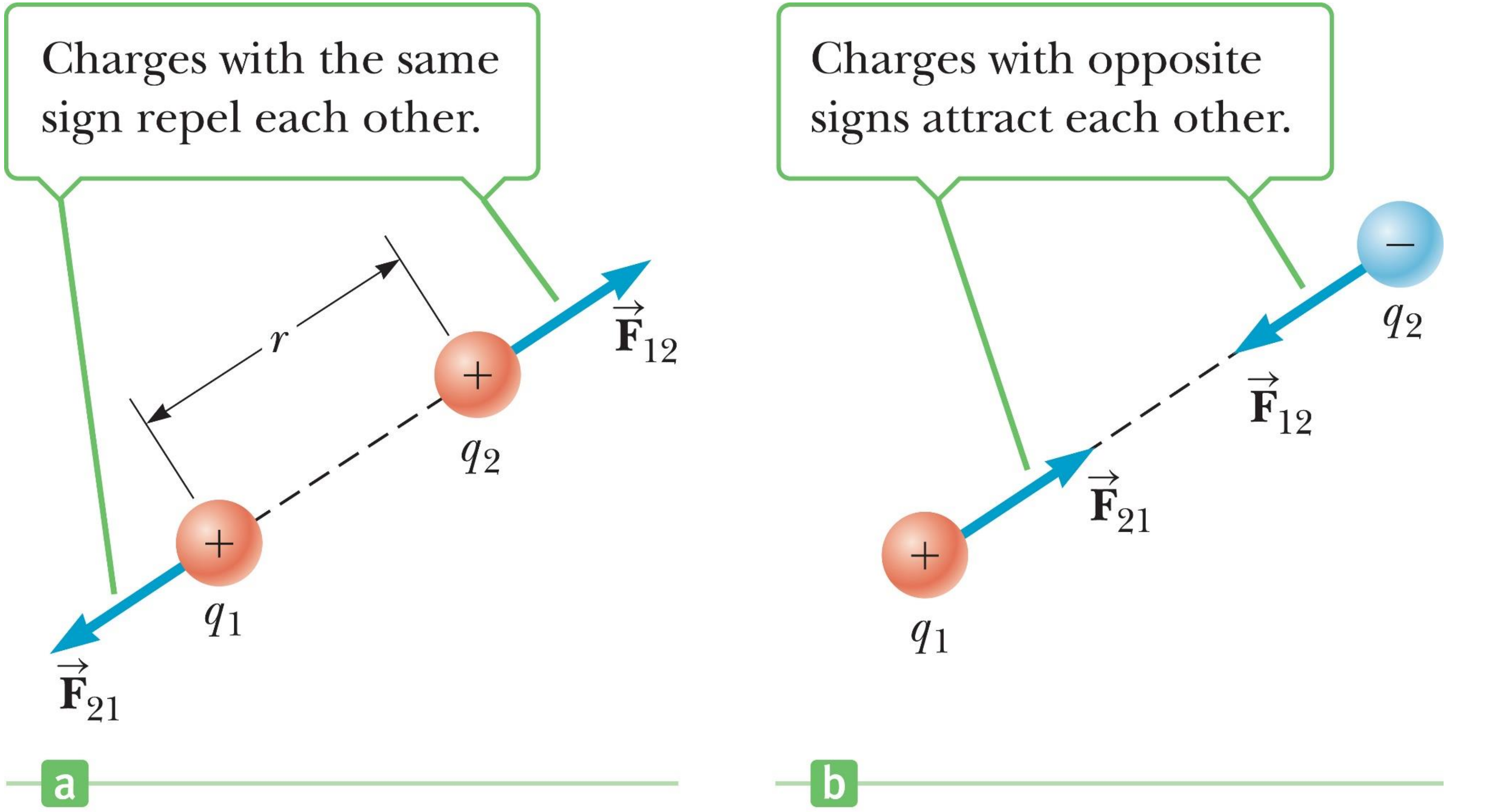
Table 15.1 Charge and Mass of the Electron, Proton, and Neutron

Particle	Charge (C)	Mass (kg)
Electron	-1.60×10^{-19}	9.11×10^{-31}
Proton	$+1.60 \times 10^{-19}$	1.67×10^{-27}
Neutron	0	1.67×10^{-27}

$$\frac{1}{e} = \frac{1 \text{ proton}}{1.6\times10^{-19}\ \text{C}} = 6.3\times10^{18}\ \text{protons}$$

It takes 6.3×10^{18} protons to equal 1 C.

Coulomb's Law



Coulomb's Law

Object A has a charge of +2 μC, and object B has a charge of +6 μC. Which statement is true?

1. $\vec{\mathbf{F}}_{AB} = -3\vec{\mathbf{F}}_{BA}$

2. $\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}$

3. $3\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}$

Coulomb's Law

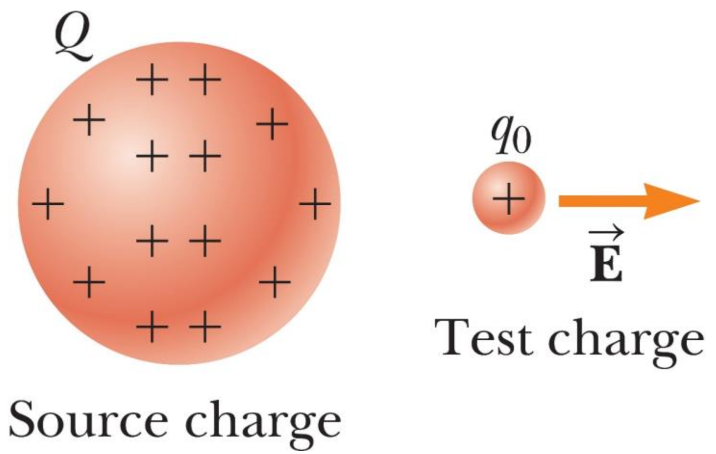
$$F = k_e \frac{|q_1||q_2|}{r^2} \qquad F_g = G\frac{m_1 m_2}{r^2}$$

1. Electric forces: attractive or repulsive; gravitational forces: always attractive

2. Electric force much stronger than gravitational force

Electric Fields

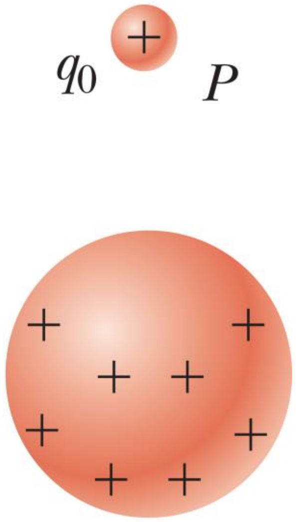
$$\vec{\mathbf{E}} \equiv \frac{\vec{\mathbf{F}}}{q_0}$$ SI unit: N/C



- When a small charge is placed near a big charge it is subjected to an electric field

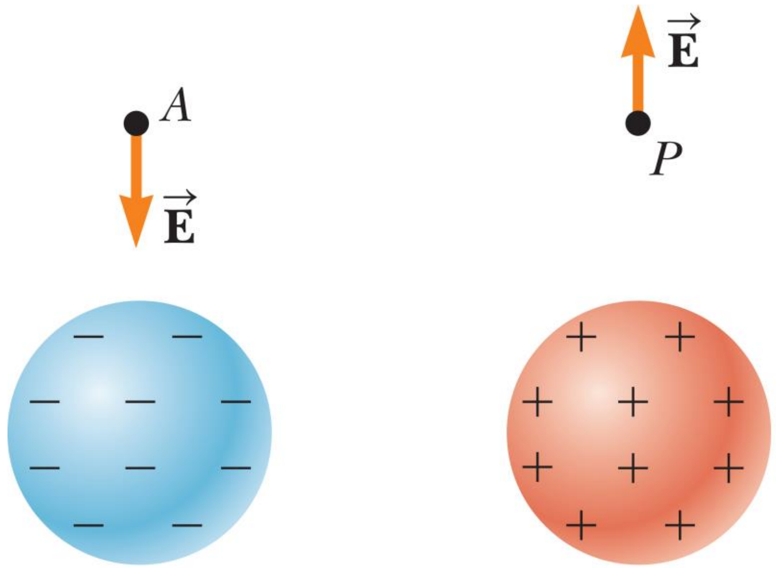
- This electric field is equal to the force vector divided by the charge of the smaller particle.

Electric Fields



- If the smaller charge is relatively the same as our big charge, then a redistribution of charge occurs in our big charge.

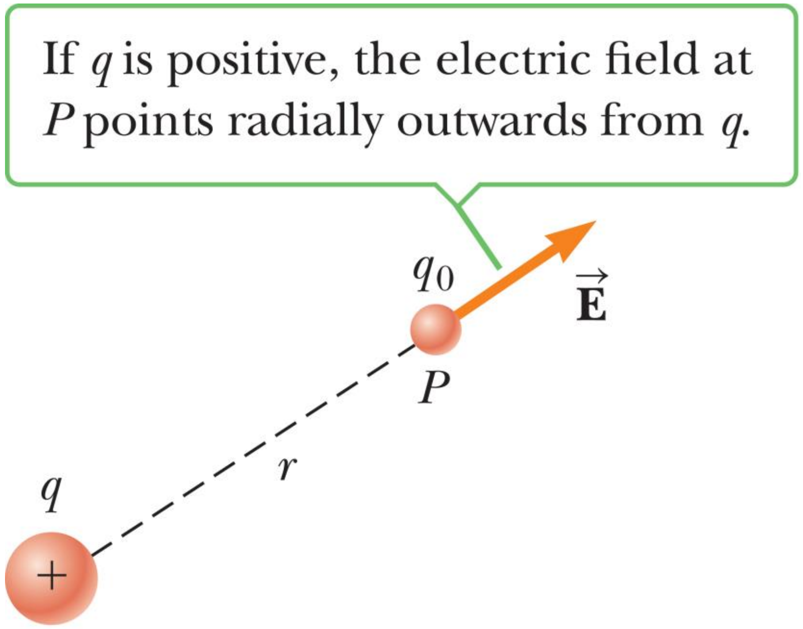
Electric Fields

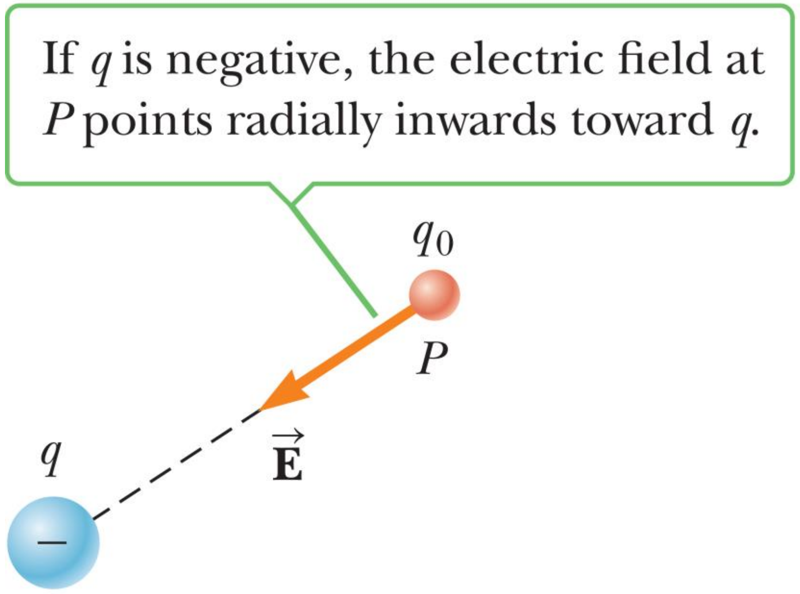


$$\vec{\mathbf{F}} = q\vec{\mathbf{E}}$$

- The direction of the electric field always points to where the charge is moving. If A is a positive charge then the directions of the fields are as shown.

Electric Fields

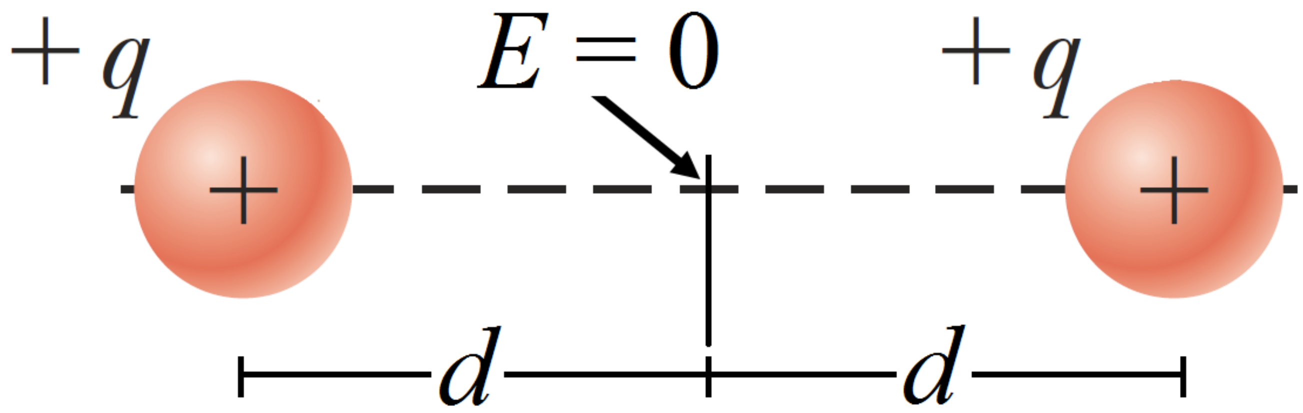




$$F = k_e \frac{|q||q_0|}{r^2}$$

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

Electric Fields



- Electric fields follow the superposition principle (CRAZY!)
- Meaning in a system with multiple source charges we can calculate the electric field induced by each charge at a point to determine the net electric field.

Electric Fields

A test charge of +3 μC is at a point *P* where the electric field due to other charges is directed to the right and has a magnitude of 4×10^6 N/C. If the test charge is replaced with a –3 μC charge, the electric field at *P*

1. has the same magnitude as before, but changes direction.
2. increases in magnitude and changes direction.
3. remains the same.
4. decreases in magnitude and changes direction.

Electric Fields

A circular ring of charge of radius b has a total charge q uniformly distributed around it. Choose the magnitude of the electric field at the center of the ring.

1. 0
2. $k_e q/b^2$
3. $k_e q^2/b^2$
4. $k_e q^2/b$
5. None of these answer choices is correct.

Electric Fields

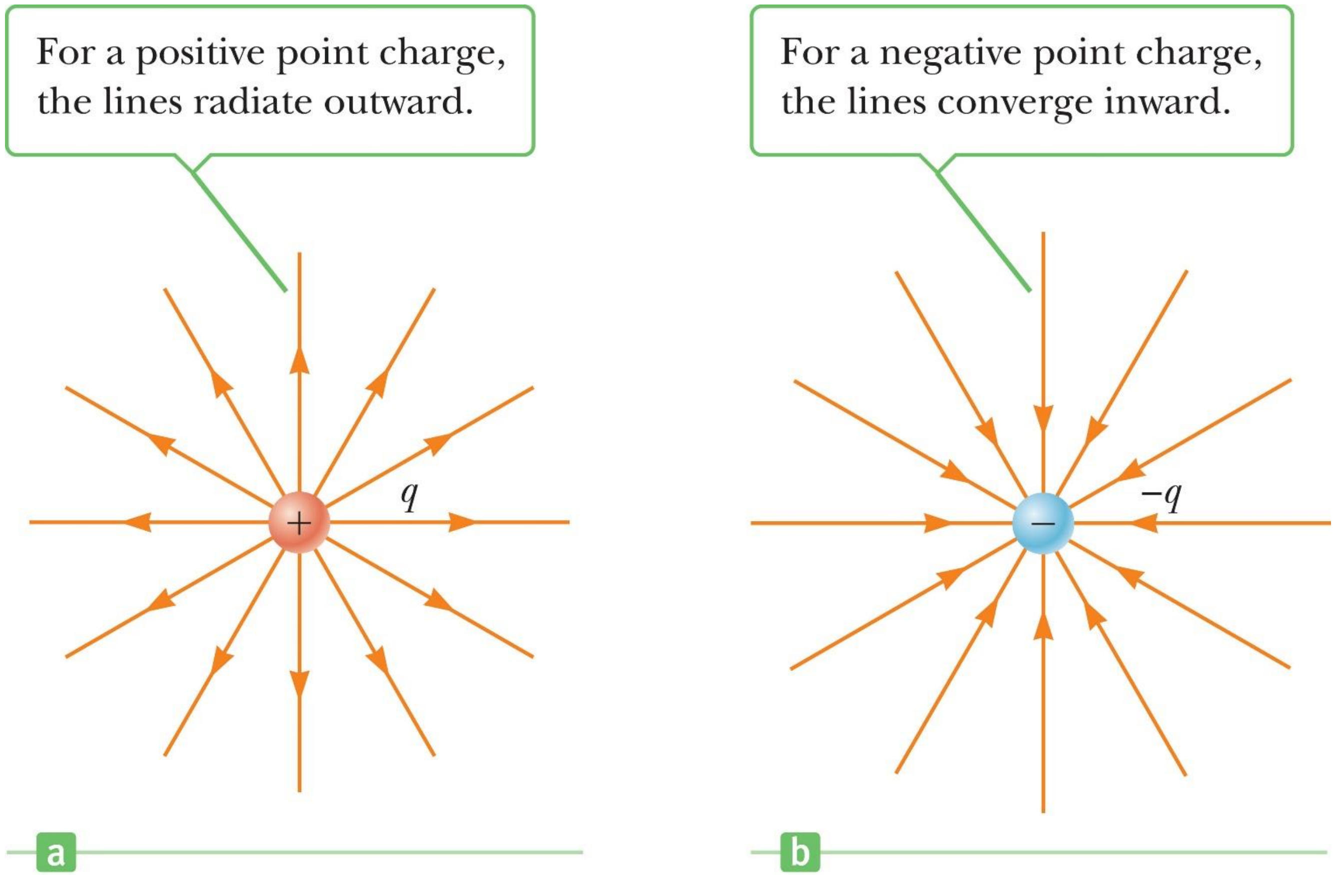
A “free” electron and a “free” proton are placed in an identical electric field. Is the following statement true or false?
Each particle is acted upon by equal-magnitude electric forces and both have the same magnitude of acceleration.

1. False
2. True

Strategy for solving Electric Field and Force problems

1. Draw
2. Identify charge
3. Convert all units
4. Apply Coulomb's law
5. Sum all the *x*-components
6. Sum all the *y*-components
7. Use the Pythagorean theorem and trigonometry

Electric Field Lines

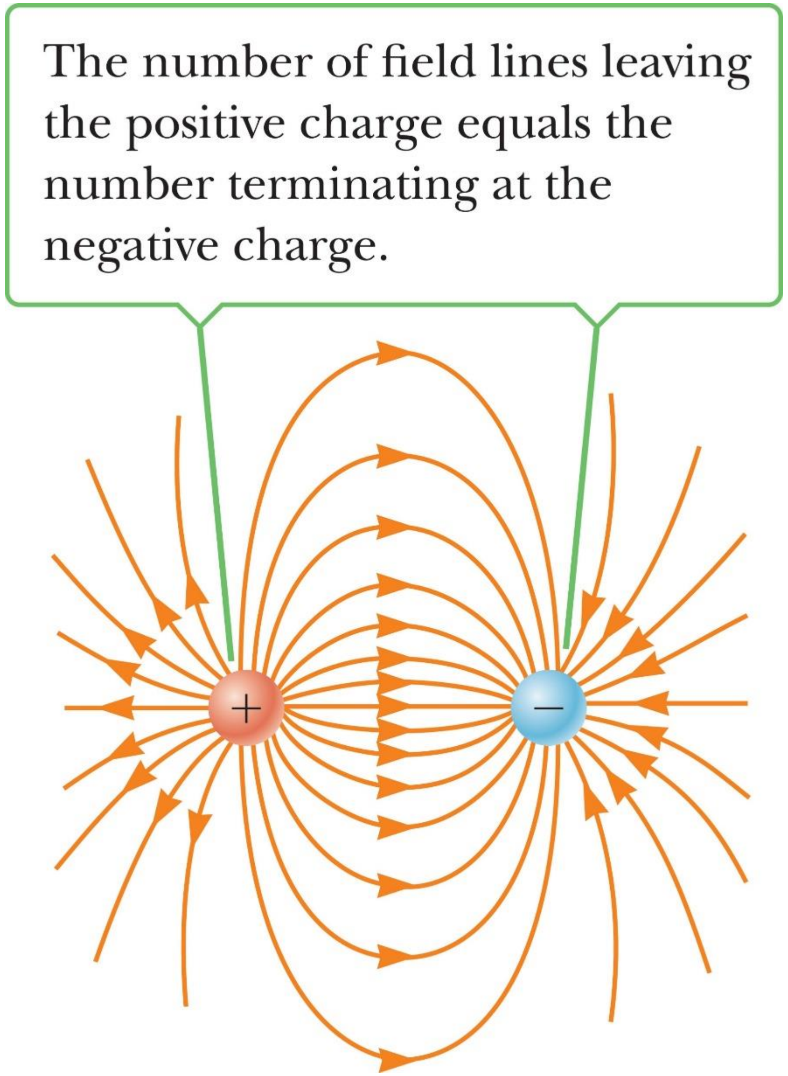


1. **E** is tangent to the electric field lines at each point
2. The number of lines proportional to the field strength

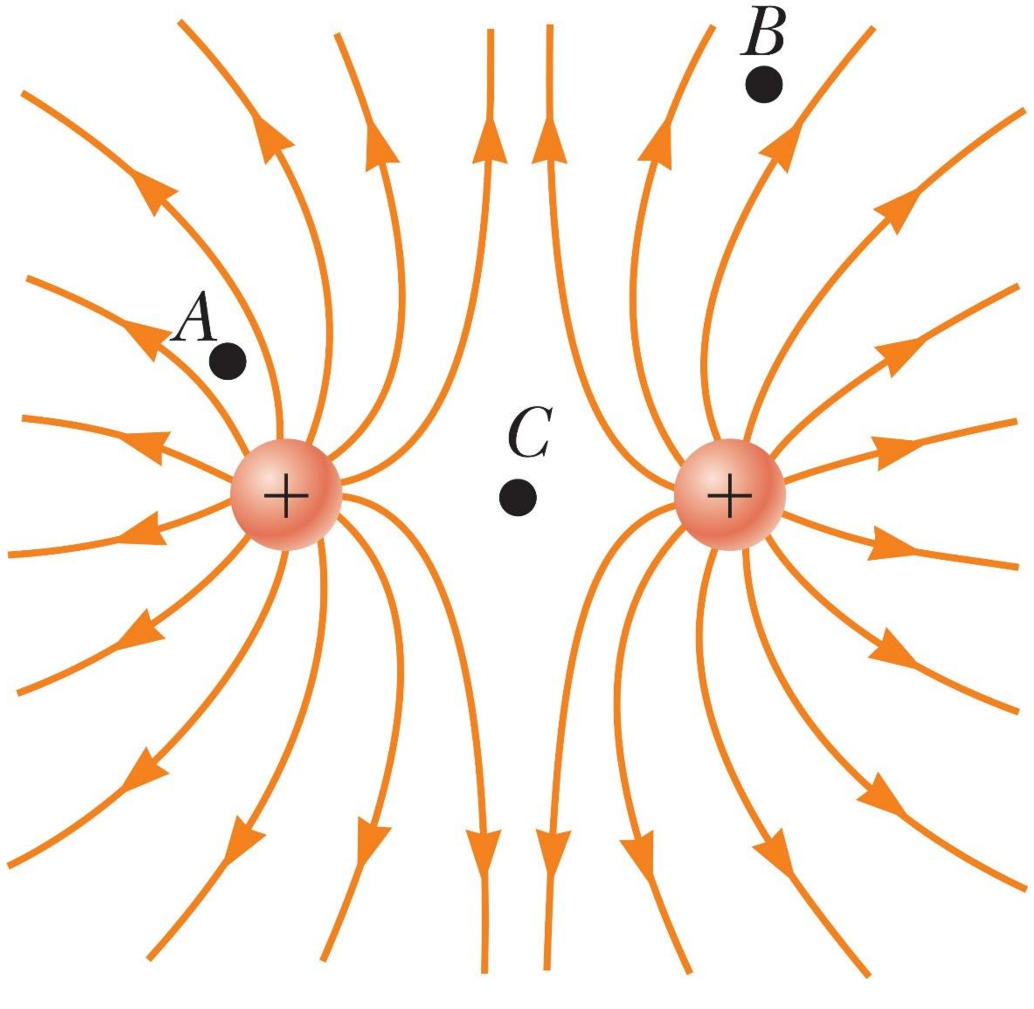
Electric Field Lines

Drawing Field Lines:

1. Lines begin on positive charges and end on negative charges
2. Number of lines is proportional to charge magnitude
3. Field lines cannot cross



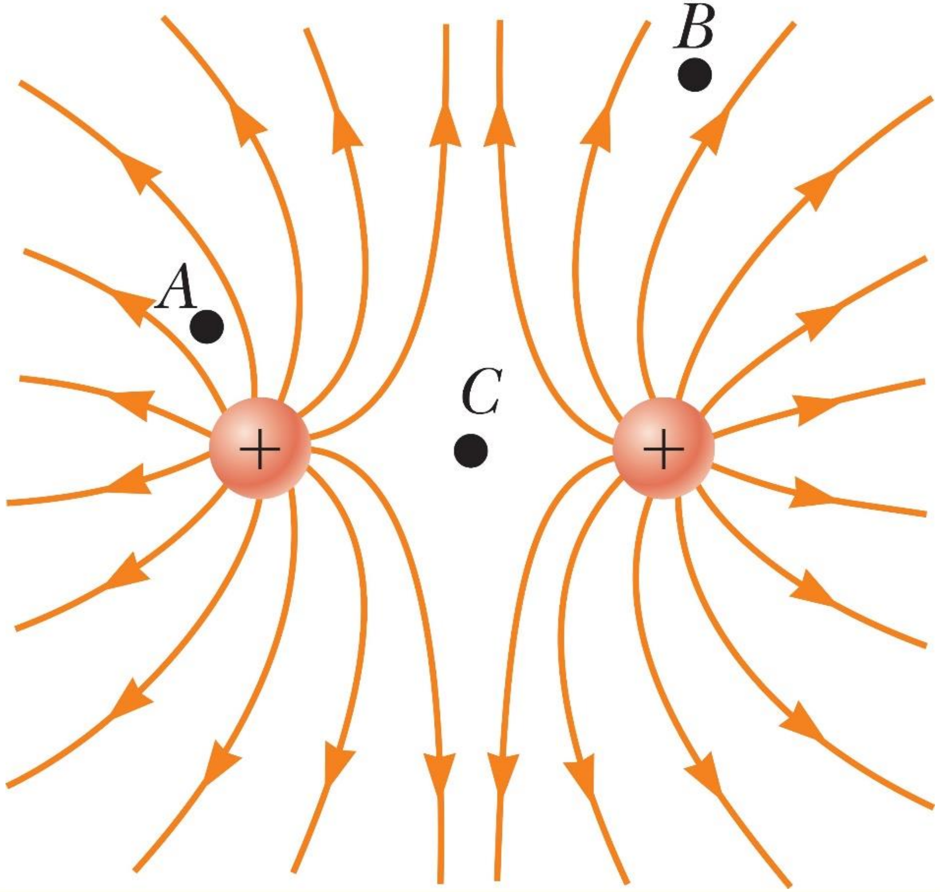
Electric Field Lines



Electric Field Lines

Rank the magnitude of the electric field at points *A*, *B*, and *C* in the figure below, largest magnitude first.

1. A, B, C
2. A, C, B
3. C, A, B
4. The answer can't be determined by visual inspection.



Conductors in Electrostatic Equilibrium

- Simply put: If the electric field is zero at every point within your conducting material then the material is said to be in electrostatic equilibrium.

Electric Flux & Guass's Law

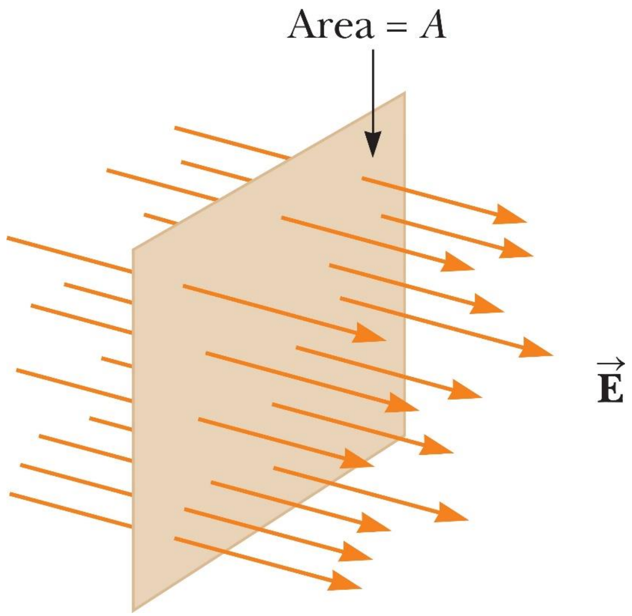
- Electric Flux is a means to describe the electric field that propagates through a surface.

- It basically let's us calculate the average electric field across a surface.

- The electric flux is proportional to the number of field lines that pass through some area A oriented perpendicular to the field.

- You multiply the Electric Field by the Area of the surface

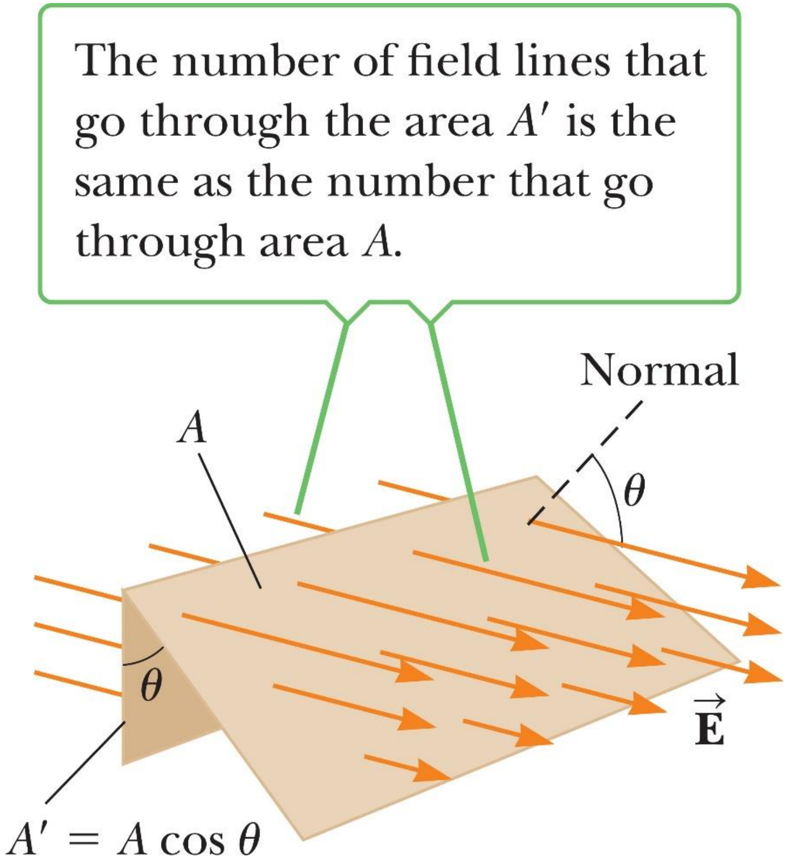
Electric Flux



$$\frac{N}{A} \propto E \rightarrow N \propto EA$$

$$\Phi_E = EA \quad \text{SI units: N} \cdot \text{m}^2/\text{C}$$

Electric Flux



$$\Phi_E = EA\cos\theta$$

Electric Flux

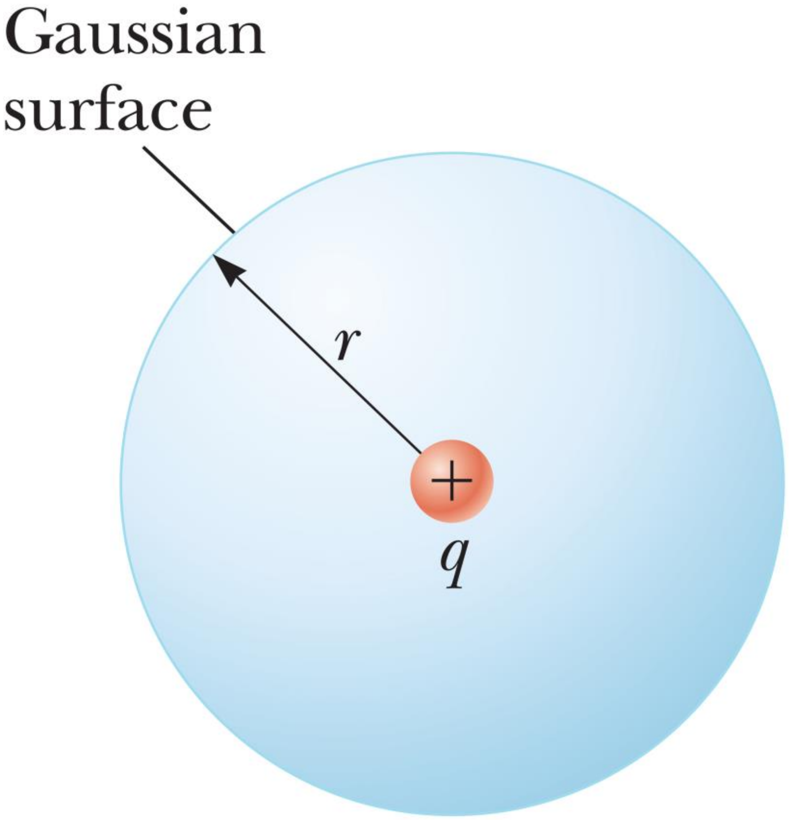
Calculate the magnitude of the flux of a constant electric field of 5.00 N/C in the z-direction, through a rectangle with area 4.00 m^2 in the xy-plane.

Electric Flux

Calculate the magnitude of the flux of a constant electric field of 5.00 N/C tilted 60° away from the positive z-direction, through a rectangle with area 4.00 m^2 in the xy-plane.

Guass's Law

- This is a law that describes the electric field that propagates through a spherical surface.



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

$$\Phi_E = EA$$

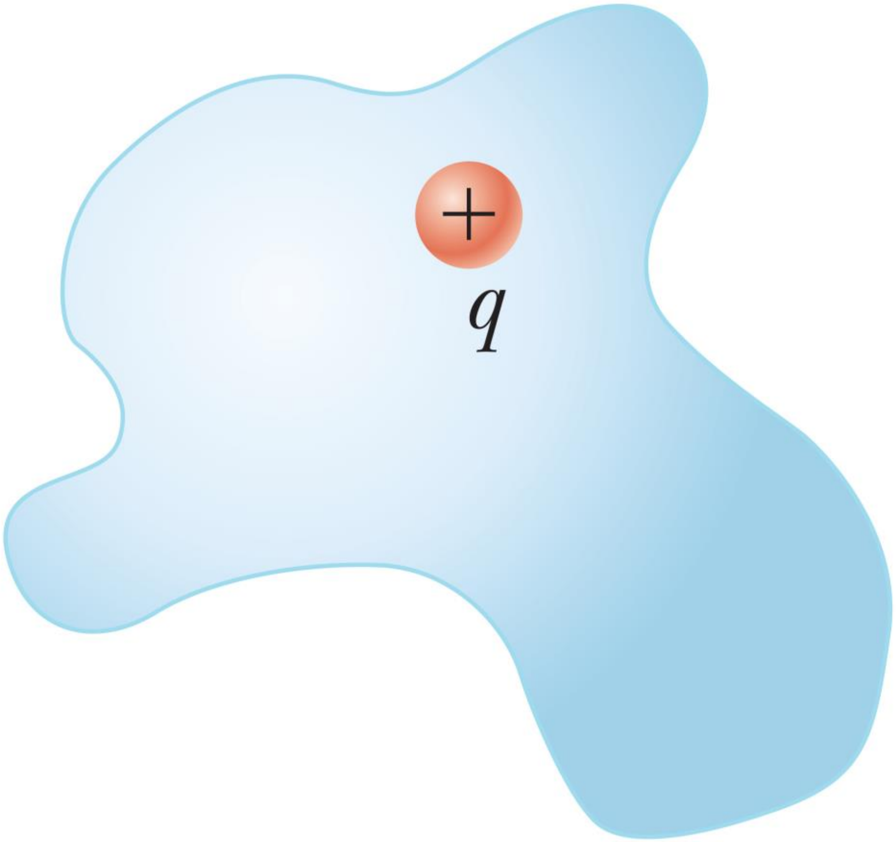
$$= k_e \frac{q}{r^2 \left(4\pi r^2\right)}$$

$$= 4\pi k_e q$$

$$k_e = \frac{1}{4\pi\varepsilon_0} \qquad \varepsilon_0 = \frac{1}{4\pi k_e} = 8.85\times10^{-12}\ \mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2$$

Guass's Law

- Main takeaway is that gauss's Law only takes into account charges on the inside of our surface.

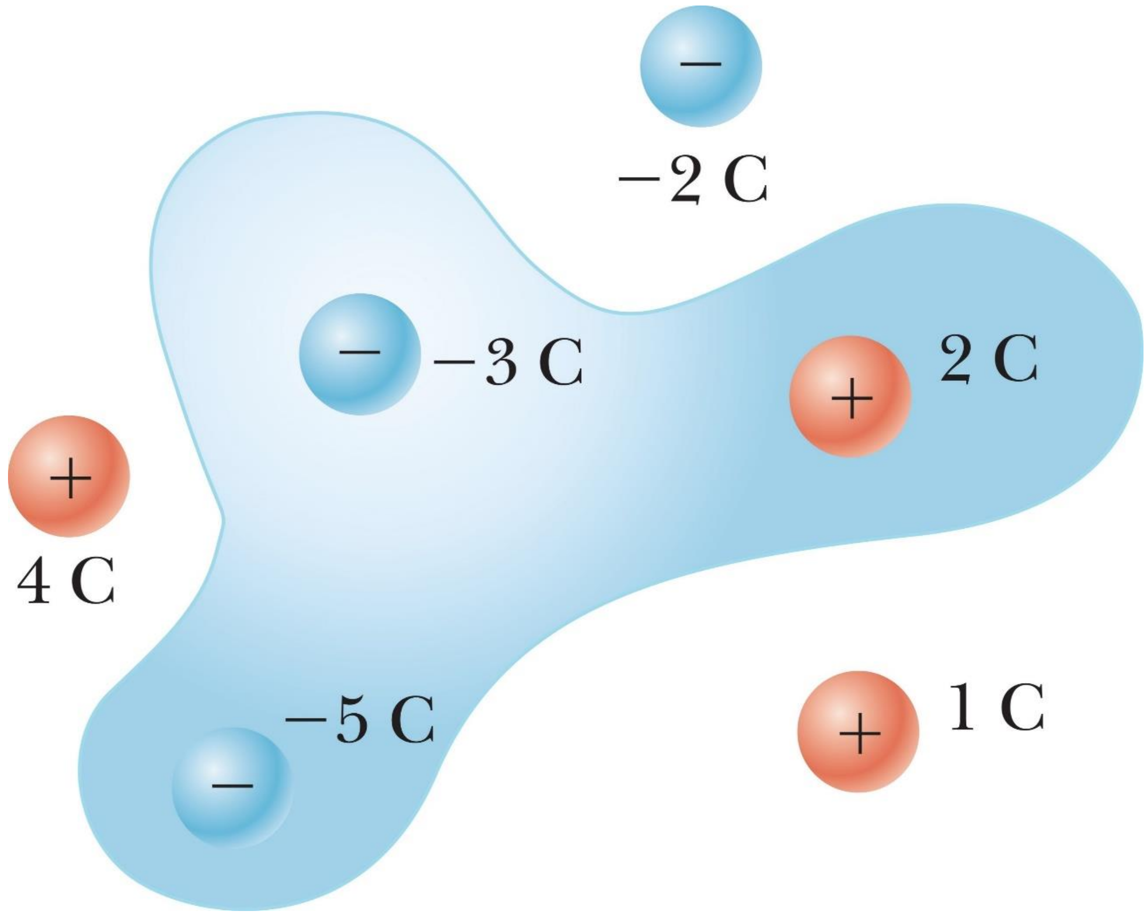


$$\Phi_E = 4\pi k_e q = \frac{q}{\varepsilon_0}$$

$$\Phi_E = \frac{Q_{\text{inside}}}{\varepsilon_0}$$

Guass’s Law

Find the electric flux through the surface in the figure below.



Guass's Law

For a closed surface through which the net flux is zero, each of the following four statements *could* be true. Which of the statements *must* be true? (There may be more than one.)
(a) There are no charges inside the surface.
(b) The net charge inside the surface is zero.
(c) The electric field is constant everywhere on the surface.
(d) The number of electric field lines entering the surface equals the number leaving the surface.

1. (a) only
2. (b) only
3. (b) and (d)
4. (a) and (d)

Guass's Law

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3. (b) and (d)
4. (a) and (d)

Summary

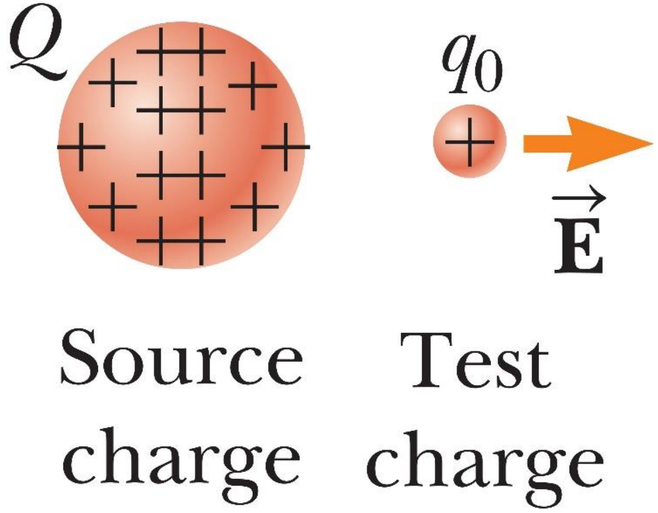
- **Electric Charges, Insulators, and Conductors**

- **Coulomb's Law**

$$F = k_e \frac{|q_1||q_2|}{r^2} \qquad k_e \approx 8.99 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$$

- **Electric Fields**

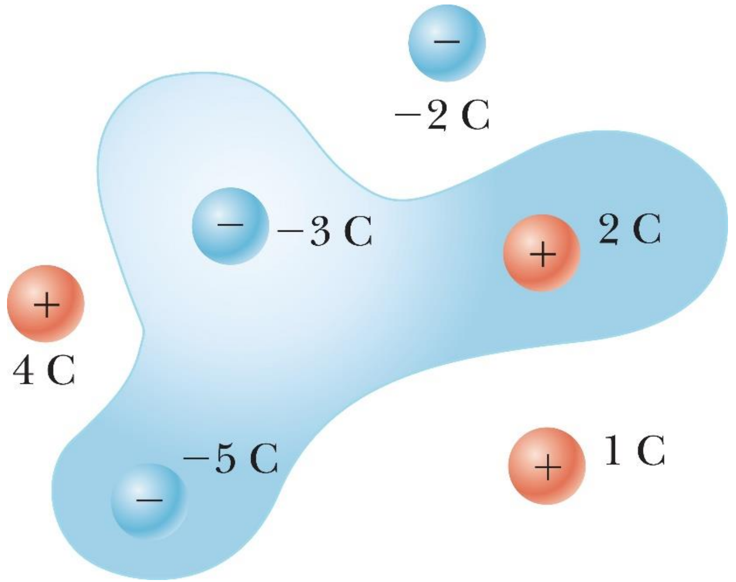
$$\vec{\mathbf{E}} \equiv \frac{\vec{\mathbf{F}}}{q_0} \qquad E = k_e \frac{|q_1|}{r^2}$$



Summary

- **Electric Field Lines**
- **Conductors in Electrostatic Equilibrium**
- **Electric Flux and Gauss's Law**

$$EA = \Phi_E = \frac{Q_{\text{inside}}}{\varepsilon_0}$$



Applied Practice

A 7.50-nC charge is located 1.80 m from a 4.20-nC charge. (a) Find the magnitude of the electrostatic force that one particle exerts on the other. (b) Is the force attractive or repulsive?

Applied Practice

A small sphere of mass m = 7.50 g and charge q_1 = 32.0 nC is attached to the end of a string and hangs vertically. A second charge of equal mass and charge q_2 = -58.0 nC is located below the first charge a distance d = 2.00cm below the first charge. (a) Find the tension in the string. (b) If the string can withstand a maximum tension of 0.180 N, what is the smallest value d can have before the string breaks?

Applied Practice

Two small identical conducting spheres are placed with their centers 0.30 m apart. One is given a charge of 12×10^{-9} C and the other a charge of -18×10^{-9} C. (a) Find the electrostatic force exerted on one sphere by the other. (b) The spheres are connected by a conducting wire. Find the electrostatic force between the two after equilibrium is reached, where both spheres have the same charge.

Applied Practice

Who wants to bet?

Particle A of charge 2.00 x 10^{-4} C is at the origin. Particle B of charge -6.00 x 10^{-4} is at (4.00m, 0). Particle C of charge 1.00 X 10^{-4} C is at (0,3.00m). Find the resultant electrostatic force vector of Particle A.

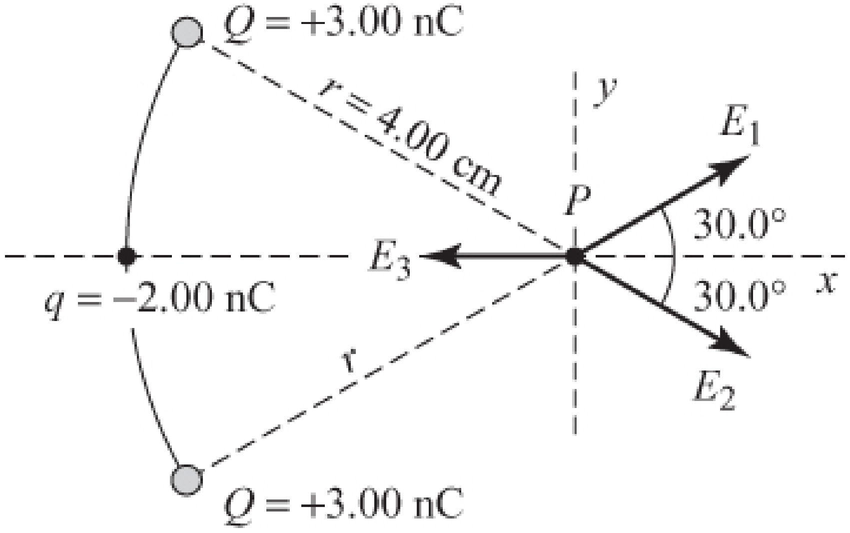
Applied Practice

An electron is accelerated by a constant electric field of magnitude 300N/C. (a) Find the acceleration of the electron. (b) what is the velocity of the electron after 1.00×10^{-8} seconds, assuming it started from rest.

Mass of electron = 9.11×10^{-31} kg

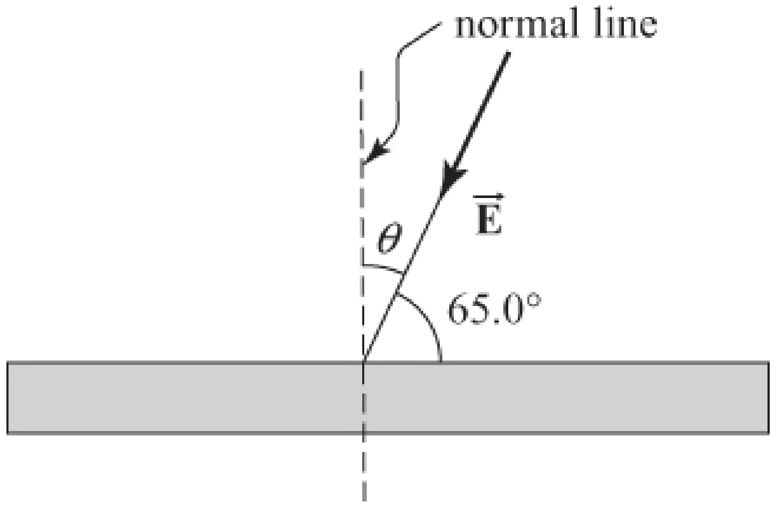
Applied Practice

Three point charges are located on a circular arc as shown. What is the total electric field at P, The center of the arc?



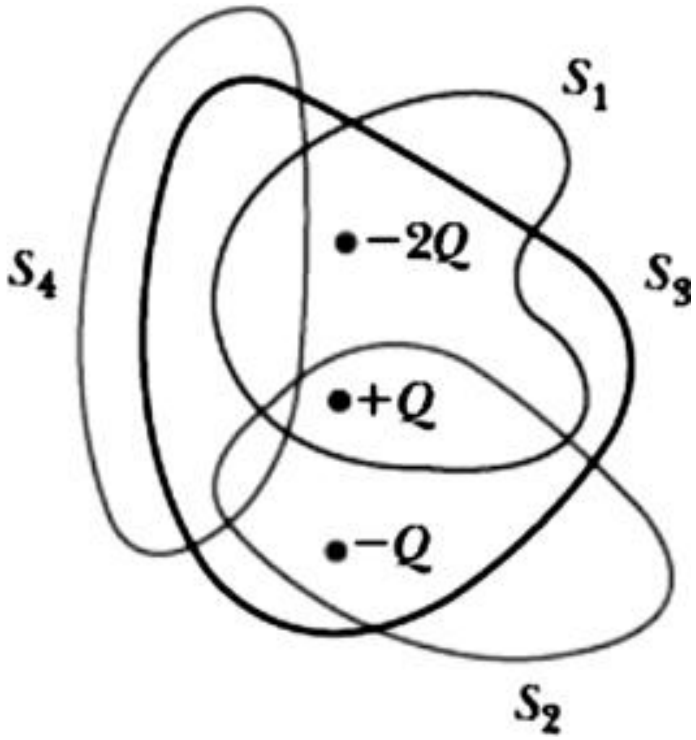
Applied Practice

A uniform electric field of magnitude E = 435 N/C makes an angle of 65.0^0 with a plane surface of area A = 3.50 m^2. Find the electric flux through the surface.



Applied Practice

Four closed surfaces, S_1 through S_4, together with the charges -2Q, Q, and -Q are sketched in the figure. Find the electric flux through each surface.



AP Physics

Chapter 15: Electric Forces and Fields

HW: Pg 521 – 525

Problems: 2,5,8,11,15,22,23,25,30,32,34,45

Win bet: Take away #8
Loose bet: Better do all the problems