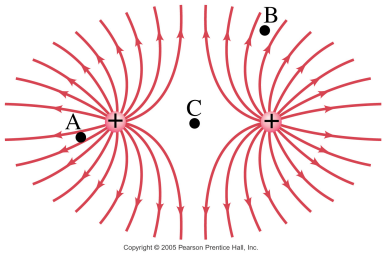
Chapter 21 & 22

Electric Charge and Electric Field; Gauss's



Units of Chapter 21

- Static Electricity; Electric Charge and Its Conservation
- Electric Charge in the Atom
- Insulators and Conductors
- Induced Charge; the Electroscope
- Coulomb's Law
- Solving Problems Involving Coulomb's Law and Vectors
- The Electric Field

Units of Chapter 21 & 22

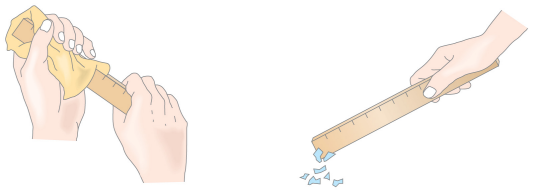
- Field Lines
- Electric Fields and Conductors

Chaper 22

- Electric Flux
- Gauss's Law
- Electric Forces in Molecular Biology: DNA Structure and Replication

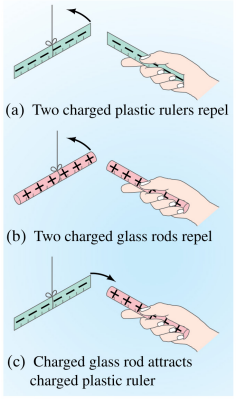
21.1 Static Electricity; Electric Charge and Its Conservation

Objects can be charged by rubbing



(a) (b)

21.1 Static Electricity; Electric Charge and Its Conservation



(a) Two charged plastic rulers repel

(b) Two charged glass rods repel

(c) Charged glass rod attracts charged plastic ruler

Charge comes in two types, positive and negative; like charges repel and opposite charges attract

21.1 Static Electricity; Electric Charge and Its Conservation

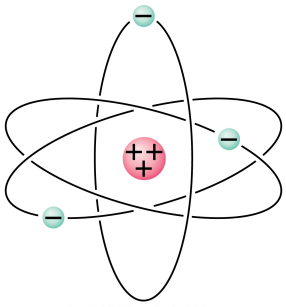
Electric charge is conserved – the arithmetic sum of the total charge cannot change in any interaction.

21.2 Electric Charge in the Atom

Atom:

Nucleus (small, massive, positive charge)

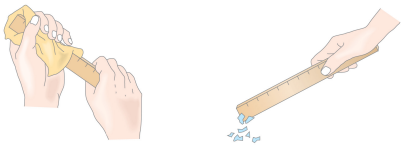
Electron cloud (large, very low density, negative charge)



21.2 Electric Charge in the Atom

Atom is electrically neutral.

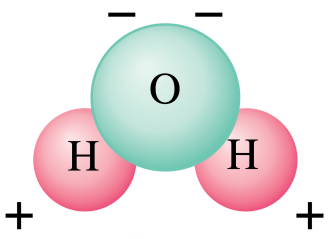
Rubbing charges objects by moving electrons from one to the other.



(a) (b)

21.2 Electric Charge in the Atom

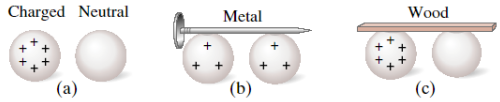
Polar molecule: neutral overall, but charge not evenly distributed



21.3 Insulators and Conductors

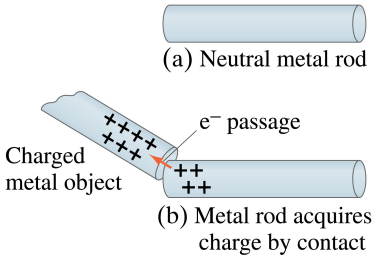
Conductor:	Insulator:
Charge flows freely	Almost no charge flows
Metals	Most other materials

Some materials are semiconductors.



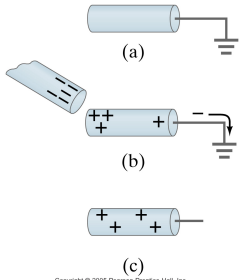
21.4 Induced Charge; the Electroscope

Metal objects can be charged by conduction:



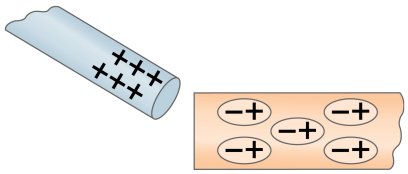
21.4 Induced Charge; the Electroscope

They can also be charged by induction:



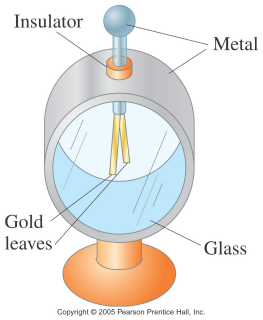
21.4 Induced Charge; the Electroscope

Nonconductors won't become charged by conduction or induction, but will experience charge separation:



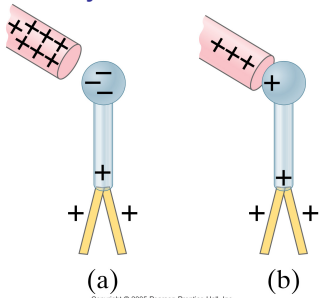
21.4 Induced Charge; the Electroscope

The electroscope can be used for detecting charge:



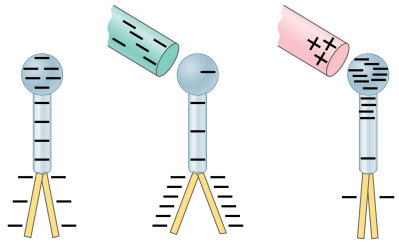
21.4 Induced Charge; the Electroscope

The electroscope can be charged either by conduction or by induction.



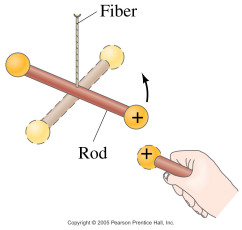
21.4 Induced Charge; the Electroscope

The charged electroscope can then be used to determine the sign of an unknown charge.



21.5 Coulomb's Law

Experiment shows that the electric force between two charges is proportional to the product of the charges and inversely proportional to the distance between them.



21.5 Coulomb's Law

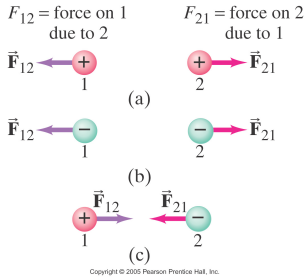
Coulomb's law:

$$F = k\frac{Q_1 Q_2}{r^2}$$

This equation gives the magnitude of the force.

21.5 Coulomb's Law

The force is along the line connecting the charges, and is attractive if the charges are opposite, and repulsive if they are the same.



21.5 Coulomb's Law

Unit of charge: coulomb, C

The proportionality constant in Coulomb's law is then:

$$k = 8.988 \times 10^9\ \mathrm{N \cdot m^2/C^2}$$

Charges produced by rubbing are typically around a microcoulomb:

$$1\ \mu\mathrm{C} = 10^{-6}\ \mathrm{C}$$

21.5 Coulomb's Law

Charge on the electron:

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

Electric charge is quantized in units of the electron charge.

21.5 Coulomb's Law

The proportionality constant k can also be written in terms of ϵ_0, the permittivity of free space:

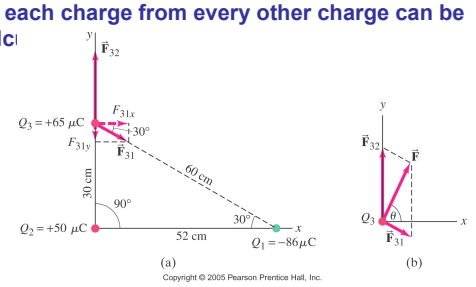
$$F = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}$$

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2}$$

21.5 Coulomb's Law

Coulomb's law strictly applies only to point charges.

Superposition: for multiple point charges, the forces on each charge from every other charge can be calc



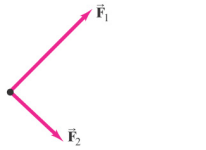
21.5 Solving Problems Involving Coulomb's Law and Vectors

The net force on a charge is the vector sum of all the forces acting on it.

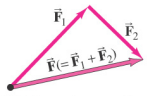
$$\vec{\mathbf{F}}_{\mathrm{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \cdots$$

21.5 Solving Problems Involving Coulomb's Law and Vectors

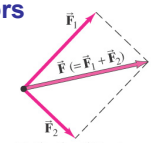
Vector addition review:



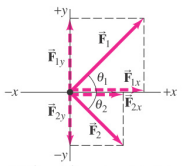
(a) Two forces acting on an object.



(b) The total, or net, force is $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the tail-to-tip method of adding vectors.



(c) $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the parallelogram method.

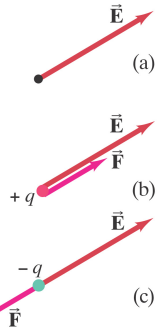


(d) $\vec{F}_1$ and $\vec{F}_2$ resolved into their x and y components.

21.6 The Electric Field

The electric field is the force on a small charge, divided by the charge:

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



21.6 The Electric Field

For a point charge:

$$E = k\frac{Q}{r^2}$$

$$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$

21.6 The Electric Field

Force on a point charge in an electric field:

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

Superposition principle for electric fields:

$$\vec{\mathbf{E}} = \vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2 + \cdots$$

21.6 The Electric Field

Problem solving in electrostatics: electric forces and electric fields

1. Draw a diagram; show all charges, with signs, and electric fields and forces with directions
2. Calculate forces using Coulomb's law
3. Add forces vectorially to get result

21.8 Field Lines

The electric field can be represented by field lines. These lines start on a positive charge and end on a negative charge.

(a) (b)

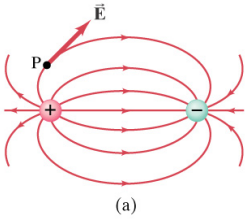
21.8 Field Lines

The number of field lines starting (ending) on a positive (negative) charge is proportional to the magnitude of the charge.

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

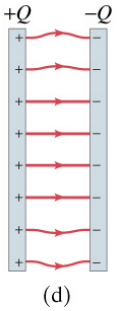
21.8 Field Lines

Electric dipole: two equal charges, opposite in sign:



(a)

21.8 Field Lines



(d)

The electric field between two closely spaced, oppositely charged parallel plates is constant.

21.8 Field Lines

Summary of field lines:

1. Field lines indicate the direction of the field; the field is tangent to the line.
2. The magnitude of the field is proportional to the density of the lines.
3. Field lines start on positive charges and end on negative charges; the number is proportional to the magnitude of the charge.

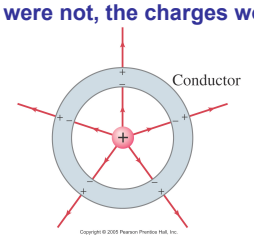
21.8 Field Lines

Summary of field lines:

4. Field lines never cross because the electric field cannot have two values for the same point.

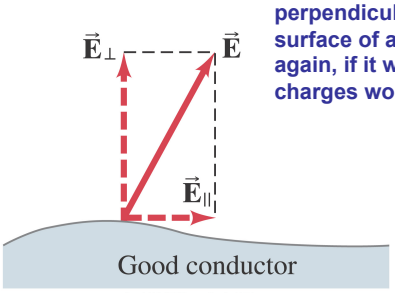
21.9 Electric Fields and Conductors

The static electric field inside a conductor is zero – if it were not, the charges would move.



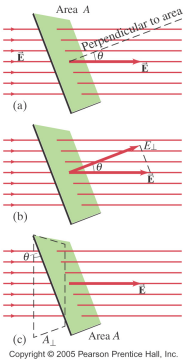
The net charge on a conductor is on its surface.

21.9 Electric Fields and Conductors



The electric field is perpendicular to the surface of a conductor – again, if it were not, charges would move.

22.1 Electric Flux



Electric flux:

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

$$= E_\perp A = EA_\perp$$

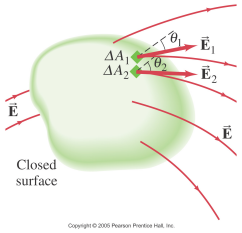
Electric flux through an area is proportional to the total number of field lines crossing the area.

22.1 Electric Flux

Flux through a closed surface:

$$\Phi_E = E_1\,\Delta A_1\cos\theta_1 + E_2\,\Delta A_2\cos\theta_2 + \cdots$$

$$= \sum E\,\Delta A\cos\theta = \sum E_\perp\,\Delta A,$$



22.2 Gauss's Law

The net number of field lines through the surface is proportional to the charge enclosed, and also to the flux, giving Gauss's law:

$$\sum_{\substack{\text{closed}\\ \text{surface}}} E_{\perp}\,\Delta A = \frac{Q_{\text{encl}}}{\epsilon_0}$$

$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{Q_{encl}}{\varepsilon_0}$$

This can be used to find the electric field in situations with a high degree of symmetry.

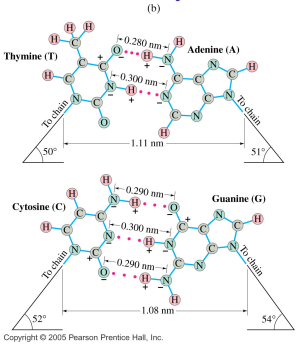
Prob 21.80 Electric Forces in Molecular Biology: DNA Structure and Replication

Molecular biology is the study of the structure and functioning of the living cell at the molecular level.

The DNA molecule is a double helix:

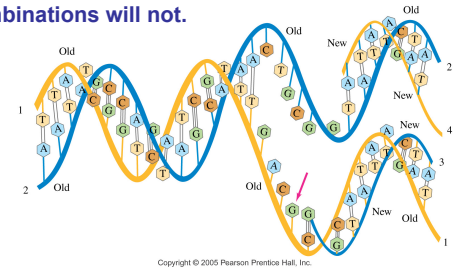
Prob 21.80 Electric Forces in Molecular Biology: DNA Structure and Replication

The A-T and G-C nucleotide bases attract each other through electrostatic forces.



Prob 21.80 Electric Forces in Molecular Biology: DNA Structure and Replication

Replication: DNA is in a "soup" of A, C, G, and T in the cell. During random collisions, A and T will be attracted to each other, as will G and C; other combinations will not.



Summary of Chapter 21

- Two kinds of electric charge – positive and negative
- Charge is conserved
- Charge on electron:

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

- Conductors: electrons free to move
- Insulators: nonconductors

Summary of Chapter 21

- Charge is quantized in units of e
- Objects can be charged by conduction or induction
- Coulomb's law: $F = k\dfrac{Q_1 Q_2}{r^2}$
- Electric field is force per unit charge:

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

Summary of Chapter 21

- Electric field of a point charge: $E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$
- Electric field can be represented by electric field lines
- Static electric field inside conductor is zero; surface field is perpendicular to surface

Summary of Chapter 22

- Electric flux: $\Phi_E = EA\cos\theta$
- Gauss's law:

$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{Q_{encl}}{\varepsilon_0}$$