GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

PRESIDENCY UNIVERSITY

Coulomb’s Law & Electric Field

Learning Objectives

- ✓ Explain Coulomb’s law in electro statics
- ✓ Use Coulomb’s law to calculate the electric field of a given charge distribution

Electrostatics

Electrostatics, is the study of stationary electric charges.

A rod of plastic rubbed with fur or a rod of glass rubbed with silk will attract small pieces of paper and is said to be electrically charged.

The charge on plastic rubbed with fur is defined as negative, and the charge on glass rubbed with silk is defined as positive.

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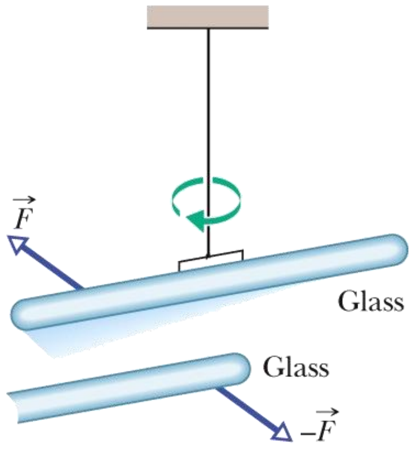
The charge on plastic rubbed with fur is defined as **negative**, and the charge on glass rubbed with silk is defined as **positive**.

Electric charge

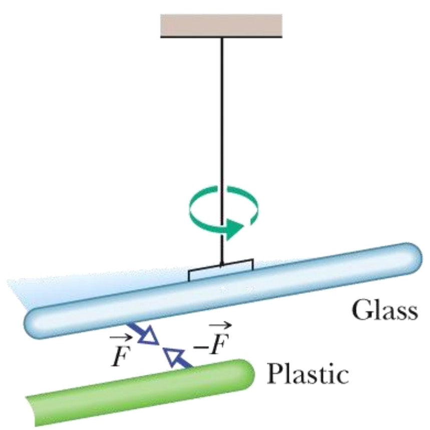
Electrically charged objects have several important characteristics:

- Like charges repel one another; that is, positive repels positive and negative repels negative.
- Unlike charges attract each another; that is, positive attracts negative.
- Charge is conserved. A neutral object has no net charge. If the plastic rod and fur are initially neutral, when the rod becomes charged by the fur, a negative charge is transferred from the fur to the rod. The net negative charge on the rod is equal to the net positive charge on the fur.

Properties of Electric Charges



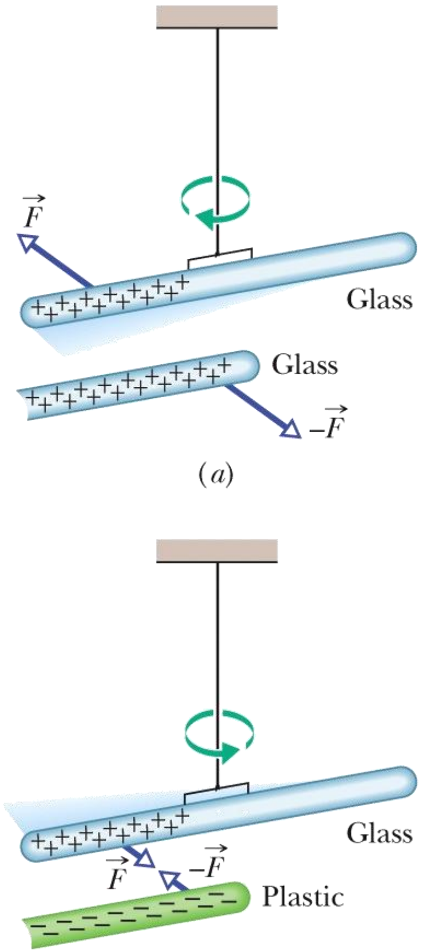
(*a*)



(a) The two glass rods each rubbed with a silk cloth and one was suspended by thread. When they are close to each other, they repel each other.

(b) The plastic rod was rubbed with fur. When brought close to the glass rod, the rods attract each other.

Properties of Electric Charges cont..



(a) Two charged rods of the same sign repel each other.

(b) Two charged rods of opposite signs attract each other. Plus signs indicate a positive net charge, and minus signs indicate a negative net charge.

Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

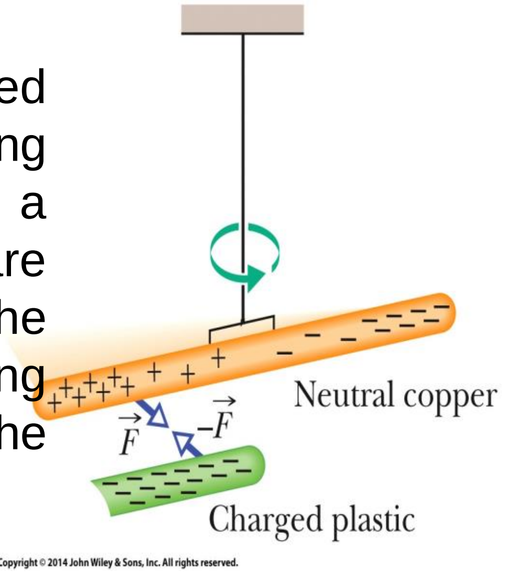
Materials classified based on their ability to move charge

- **Conductors** are materials in which a significant number of electrons are free to move. Examples include metals.
- The charged particles in nonconductors (**insulators**) are not free to move. Examples include rubber, plastic, glass.
- **Semiconductors** are materials that are intermediate between conductors and insulators; examples include silicon and germanium in computer chips.
- **Superconductors** are materials that are perfect conductors, allowing charge to move without any hindrance.

CONDUCTION ELECTRONS AND INDUCED CHARGES

- **Charged Particles.** The properties of conductors and insulators are due to the structure and electrical nature of atoms. Atoms consist of positively charged *protons*, negatively charged *electrons*, and electrically neutral *neutrons*. The protons and neutrons are packed tightly together in a central nucleus and do not move.
- When atoms of a conductor like copper come together to form the solid, some of their outermost—and so most loosely held—electrons become free to wander about within the solid, leaving behind positively charged atoms (positive ions). We call the mobile electrons **conduction electrons**. There are few (if any) free electrons in a nonconductor.

Induced Charge. A neutral copper rod is electrically isolated from its surroundings by being suspended on a non-conducting thread. Either end of the copper rod will be attracted by a charged rod. Here, conduction electrons in the copper rod are repelled to the far end of that rod by the negative charge on the plastic rod. Then that negative charge attracts the remaining positive charge on the near end of the copper rod, rotating the copper rod to bring that near end closer to the plastic rod.



Charging by Induction

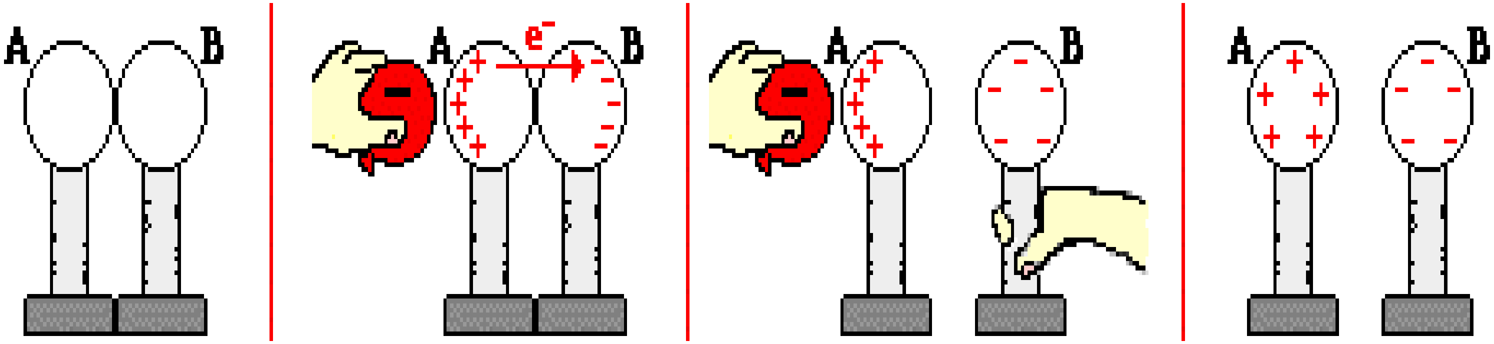


Diagram i.

Two metal spheres are mounted on insulating stands.

Diagram ii.

The presence of a – charge induces e^- to move from sphere A to B. The two-sphere system is polarized.

Diagram iii.

Sphere B is separated from sphere A using the insulating stand. The two spheres have opposite charges.

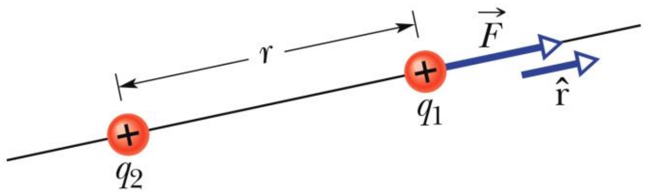
Diagram iv.

The excess charge distributes itself uniformly over the surface of the spheres.

Coulomb's Law

Coulomb's law describes the **electrostatic force** (or electric force) between two charged particles. If the particles have charges q_1 and q_2, are separated by distance r, and are at rest (or moving only slowly) relative to each other, then the magnitude of the force acting on each due to the other is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2} \quad \text{(Coulomb's law)},$$



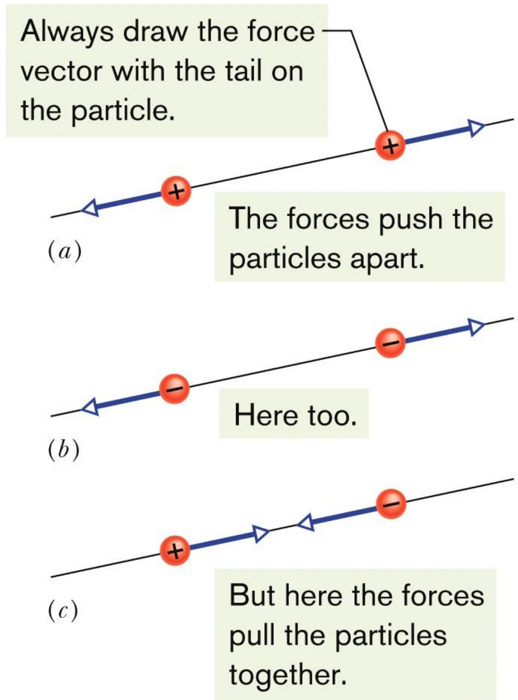
The electrostatic force on particle 1 can be described in terms of a unit vector ***r*** along an axis through the two particles, radially away from particle 2.

where $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N.m^2$ is the permittivity constant. The ratio $1/4\pi\varepsilon_0$ is often replaced with the electrostatic constant (or Coulomb constant) $k = 8.99\times10^9\ N.m^2/C^2$. Thus $k = 1/4\pi\varepsilon_0$.

Coulomb's Law cont…

- The electrostatic force vector acting on a charged particle due to a second charged particle is either directly toward the second particle (opposite signs of charge) or directly away from it (same sign of charge).

- If multiple electrostatic forces act on a particle, the net force is the vector sum (not scalar sum) of the individual forces.



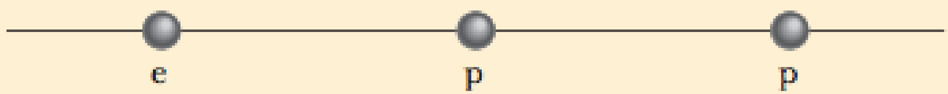
Two charged particles repel each other if they have the same sign of charge, either (a) both positive or (b) both negative. (c) They attract each other if they have opposite signs of charge.

Coulomb’s Law cont…

Multiple Forces: If multiple electrostatic forces act on a particle, the net force is the vector sum (not scalar sum) of the individual forces.

$$\vec{F}_{1,\text{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n},$$

Checkpoint 2



The figure shows two protons (symbol p) and one electron (symbol e) on an axis. On the central proton, what is the direction of (a) the force due to the electron, (b) the force due to the other proton, and (c) the net force?

Answer: (a) left towards the electron
(b) left away from the other proton
(c) left

Charge is Quantized

- Electric charge is quantized (restricted to certain values).

- The charge of a particle can be written as ne, where *n* is a positive or negative integer and *e* is the elementary charge. Any positive or negative charge *q* that can be detected can be written as

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots,$$

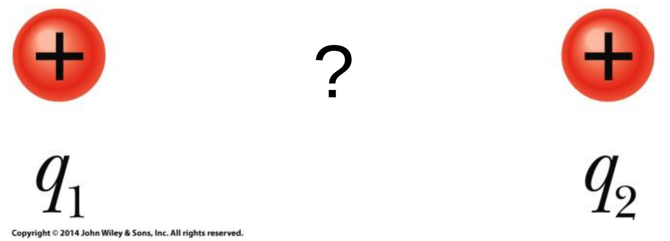
in which *e*, the elementary charge, has the approximate value

$$e = 1.602 \times 10^{-19}\ \mathrm{C}.$$

Table 21-1 The Charges of Three Particles

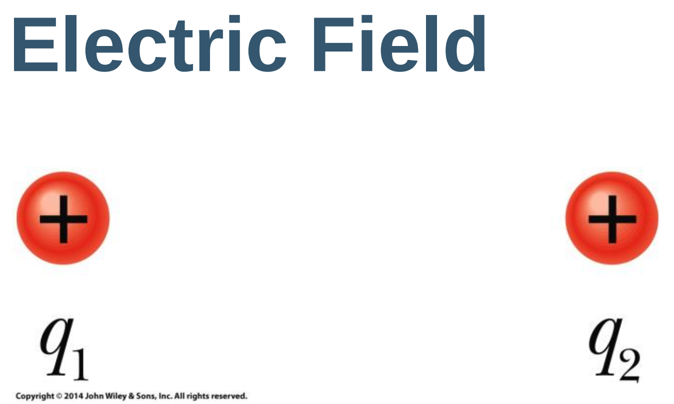
Particle	Symbol	Charge
Electron	e or e^-	$-e$
Proton	p	$+e$
Neutron	n	0

The Electric Field



How does particle 1 “know” of the presence of particle 2? That is, since the particles do not touch, how can particle 2 push on particle 1—how can there be such an action at a distance?

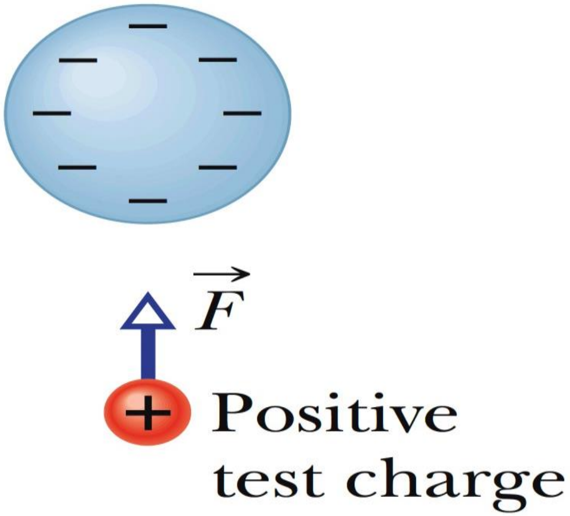
The Electric Field



The explanation that we shall examine here is this: Particle 2 sets up an electric field at all points in the surrounding space, even if the space is a vacuum. If we place particle 1 at any point in that space, particle 1 knows of the presence of particle 2 because it is affected by the electric field particle 2 has already set up at that point. Thus, particle 2 pushes on particle 1 not by touching it as you would push on a coffee mug by making contact. Instead, particle 2 pushes by means of the electric field it has set up.

The Electric Field cont….

Electric Field definition



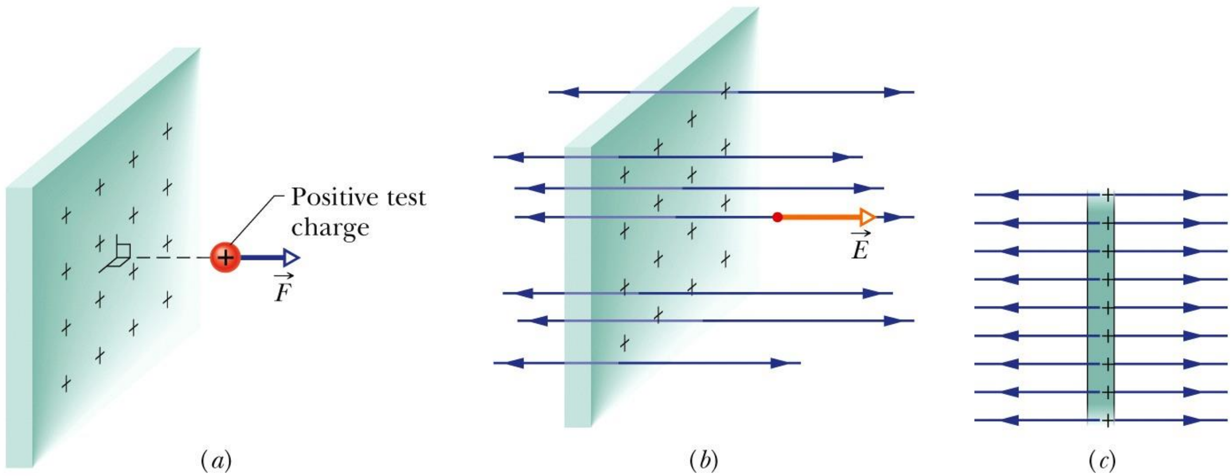
a region around a charged particle or object within which a force would be exerted on other charged particles or objects.

The electric field ***E*** at any point is defined in terms of the electrostatic force ***F*** that would be exerted on a positive test charge q_0 placed there:

$$\vec{E} = \frac{\vec{F}}{q_0}$$

The Electric Field Lines

Electric field lines help us visualize the direction and magnitude of electric fields. The electric field vector at any point is tangent to the field line through that point. The density of field lines in that region is proportional to the magnitude of the electric field there.



(a) The force on a positive test charge near a very large, non-conducting sheet with uniform positive charge on one side. (b) The electric field vector ***E*** at the test charge's location, and the nearby electric field lines, extending away from the sheet. (c) Side view.

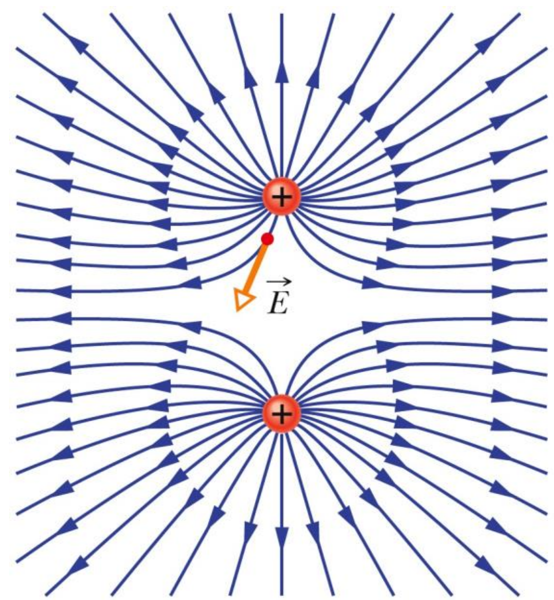
Properties of Electric Field Lines

Electric field lines extend away from positive charge (where they originate) and toward negative charge (where they terminate).

(1) The electric field vector at any given point must be tangent to the field line at that point and in the same direction, as shown for one vector.

(2) A closer spacing means a larger field magnitude.

(3) No two field lines can cross each other.

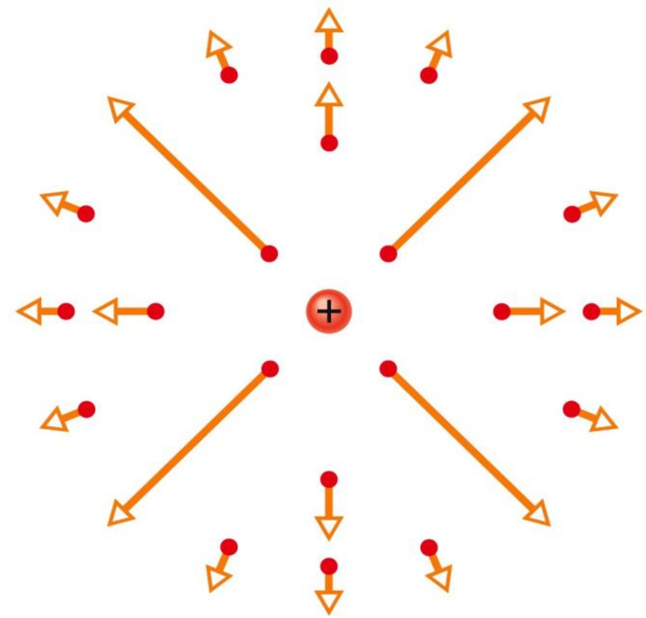


Field lines for two particles with equal positive charge. Doesn't the pattern itself suggest that the particles repel each other?

The Electric Field Due to a Charged Particle

To find the electric field due to a point charge q (or charged particle) at any point a distance r from the point charge, we put a positive test charge q_0 at that point. From Coulomb's law the electrostatic force acting on q_0 is

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\,\hat{\mathrm{r}}\,.$$

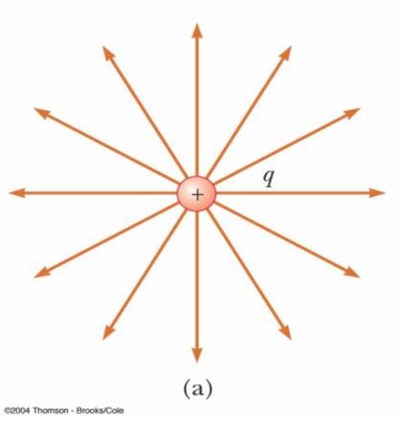


The electric field vectors at various points around a positive point charge.

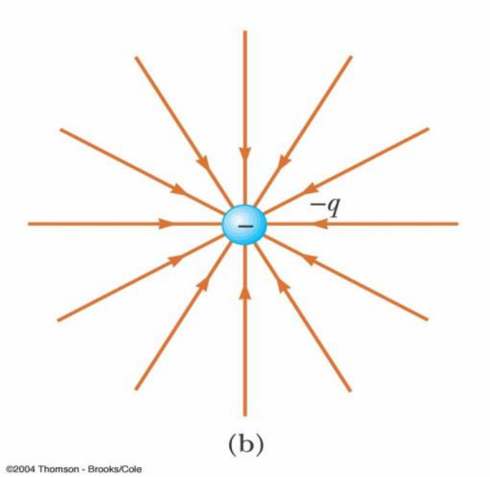
Therefore electric field is

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{\mathrm{r}}$$

The **electric field vectors** set up by a positively charged particle all point directly away from the particle. Those set up by a negatively charged particle all point directly toward the particle.



If more than one charged particle sets up an electric field at a point, the net electric field is the vector **sum** of the individual electric fields—**electric fields obey the superposition principle**.



$$\vec{E} = \frac{\vec{F}_0}{q_0} = \frac{\vec{F}_{01}}{q_0} + \frac{\vec{F}_{02}}{q_0} + \cdots + \frac{\vec{F}_{0n}}{q_0}$$
$$= \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n.$$

Summary

Electric Charge

- The strength of a particle's electrical interaction with objects around it depends on its electric charge, which can be either positive or negative.

Conductors and Insulators

- Conductors are materials in which a significant number of electrons are free to move. The charged particles in nonconductors (insulators) are not free to move.

Conservation of Charge

- The net electric charge of any isolated system is always conserved.

Coulomb's Law

- The magnitude of the electrical force between two charged particles is proportional to the product of their charges and inversely proportional to the square of their separation distance.
- . $$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2}$$

The Elementary Charge

- Electric charge is quantized (restricted to certain values).
- *e* is the elementary charge

$$e = 1.602 \times 10^{-19}\ \mathrm{C}.$$

Summary

Definition of Electric Field

- The electric field at any point

$$\vec{E} = \frac{\vec{F}}{q_0}.$$

Electric Field Lines

- provide a means for visualizing the directions and the magnitudes of electric fields

Field due to a Point Charge

- The magnitude of the electric field ***E*** set up by a point charge *q* at a distance *r* from the charge is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}.$$