Class 1

January 17, 2023 9:04 AM

ENGI-1500
Physics -2

Faruk Erkmen, Professor

Faculty of Applied Sciences & Technology
Humber Institute of Technology and Advanced Learning
Winter 2023

HUMBER

Introduction

About the instructor

About the course

Objective

- To understand the basics of Coulomb's law, Gauss' law, Kirchhoff's laws, Ampere's law, Ohm's law, Faraday's Law, Lenz's law and energy theorems.

- To understand the applications of these laws to a variety of physical phenomena related to static charges, electric and magnetic fields, electric currents, circuits, power, induction, coils, and solenoids.
- To learn the fundamentals of electromagnetic principles.
- To learn the fundamentals of light and optics.
- Acquiring a solid foundation both in theory and practice through
  - Lectures
  - Hands-on laboratory sessions

About the course

- Lectures
  - 3 hrs / week
  - Tuesdays 8:55am to 11:35am (for Sections 0NA and 0NB)
  - In-person in BCTI-310
  - Presentation format
  - Interactive discussions
  - Solving examples in class
  - Group exercises
  - Q & A

- Labs / Tutorials
  - 2 hrs / week in smaller sections
    - For Section [0NA] – Tuesday 1:30pm to 3:15pm (J-214)
    - For Section [0NB] – Friday 1:30pm to 3:15pm (J-214)
  - In-person in J-214
  - Hands on examples / experiments / demos
  - Group exercises
  - Lab reports

About the course

Required Resources

Serway, R. A. and Jewett, J. W. (2018) Physics for scientists and engineers with modern physics (10th ed.). Brooks Cole. ISBN-13: 978-1337553292

Supplemental Resources

Halliday, D. & Resnick, R. & Walker, J. (2018). Fundamentals of Physics: Extended. (11th edition). Wiley. ISBN: 978-1-119-
30685-6

About the course

Week	Class Date (for 0NA & 0NB)	Topics	Reading	Lab & Tutorials (Total 25%)
1	Jan. 10	Course overview, introductions Electric Fields	Ch. 22	**Tutorial-1**: Introductions Review of Ch. 22
2	Jan. 17	Cont. Charge Dist. & Gauss's Law Electric Potential	Ch. 23 Ch. 24	**Tutorial-2:** Review of Ch. 23 & 24
3	Jan. 24	Capacitance and Dielectrics Current and Resistance	Ch. 25 Ch. 26	**Lab-1:** Electric Field & Potential **(4 %)**
4	Jan. 31	Direct Current Circuits **Assignment-1 (5%) Due Feb. 7th**	Ch. 27	**Lab-2:** Resistors and Capacitors **(4 %)**
5	Feb. 7	Magnetic Fields	Ch. 28	**Tutorial-3:** Review of Ch. 25 - 28
6	Feb. 14	Sources of Magnetic Fields	Ch. 29	**Lab-3:** Magnetic Force **(4 %)**
7	Feb. 21	**Midterm Exam (20%) [all content]**		**Tutorial-4:** Review of Ch. 29
8	Feb. 27 – Mar. 3	**Reading week – college is open but no classes**		
9	Mar. 7	Faraday's Law	Ch. 30	**Lab-4:** Mag. Field of a Solenoid **(5 %)**
10	Mar. 14	Inductance Alternating Current Circuits	Ch. 31 Ch. 32	**Tutorial-5:** Review of Ch. 30 - 32
11	Mar. 21	Electromagnetic Waves **Assignment-2 (5%) Due Mar. 28th**	Ch. 33	**Lab-5:** Electromagnetic Propagation and Path Loss **(4 %)**
12	Mar. 28	Nature of Light and Ray Optics	Ch. 34	**Tutorial-6:** Review of Ch. 33 & 34 **BUS Project**
13	Apr. 4	Image Formation	Ch. 35	**Lab-6:** Ray and Wave Optics **(4 %)**
14	Apr. 11	Wave Optics Diffraction and Polarization	Ch. 36 Ch. 37	**Tutorial-7:** Review of Ch. 35 - 37 **BUS Project**
15	Apr. 18	**Final Exam (30%) [all content]**		
		BUS Project Report (15%) Due April 14th		

About the course

Evaluation

ENGI-1500 Evaluation	
Description	**Weight**
Assignments	10%
Bus project	15%
Midterm exam	20%
Final exam	30%
Sub-total	75%
Labs	25%
Total	100%

Course Specific Policies and Expectations

The minimum passing grade in this course is 60%.

Outline of Week 1, Class 1

- Course overview
- Electric Fields (Ch. 22)
  - Properties of electric charges
  - Charging objects by induction
  - Coulomb's Law
  - Electric field lines
  - Particle in a field (Electric)
  - Motion of Charged Particle in a Uniform Electric Field
- Examples

Course overview

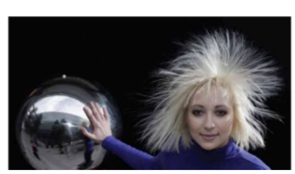
Electric Fields (Ch. 22)
- → **Properties of electric charges**
- Charging objects by induction
- Coulomb's Law
- Particle in a field (Electric)
- Electric field lines
- Motion of Charged Particle in a Uniform Electric Field

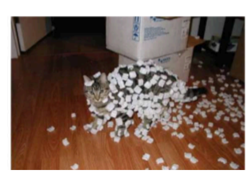
Electric Fields (Ch. 22)

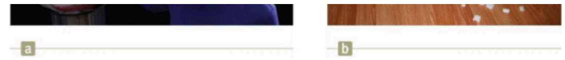
Properties of electric charges

Properties of Electrical Charges

- From the first semester, we are familiar with the concept of ***force***.
  - The electromagnetic force between charged particles is one of the fundamental forces of nature.







- Simple experiments demonstrate the existence of electric forces.
  - Electrically charged hair will have a repulsive force
  - Rubbing a balloon on your hair
  - Rubbing a glass rod with silk

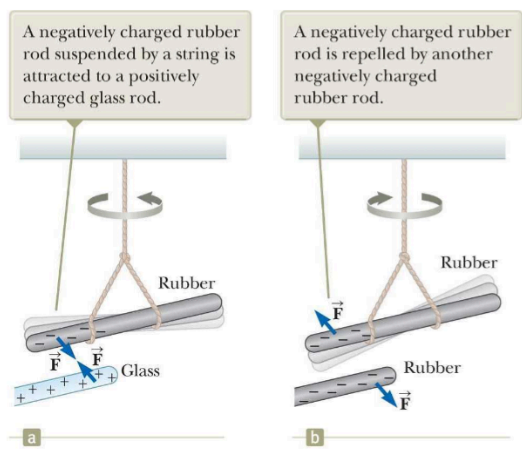
Figure (a): woman's body becomes charged → *repulsive* force between hairs on her head
Figure (b): cat rubbed its body against Styrofoam peanuts → *attractive* force: Styrofoam peanuts stuck to its body

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage Learning, 2018.

Properties of Electrical Charges

- Through series of experiments, it was found that there are two kinds of charges – which were named as ***positive*** and ***negative*** by Benjamin Franklin (1706 - 1790).

- Also through experiments it was proved that
  - charges of the ***same sign repel*** each other
  - charges with ***opposite signs attract*** each other



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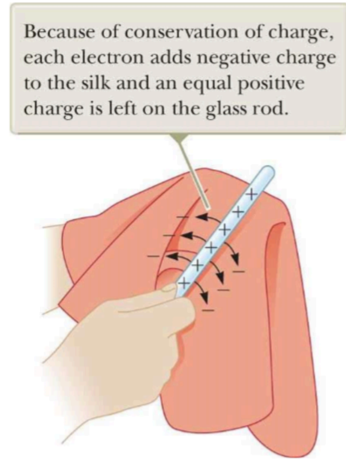
- Electric charge is always ***conserved*** in an isolated system.
  - When objects are rubbed against each other, charge is not created – they are transferred (i.e. electrons)



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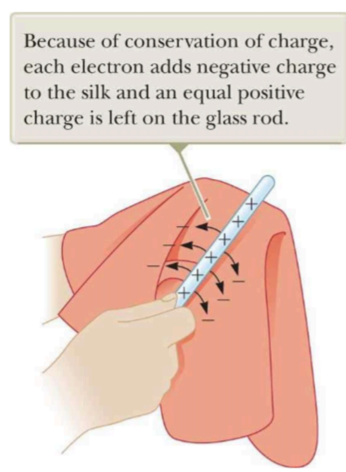
Properties of Electrical Charges

- In 1909, Robert Millikan discovered that electric charge occurs as integral multiples of a fundamental amount of charge ***e***.

- Electric charge q ***quantized***
  - q = standard symbol used for charge as a variable
  - electric charge exists as ***'discrete packets'***

- ***q = ±Ne*** where N is some integer.
  - Other experiments in same period showed ***electron*** has a charge ***–e*** and the ***proton*** has a charge of equal magnitude but opposite sign ***+e***.



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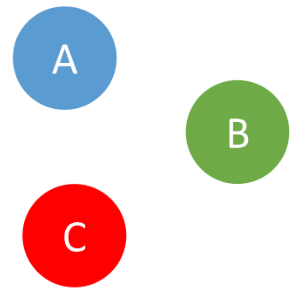
Properties of Electrical Charges

Quick Quiz

Three objects are brought close to each other, two at a time.

- When objects A and B are brought together, they repel.
- When objects B and C are brought together, they also repel.

Which of the following are true?



(a) Objects A and C possess charges of the same sign.

(b) Objects A and C possess charges of opposite sign.

(c) All three objects possess charges of the same sign.

(d) One object is neutral.

(e) Additional experiments must be performed to determine the signs of the charges.

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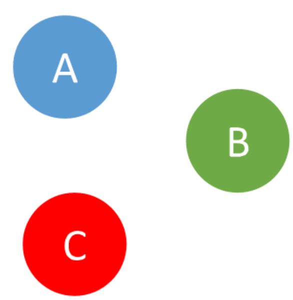

True → **(a) Objects A and C possess charges of the same sign.**

(b) Objects A and C possess charges of opposite sign.

True → **(c) All three objects possess charges of the same sign.**

(d) One object is neutral.

True → **(e) Additional experiments must be performed to determine the signs of the charges.**

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Course overview

Electric Fields (Ch. 22)
- Properties of electric charges
- → **Charging objects by induction**
- Coulomb's Law
- Particle in a field (Electric)
- Electric field lines
- Motion of Charged Particle in a Uniform Electric Field

Electric Fields (Ch. 22)

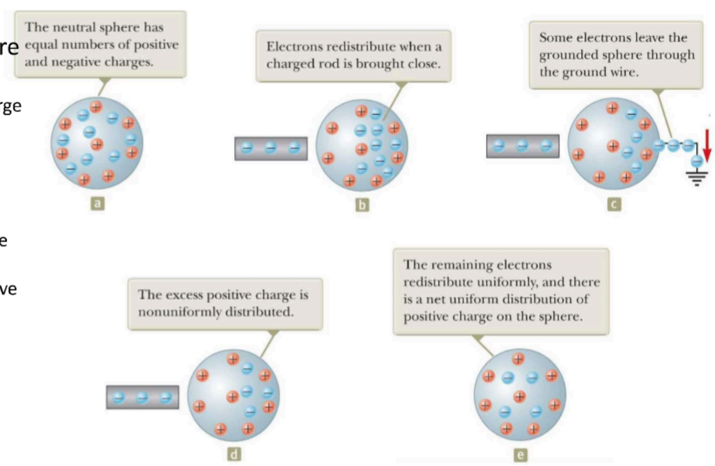
Charging Objects by Induction

The Atom

Please feel free to review the slides at the end

Charging Objects by Induction

- Consider a neutral (uncharged) conducting sphere insulated from the ground - ***Figure (a)***
    - Electrons move freely within the conductor but net charge on the sphere is 0.
- When a negatively charged rubber rod brought near the sphere - ***Figure (b)***
    - Electrons in the region near the rod experience repulsive force and migrate to the opposite side of the sphere
    - The side of the sphere near the rod with effective positive charge because of diminished number of electrons
    - But remember only the electrons are free to move
    - Occurs even though the rod never touches the sphere



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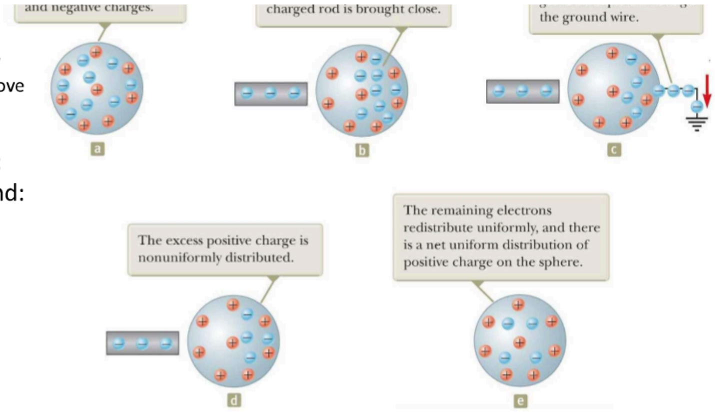
Charging Objects by Induction

- Same experiment performed with a conducting

Same experiment performed with a conducting wire connected the sphere to Earth - ***Figure (c)***
    - Some electrons in the conductor so strongly repelled by the presence of the negative charge in the rod - they move out of the sphere through the wire and into Earth

- **Note**: symbol at the end of the wire in figure (c): indicates that the wire is connected to the ground:
    - Reservoir, such as Earth, that can accept or provide electrons freely with negligible effect on its electrical characteristics



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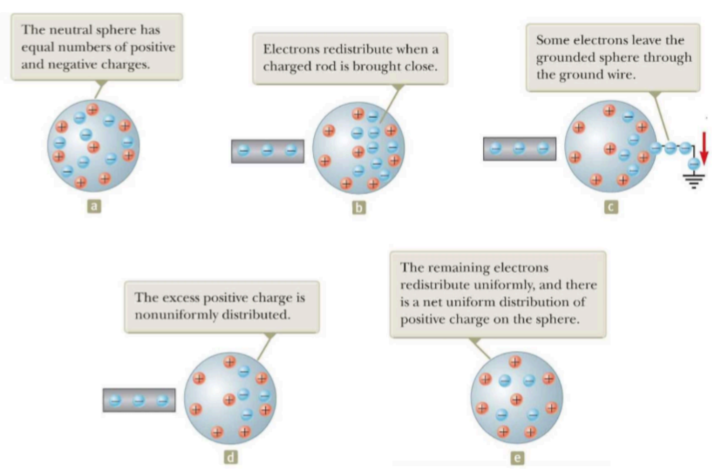
Charging Objects by Induction

- If the wire to ground then removed - ***Figure (d)***
    - Conducting sphere contains excess of the induced positive charge
    - Has fewer electrons than it needs to cancel out the positive charge of protons

- When the rubber rod is removed from the vicinity of the sphere - ***Figure (e)***
    - ***<u>Induced</u>*** positive charge remains on the ungrounded sphere
    - **Note**: The rubber rod loses none of its negative charge during this process
    - Charging by induction requires no contact with the object inducing the charge. In contrast to charging the object by rubbing (by conduction) requires contact between the objects



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Course overview

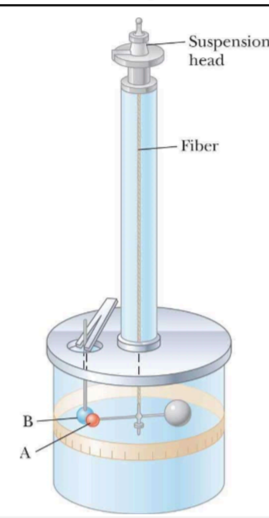
Electric Fields (Ch. 22)
Properties of electric charges
Charging objects by induction
Coulomb's Law
Particle in a field (Electric)
Electric field lines
Motion of Charged Particle in a Uniform Electric Field

Electric Fields (Ch. 22)

Coulomb's Law

Electric Forces between Charged Objects

- Charles Coulomb: invented the torsion balance (figure) to measure the magnitudes of electric forces between charged objects:
  - Electric force between charged spheres A and B causes the spheres to either attract or repel each other:
  - Resulting motion causes the suspended fiber to twist
  - Restoring torque of the twisted fiber is proportional to the angle through which fiber rotates
  - Measurement of the angle provides a quantitative measure of the electric force of attraction or repulsion
- Gravitational force can be neglected



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Coulomb's Law

- Coulomb's experiments revealed the properties of ***electric (or electrostatic) force*** *between two stationary charged particles **(F_e)***
- k_e is the Coulomb's constant
- SI unit of charge is ***Coulomb***
- ε_0 is the permittivity of free space
- Smallest unit of free charge known in the nature is the charge of an electron: ***e***
- ***r***: the distance between two charges

$$\boxed{F_e = k_e \frac{|q_1||q_2|}{r^2}}$$

$$k_e = 8.9876 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$$

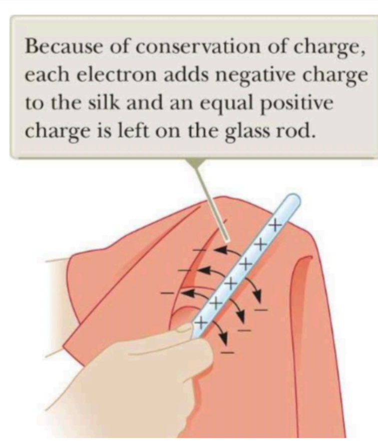
$$k_e = \frac{1}{4\pi\varepsilon_0}$$

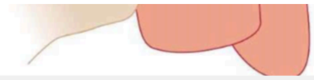
$$\varepsilon_0 = 8.8542 \times 10^{-12} \ \mathrm{C^2/N \cdot m^2}$$

$$e = 1.60218 \times 10^{-19} \ \mathrm{C}$$

Coulomb of Charge

- 1 C of charge ≈ charge of 6.24 x 10^{18} electrons or protons
  - The number of free electrons in 1 cm^3 of copper ≈ 10^{23}
- 1 C: substantial amount of charge
  - In typical experiments in which rubber or glass rod charged by friction → net charge ≈ 10^{-6} C
  - Only very small fraction of the total available charge is transferred between the rod and the rubbing material





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Charges and Masses of Atomic Particles

TABLE 22.1 Charge and Mass of the Electron, Proton, and Neutron

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.602\,176\,5 \times 10^{-19}$	$9.109\,4 \times 10^{-31}$
Proton (p)	$+1.602\,176\,5 \times 10^{-19}$	$1.672\,62 \times 10^{-27}$
Neutron (n)	0	$1.674\,93 \times 10^{-27}$

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Coulomb's Law

Example 22-1: The Hydrogen Atom

Example 22.1 **The Hydrogen Atom**

The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately 5.3×10^{-11} m. Find the magnitudes of the electric force and the gravitational force between the two particles.

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Solution

Use Coulomb’s law to find the magnitude of the electric force: $\rightarrow F_e = k_e \dfrac{|e||-e|}{r^2}$

Use Newton’s law to find the magnitude of the gravitational force: $\rightarrow F_g = G \dfrac{m_e m_p}{r^2}$

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Use Coulomb's law to find the magnitude of the electric force: $\rightarrow$ $F_e = k_e \frac{|e||-e|}{r^2} = (8.988 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(1.60 \times 10^{-19} \text{ C})^2}{(5.3 \times 10^{-11} \text{ m})^2}$

Use Newton's law to find the magnitude of the gravitational force: $\rightarrow$ $F_g = G \frac{m_e m_p}{r^2}$

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$$= \boxed{8.2 \times 10^{-8} \text{ N}}$$

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Use Newton’s law to find the magnitude of the gravitational force:

$$F_g = G \frac{m_e m_p}{r^2} = (6.674 \times 10^{-11} \mathrm{~N \cdot m^2/kg^2}) \frac{(9.11 \times 10^{-31} \mathrm{~kg})(1.67 \times 10^{-27} \mathrm{~kg})}{(5.3 \times 10^{-11} \mathrm{~m})^2}$$

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The ratio of these two forces:

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The ratio of these two forces:

$$\frac{F_e}{F_g} = \frac{8.2\times10^{-8}\text{ N}}{3.6\times10^{-47}\text{ N}} \approx 2\times10^{39}$$

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The ratio of these two forces:

$$\frac{F_e}{F_g} = \frac{8.2\times10^{-8}\text{ N}}{3.6\times10^{-47}\text{ N}} \approx 2\times10^{39}$$

→ Therefore, the gravitational force between charged atomic particles is negligible when compared with the electric force.

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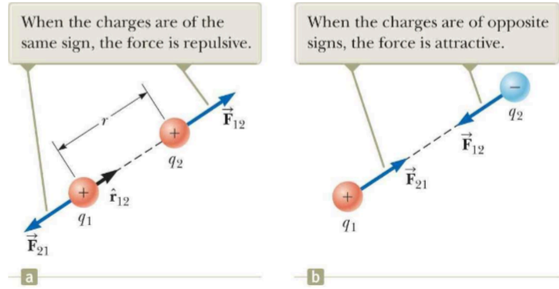
Coulomb's Law in Vector Form

- Coulomb's law in vector form for electric force exerted by a charge $\mathbf{q_1}$ on a charge $\mathbf{q_2}$:
  - r_{12} = unit vector directed from q_1 toward q_2 (figure (a))
- Electric force obeys Newton's third law:
  - $F_{21} = -F_{12}$
- If q_1 and q_2 have the same sign (figure (a)):
  - The product q_1q_2 is ***positive***
  - The electric force on one particle is ***directed away*** from the other particle
- If q_1 and q_2 have the opposite sign (figure (b)):
  - The product q_1q_2 is ***negative***
  - The electric force on one particle is ***directed toward the*** other particle

$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$



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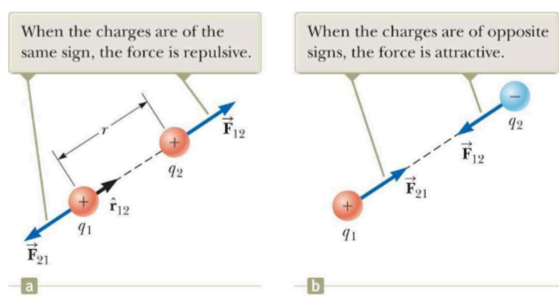
- Electric force obeys Newton's third law
  - $F_{21} = -F_{12}$
- If q_1 and q_2 have the same sign (figure (a)):
  - The product q_1q_2 is ***positive***
  - The electric force on one particle is ***directed away*** from the other particle
- If q_1 and q_2 have the opposite sign (figure (b)):
  - The product q_1q_2 is ***negative***
  - The electric force on one particle is ***directed toward the*** other particle
- When more than two charges are present: the force on any charge is given by the ***superposition*** principle (***vector sum***)

$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$



$$\sum \vec{\mathbf{F}}_1 = \vec{\mathbf{F}}_{21} + \vec{\mathbf{F}}_{31} + \vec{\mathbf{F}}_{41}$$

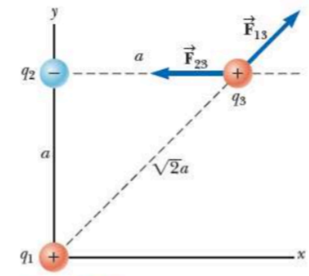
Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Coulomb’s Law in Vector Form

Example 22-2: Find the resultant force

Example 22.2 **Find the Resultant Force**

Consider three point charges located at the corners of a right triangle as shown in Figure , where $q_1 = q_3 = 5.00\ \mu C$, $q_2 = -2.00\ \mu C$, and $a = 0.100$ m. Find the resultant force exerted on q_3.



The force exerted by q_1 on q_3 is $\vec{F}_{13}$. The force exerted by q_2 on q_3 is $\vec{F}_{23}$. The resultant force $\vec{F}_3$ exerted on q_3 is the vector sum $\vec{F}_{13} + \vec{F}_{23}$.

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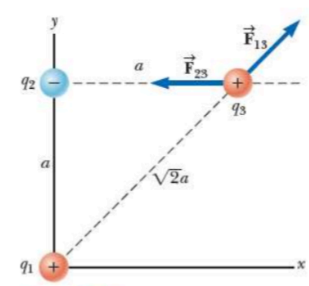
Find the magnitude of the force F_{13} first:



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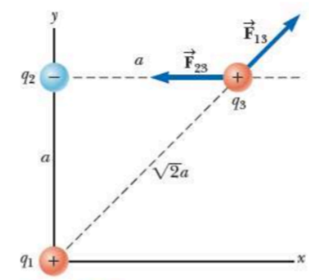
Find the magnitude of the force F_{13} first:

$$F_{13} = k_e \frac{|q_1||q_3|}{\left(\sqrt{2}a\right)^2} = \left(8.988\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\frac{\left(5.00\times10^{-6}\ \mathrm{C}\right)\left(5.00\times10^{-6}\ \mathrm{C}\right)}{2\left(0.100\ \mathrm{m}\right)^2} = 11.2\ \mathrm{N}$$



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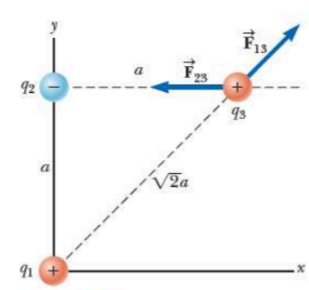

The force exerted by q_1 on q_3 is $\vec{\mathbf{F}}_{13}$. The force exerted by q_2 on q_3 is $\vec{\mathbf{F}}_{23}$.

The resultant force $\vec{F}_3$ exerted on q_3 is the vector sum $\vec{F}_{13} + \vec{F}_{23}$.

Then, find the magnitude of the force F_{23}:

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage Learning, 2018.

Coulomb's Law in Vector Form

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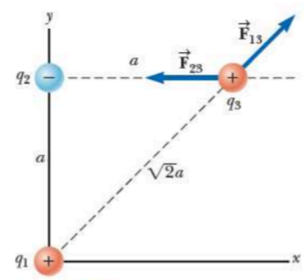

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Find the magnitude of the force F_{13} first:

$$F_{13} = k_e \frac{|q_1||q_3|}{\left(\sqrt{2}a\right)^2} = \left(8.988\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\frac{\left(5.00\times10^{-6}\ \mathrm{C}\right)\left(5.00\times10^{-6}\ \mathrm{C}\right)}{2\left(0.100\ \mathrm{m}\right)^2} = 11.2\ \mathrm{N}$$

Then, find the magnitude of the force F_{23}:

$$F_{23} = k_e \frac{|q_2||q_3|}{a^2} = \left(8.988\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\frac{\left(2.00\times10^{-6}\ \mathrm{C}\right)\left(5.00\times10^{-6}\ \mathrm{C}\right)}{\left(0.100\ \mathrm{m}\right)^2} = 8.99\ \mathrm{N}$$

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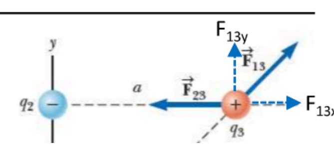
Coulomb's Law in Vector Form

Example 22-2: Find the resultant force

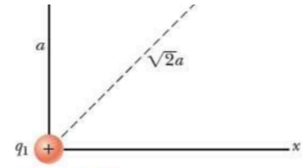
Example 22.2 **Find the Resultant Force**



Consider three point charges located at the corners of a right triangle as shown in Figure , where $q_1 = q_3 = 5.00\ \mu C$, $q_2 = -2.00\ \mu C$, and $a = 0.100$ m. Find the resultant force exerted on q_3.

Find the x and y components of F_{13} :

$F_{13} = 11.2N$
$F_{23} = 8.99N$



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Coulomb's Law in Vector Form

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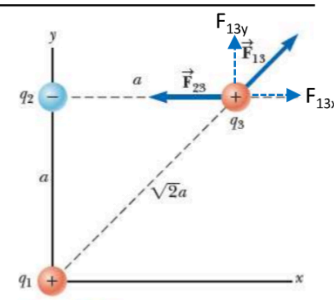
Consider three point charges located at the corners of a right triangle as shown in Figure , where $q_1 = q_3 = 5.00\ \mu C$, $q_2 = -2.00\ \mu C$, and $a = 0.100$ m. Find the resultant force exerted on q_3.

Find the x and y components of F_{13} :

$$F_{13x} = (11.2\text{ N})\cos 45.0° = 7.94\text{ N}$$
$$F_{13y} = (11.2\text{ N})\sin 45.0° = 7.94\text{ N}$$

$F_{13} = 11.2N$
$F_{23} = 8.99N$



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Coulomb’s Law in Vector Form

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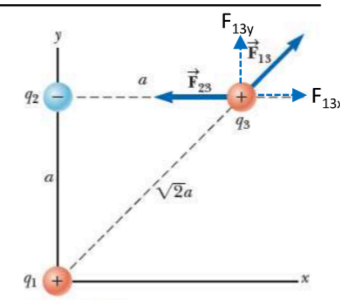

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F_{13} = 11.2N
F_{23} = 8.99N

Find the x and y components of F_{13} :

$$F_{13x} = (11.2\ \text{N})\cos 45.0° = 7.94\ \text{N}$$
$$F_{13y} = (11.2\ \text{N})\sin 45.0° = 7.94\ \text{N}$$

Find the components of the resultant force acting on q_3 :

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Coulomb’s Law in Vector Form

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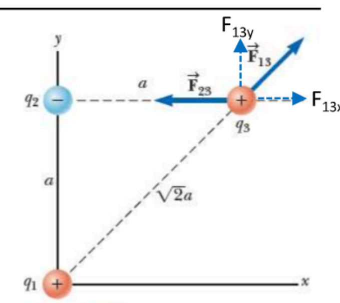

The force exerted by q_1 on q_3 is $\vec{F}_{13}$. The force exerted by q_2 on q_3 is $\vec{F}_{23}$. The resultant force $\vec{F}_3$ exerted on q_3 is the vector sum $\vec{F}_{13} + \vec{F}_{23}$.

F_{13} = 11.2N
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Find the x and y components of F_{13} :

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Find the components of the resultant force acting on q_3 :

$$F_{3x} = F_{13x} + F_{23x} = 7.94\ \text{N} + (-8.99\ \text{N}) = -1.04\ \text{N}$$
$$F_{3y} = F_{13y} + F_{23y} = 7.94\ \text{N} + 0 = 7.94\ \text{N}$$

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Coulomb’s Law in Vector Form

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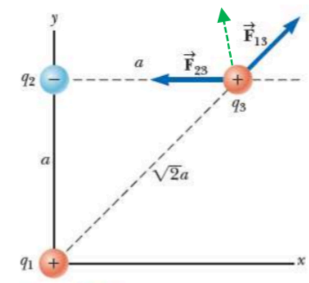

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F_{13} = 11.2N
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$$F_{3x} = F_{13x} + F_{23x} = 7.94\ \mathrm{N} + (-8.99\ \mathrm{N}) = -1.04\ \mathrm{N}$$
$$F_{3y} = F_{13y} + F_{23y} = 7.94\ \mathrm{N} + 0 = 7.94\ \mathrm{N}$$

Express the resultant force acting on q3 in unit-vector form:

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Coulomb’s Law in Vector Form

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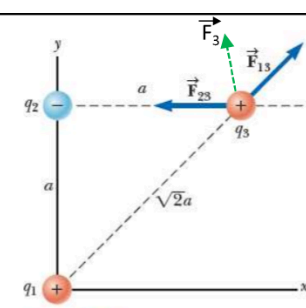

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$$F_{3y} = F_{13y} + F_{23y} = 7.94\ \mathrm{N} + 0 = 7.94\ \mathrm{N}$$

Express the resultant force acting on q3 in unit-vector form:

$$\vec{\mathbf{F}}_3 = \left(-1.04\hat{\mathbf{i}} + 7.94\hat{\mathbf{j}}\right)\ \mathrm{N}$$

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage Learning, 2018.

Course overview

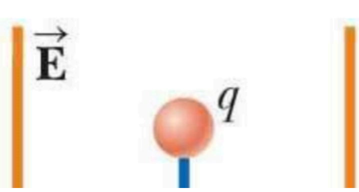
Electric Fields (Ch. 22)
- Properties of electric charges
- Charging objects by induction
- Coulomb's Law
- **Particle in a field (Electric)**
- Electric field lines
- Motion of Charged Particle in a Uniform Electric Field

Electric Fields (Ch. 22)

Particle in an Electric Field

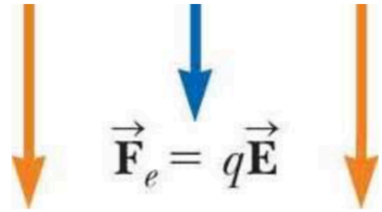
Electric Field

- Gravitational forces and electric forces are examples of field forces.
- Imagine an object with a charge that we call a



source charge. The source charge establishes an electric field ***E*** throughout the space.

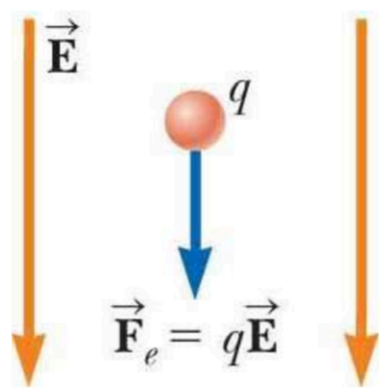
- Now imagine a particle with a charge ***q*** is placed in that field. The particle interacts with the electric field so that the particle experiences an electric force given by the equation shown.



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Electric Field

- Electric field $\vec{E}$ is a vector quantity and has the SI units of ***newtons per coulomb (N/C)***
- The direction of $\vec{E}$ is the direction of the force a positive test charge experiences when placed in the field.
- If an arbitrary charge ***q*** is placed in this electric field $\vec{E}$, it experiences an electric force given by $\vec{F}_e$



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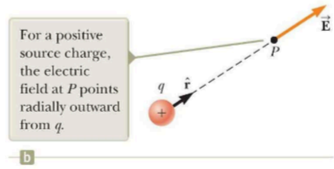
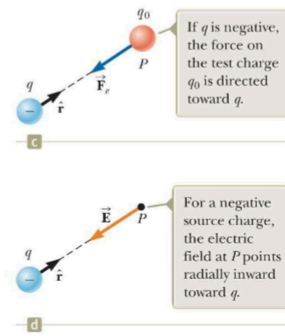
Electric Field

- If the source charge q is positive → figure (b) shows the situation with a test charge removed
  - Source charge sets up an electric field at P, directed away from q
- If q is negative (figure (c)) → the force on a positive test charge is directed towards q
- At any point P: the total electric field due to a group of source charges = vector sum of the electric fields of all charges



$$\vec{\mathbf{F}}_e = k_e \frac{q q_0}{r^2}\hat{\mathbf{r}}$$

$$\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r^2}\hat{\mathbf{r}}$$



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Electric Field

Example 22-6: Electric Field Due to Two Charges

Example 22.6 Electric Field Due to Two Charges

Charges q_1 and q_2 are located on the x axis, at distances a and b, respectively, from the origin as shown in Figure

(A) Find the components of the net electric field at the point P, which is at position $(0, y)$.

The total electric field $\vec{\mathbf{E}}$ at P equals the vector sum $\vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2$, where $\vec{\mathbf{E}}_1$ is the field due to the positive charge q_1 and $\vec{\mathbf{E}}_2$ is the field due to the negative charge q_2.

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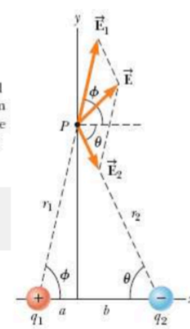

Electric Field

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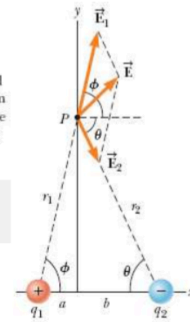

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Find the magnitude of the electric field at P due to charge ***q1***:

$$E_1 = k_e \frac{|q_1|}{r_1^2} = k_e \frac{|q_1|}{a^2 + y^2}$$

Electric Field

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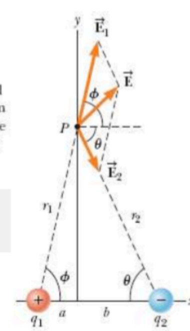

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Find the magnitude of the electric field at P due to charge ***q1***:

$$E_1 = k_e \frac{|q_1|}{r_1^2} = k_e \frac{|q_1|}{a^2 + y^2}$$

Find the magnitude of the electric field at P due to charge ***q2***:

$$E_2 = k_e \frac{|q_2|}{r_2^2} = k_e \frac{|q_2|}{b^2 + y^2}$$

Electric Field

Example 22-6: Electric Field Due to Two Charges

Example 22.6 **Electric Field Due to Two Charges**

Charges q_1 and q_2 are located on the x axis, at distances a and b, respectively, from the origin as shown in Figure

(A) Find the components of the net electric field at the point P, which is at position $(0, y)$.

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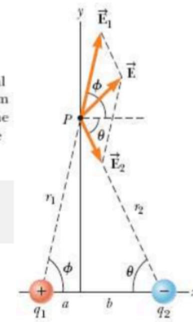

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$$E_1 = k_e \frac{|q_1|}{r_1^2} = k_e \frac{|q_1|}{a^2 + y^2}$$

Find the magnitude of the electric field at P due to charge ***q2***:

$$E_2 = k_e \frac{|q_2|}{r_2^2} = k_e \frac{|q_2|}{b^2 + y^2}$$

Write the components of the net electric field vector:

Electric Field

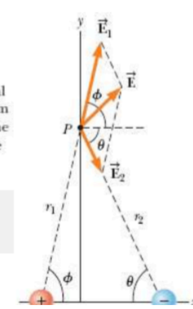
Example 22-6: Electric Field Due to Two Charges

Example 22.6 **Electric Field Due to Two Charges**

Charges q_1 and q_2 are located on the x axis, at distances a and b, respectively, from the origin as shown in Figure

(A) Find the components of the net electric field at the point P, which is at position $(0, y)$.

The total electric field $\vec{\mathbf{E}}$ at P equals the vector sum $\vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2$, where $\vec{\mathbf{E}}_1$ is the field due to the positive charge q_1 and $\vec{\mathbf{E}}_2$ is the field due to the negative charge q_2.



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Find the magnitude of the electric field at P due to charge ***q1***:

$$E_1 = k_e \frac{|q_1|}{\ } = k_e \frac{|q_1|}{\ }$$

Write the components of the net electric field vector:

$$\vec{\mathbf{E}}_1 = k_e \frac{|q_1|}{\ } \cos\phi\,\hat{\mathbf{i}} + k_e \frac{|q_1|}{\ } \sin\phi\,\hat{\mathbf{j}}$$

Find the magnitude of the electric field at P due to charge ***q2***:

$$E_2 = k_e \frac{|q_2|}{r_2^2} = k_e \frac{|q_2|}{b^2 + y^2}$$

$$\vec{\mathbf{E}}_2 = k_e \frac{|q_2|}{b^2 + y^2} \cos\theta\,\hat{\mathbf{i}} - k_e \frac{|q_2|}{b^2 + y^2} \sin\theta\,\hat{\mathbf{j}}$$

Electric Field

Example 22-6: Electric Field Due to Two Charges

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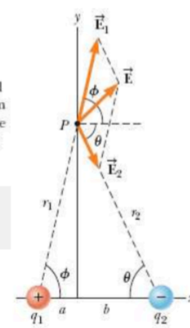
Vector sum:

The total electric field $\vec{\mathbf{E}}$ at P equals the vector sum $\vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2$, where $\vec{\mathbf{E}}_1$ is the field due to the positive charge q_1 and $\vec{\mathbf{E}}_2$ is the field due to the negative charge q_2.



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Electric Field

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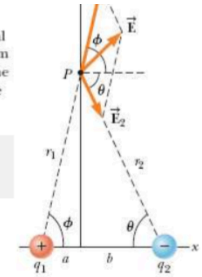

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Vector sum:

$$(1)\quad E_x = E_{1x} + E_{2x} = k_e \frac{|q_1|}{a^2 + y^2} \cos\phi + k_e \frac{|q_2|}{b^2 + y^2} \cos\theta$$

$$(2)\quad E_y = E_{1y} + E_{2y} = k_e \frac{|q_1|}{a^2 + y^2} \sin\phi - k_e \frac{|q_2|}{b^2 + y^2} \sin\theta$$

Electric Field

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(A) Find the components of the net electric field at the point P, which is at position $(0, y)$.

(B) Evaluate the electric field at point P in the special case that $|q_1| = |q_2|$ and $a = b$.

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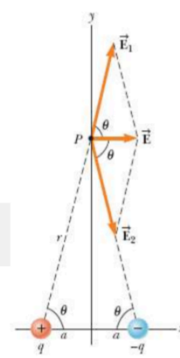

Electric Field

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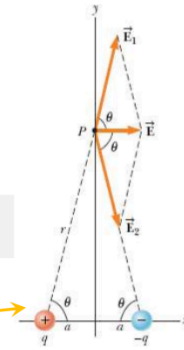

Electric Field

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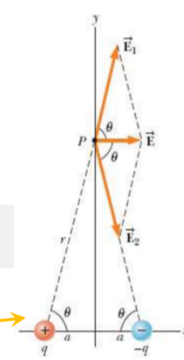

$$E_x = k_e \frac{q}{a^2 + y^2} \cos\theta + k_e \frac{q}{a^2 + y^2} \cos\theta = 2k_e \frac{q}{a^2 + y^2} \cos\theta$$

$$E_y = k_e \frac{q}{a^2 + y^2} \sin\theta - k_e \frac{q}{a^2 + y^2} \sin\theta = 0$$

Electric Field

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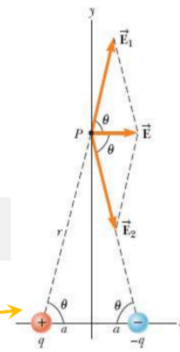

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Electric Field

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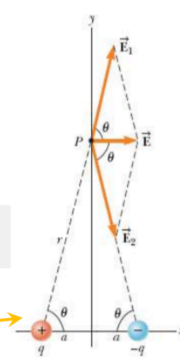

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$$E_y = k_e \frac{q}{a^2 + y^2} \sin\theta - k_e \frac{q}{a^2 + y^2} \sin\theta = \boxed{0}$$

$$\cos\theta = \frac{\;}{r} = \frac{\;}{(a^2 + y^2)^{1/2}}$$

Electric Field

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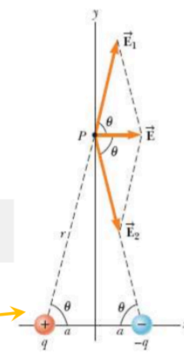

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$$E_y = k_e \frac{q}{a^2 + y^2} \sin\theta - k_e \frac{q}{a^2 + y^2} \sin\theta = \boxed{0}$$

$$\cos\theta = \frac{a}{r} = \frac{a}{(a^2 + y^2)^{1/2}}$$

$$E_x = 2k_e \frac{q}{a^2 + y^2} \left[\frac{a}{(a^2 + y^2)^{1/2}}\right] = k_e \frac{2aq}{(a^2 + y^2)^{3/2}}$$

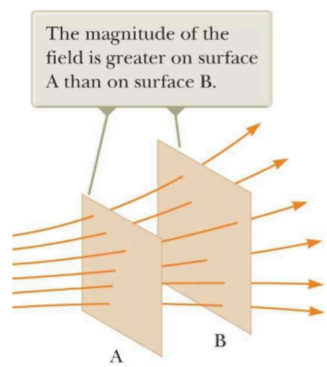
Course overview
Electric Fields (Ch. 22)
Properties of electric charges
Charging objects by induction
Coulomb's Law
Particle in a field (Electric)
Electric field lines

Electric Fields (Ch. 22)

Electric Field Lines

Electric Field Lines

- With electric field lines, we can visualize the electric field in pictorial representation:
  - Line direction (indicated by arrowhead) is same as that of the electric field vector
  - Direction of the lines is also same as that of force on a positive charge placed in the field according to the particle in a field model
- Number of lines per unit area through a surface that is perpendicular to the lines → magnitude of the electric field in the region
  - Field lines are close together where the electric field is strong
  - Field lines are far apart where the field is weak

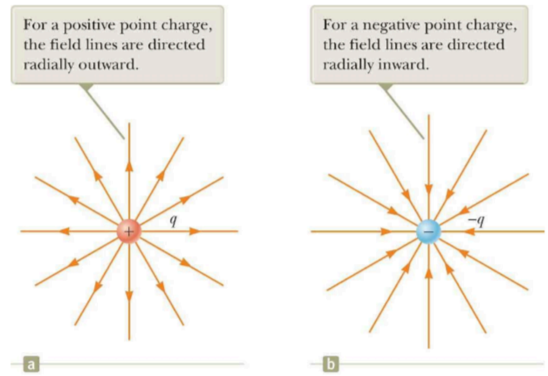


$$\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r^2}\hat{\mathbf{r}}$$

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Electric Field Lines

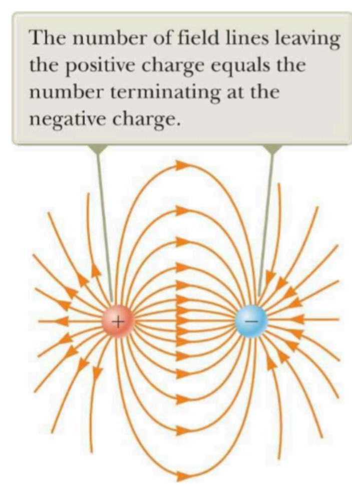
- Figure (a): Illustrating the electric field lines due to a single positive point charge
- Figure (b): Illustrating the electric field lines due to single negative point charge
- Lines must begin on positive charge and terminate on negative charge
- Two field lines ***can not*** cross



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Electric Field Lines

- Figure: electric field lines for two point charges of equal magnitude but opposite signs



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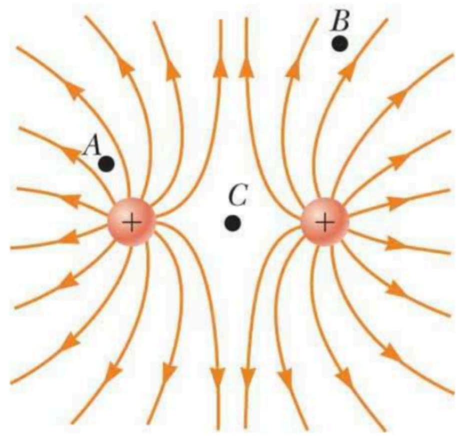
Electric Field Lines

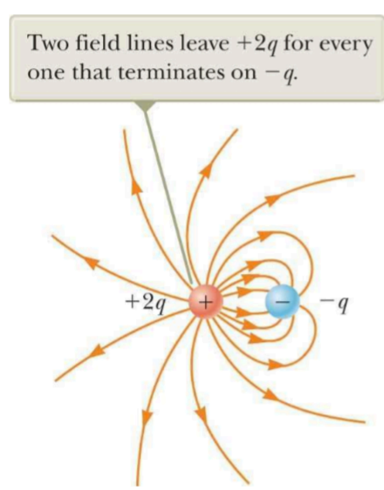
- Figure: electric field lines in vicinity of two equal positive point charges



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Electric Field Lines

- Figure: electric field lines associated with a positive charge +2q and a negative charge -q
  - Number of lines leaving +2q is twice the number terminating at -q
  - Only half of the lines that leave the positive charge reach the negative charge
- Remaining half terminate on a negative charge we assume to be at infinity
  - At distances much greater than the charge separation:
    - Electric field lines are equivalent to those of a single charge +q

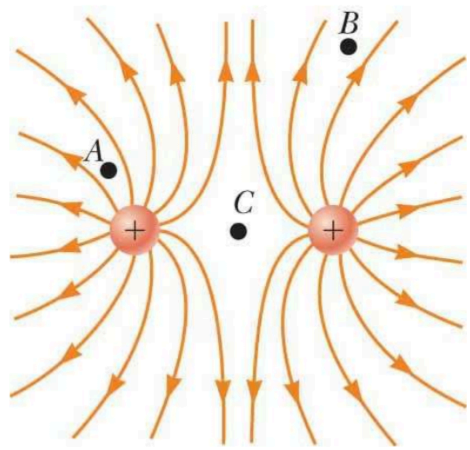


Source: Serway, Raymond A., and John W.

Electric Field Lines

Quick Quiz

Rank the magnitudes of the electric field at points A, B, and C shown in the figure (greatest magnitude first).



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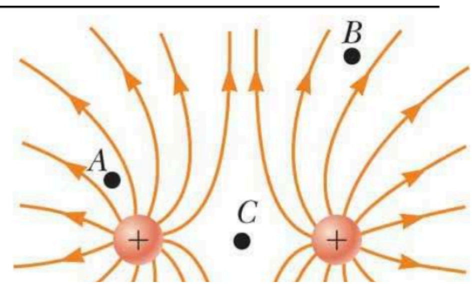
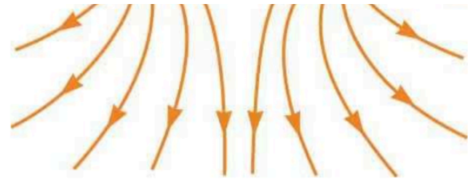


Solution

A > B > C

The field is greatest at point A because that is where the field lines are closest together. The absence of lines near point C indicates that the electric field there is zero.



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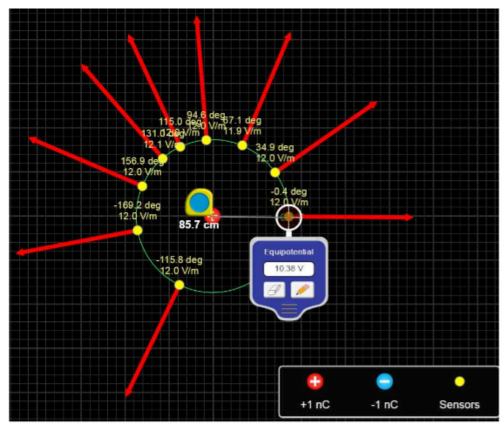
Electric Field Lines

Free online simulation

https://phet.colorado.edu/en/simulations/charges-and-fields



Electric Fields (Ch. 22)

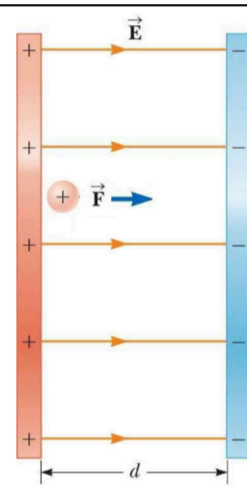
Motion of Charged Particle in a Uniform Electric Field

Charged Particle in a Uniform Ē Field

- When a particle of charge ***q*** and mass ***m*** is placed in an electric field $\vec{E}$:
  - Electric force exerted on the charge = ***qE***
- If that's the only force exerted on the particle:

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

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



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Charged Particle in a Uniform Ē Field

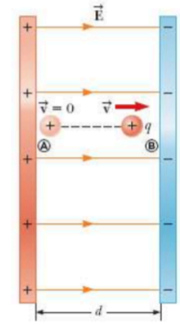
Example 22-7: Accelerating Positive Charge

Example 22.7 An Accelerating Positive Charge: Two Models

A uniform electric field $\vec{E}$ is directed along the x axis between parallel plates of charge separated by a distance d as shown in Figure . A positive point charge q of mass m is released from rest at a point Ⓐ next to the positive plate and accelerates to a point Ⓑ next to the negative plate.

(A) Find the speed of the particle at Ⓑ by modeling it as a particle under constant acceleration.

A positive point charge q in a uniform electric field $\vec{E}$ undergoes constant acceleration in the direction of the field.



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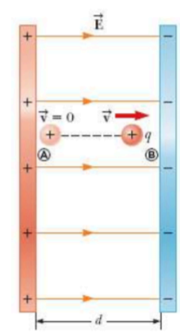

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Express the velocity of the particle as a function of position (i.e. particle under constant acceleration):

Charged Particle in a Uniform Ē Field

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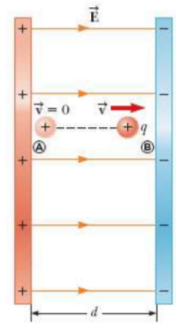

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Express the velocity of the particle as a function of position (i.e. particle under constant acceleration):

$$v_f^{\,2} = v_i^2 + 2a\left(x_f - x_i\right) = 0 + 2a\left(d - 0\right) = 2ad$$

Charged Particle in a Uniform Ē Field

Example 22-7: Accelerating Positive Charge

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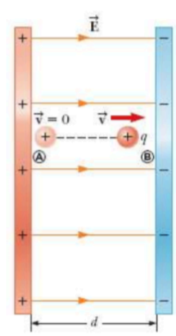

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Solve for v_f and substitute for the magnitude of the acceleration: $\vec{a} = \frac{q\vec{E}}{m}$

Charged Particle in a Uniform Ē Field

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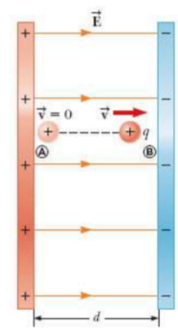

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Express the velocity of the particle as a function of position (i.e. particle under constant acceleration):

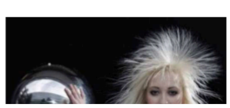
$$v_f^{\,2} = v_i^2 + 2a\left(x_f - x_i\right) = 0 + 2a\left(d - 0\right) = 2ad$$

Solve for v_f and substitute for the magnitude of the acceleration: $\vec{a} = \frac{q\vec{E}}{m}$

$$v_f = \sqrt{2ad} = \sqrt{2\left(\frac{qE}{m}\right)d} = \boxed{\sqrt{\frac{2qEd}{m}}}$$

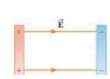
Summary of the this week

- Electrical charges
  - ***Positive*** and ***Negative*** charges
  - Same signs repel each other

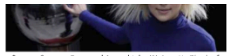


- Electric Fields

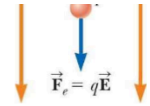
- Electric Field Lines



- Opposite signs attract each other



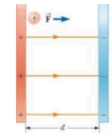
Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.



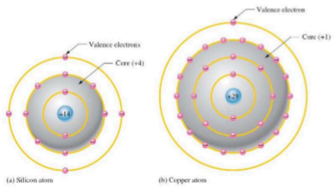
- Charges in a Uniform Field

$\sum \vec{F} = q\vec{E} = m\vec{a}$

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



- The atom - Bohr model and valence electrons



Source: Floyd, Thomas L. Electronic devices: conventional current version. Pearson, 2012.

- Coulomb's Law

Electric force between charges

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

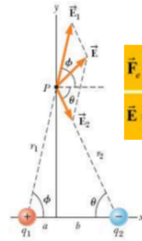
$$k_e = 8.9876\times10^{9}\ \mathrm{N\cdot m^2/C^2}$$

$$k_e = \frac{1}{4\pi\varepsilon_0}$$

$$\varepsilon_0 = 8.8542\times10^{-12}\ \mathrm{C^2/N\cdot m^2}$$

$$e = 1.60218\times10^{-19}\ \mathrm{C}$$

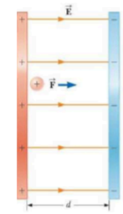
Electric field due to charges



$$\vec{F}_e = k_e \frac{q q_0}{r^2}\hat{r}$$

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

- Motion of a charged particle in uniform E field



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Reading / Preparation for Next Week

Topics for next week:

- Continuous Charge Distributions and Gauss's Law (Ch. 23)
  - Electric field of cont. charge dist.
  - Electric flux
  - Gauss's Law
  - Application of Gauss's law to various charge distributions
- Electrical Potential (Ch. 24)
  - Electric potential and potential difference
  - Potential difference in a uniform electric field
  - Electric potential and potential energy due to point charges
  - Obtaining the Electric Field from the Electric Potential
  - Electric potential due to continuous charge distributions
  - Conductors in Electrostatic Equilibrium

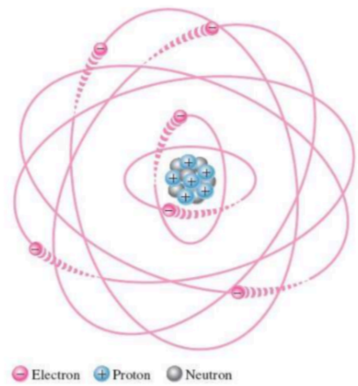
Optional Review Slides

The Atom

The Atom

The Bohr model

- Atom is the smallest particle of an element.
- Classical Bohr model states that atoms have a planetary type of structure:
  - Central nucleus that consists of ***protons*** (+) and ***neutrons*** (0)
  - Surrounded by orbiting ***electrons*** (-)



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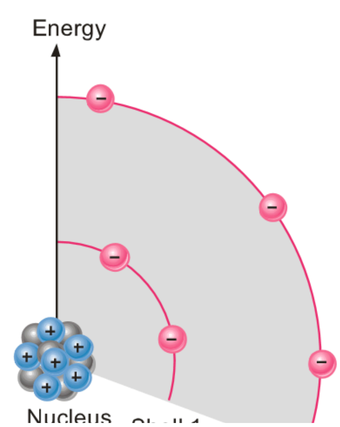
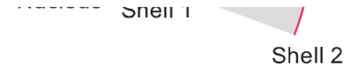
The Atom

The Bohr model

- Atom is the smallest particle of an element.
- Classical Bohr model states that atoms have a planetary type of structure:
  - Central nucleus that consists of ***protons*** (+) and ***neutrons*** (0)
  - Surrounded by orbiting ***electrons*** (-)
- Electrons orbit the atom at certain orbits corresponding to certain energy levels – known as ***shells***.





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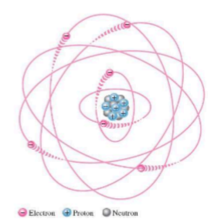
The Atom

Relative size of nucleus

- Different elements have different size atoms but 10^{-10}m (0.1nm) is an average atom diameter.
- The nucleus of the atom is much smaller, about 10^{-15}m. About 1/100,000 of the atom.



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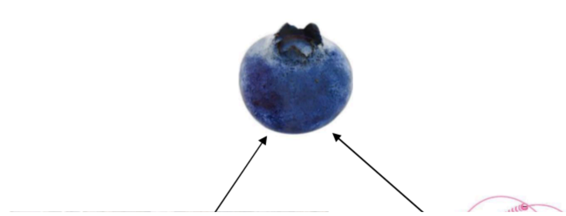
The Atom

Relative size of nucleus



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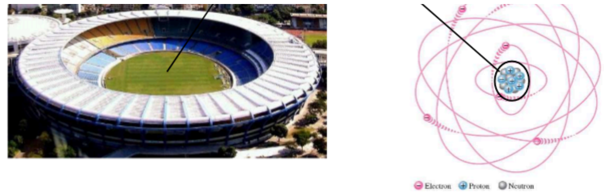
- Even if we use 10 times that, the analogy is like a blueberry at the center of a football stadium.



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https://www.uniworldnews.org/storage/2014/03/Maracana-Stadium1.jpg

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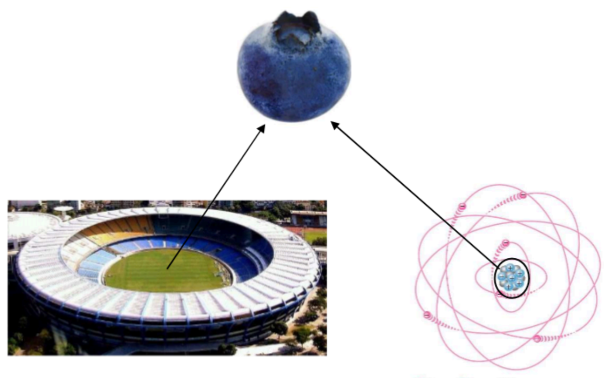
- The nucleus of the atom is much smaller, about 10^{-15}m. About 1/100,000 of the atom.
- Even if we use 10 times that, the analogy is like a blueberry at the center of a football stadium.
- Yet the nucleus carries 99.9% of the mass.



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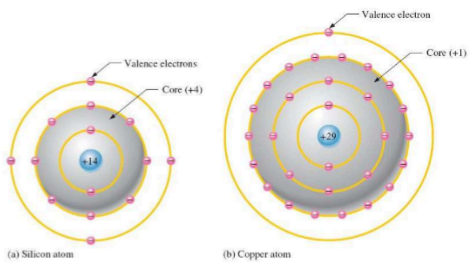
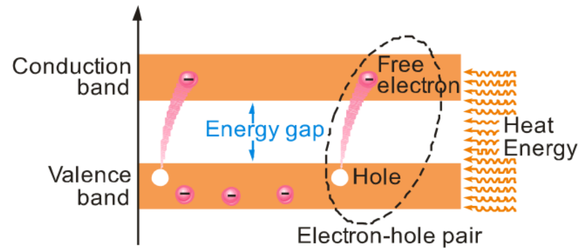
The Atom

Valence electrons

Electrons in the farther orbits from the nucleus have higher energy and are less tightly bound to the atom than those closer to the nucleus. This outermost shell is known as the valence shell.

When a valence electron gains sufficient energy from an external source, it can break free from its atom and becomes a freely moving charged particle – which is the basis for conduction.





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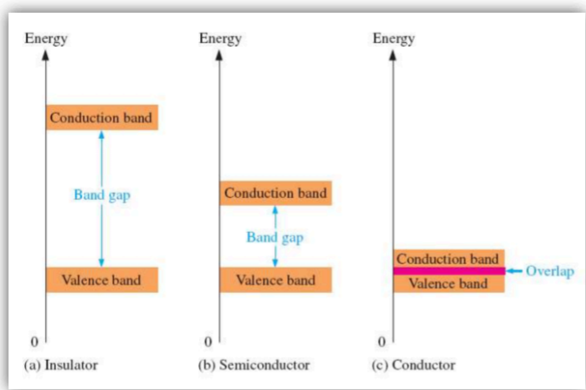
Insulators, conductors and semiconductors

Insulators:
Materials that do not conduct current under normal circumstances. They have very high resistivities. Valence electrons are tightly bound to the atoms; therefore, there are very few free electrons. Ex: rubber, glass, plastics.

Conductors:
Materials that easily conduct electrical current. Most metals are good conductors. The best conductors are single element metals such as copper (Cu), silver (Ag), gold (Au) and aluminum (Al) all of which have a single valence electron that's very loosely bound to the nucleus.

Semiconductors:
Materials that are between conductors and insulators (neither good conductor nor good insulator). Examples to single element semiconductors are Silicon (Si) and germanium (Ge). Example to compound semiconductors are gallium arsenide and gallium nitride.

Energy diagrams for the three types of materials.



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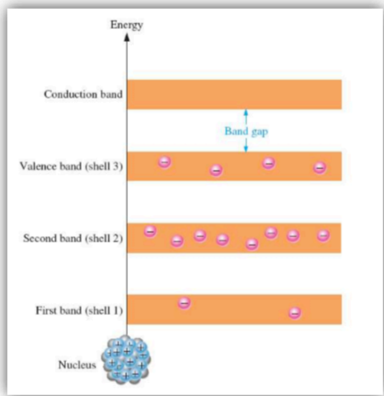
Electrical current in semiconductors

Silicon example

Energy band diagram for unexcited Silicon atom.



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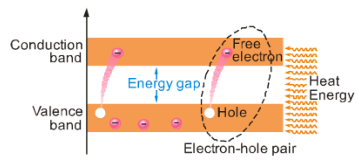
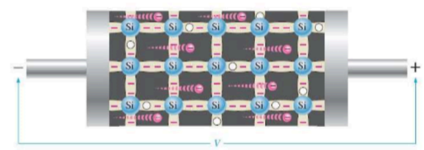
A piece of intrinsic silicon at room temperature has a number of conduction-band (free) electrons that are unattached to any atom. There is also an equal number of holes in the valence band. Together they form ***electron-hole pairs***.

When a voltage is applied electrons and holes will move, creating a current. But it is much weaker than a copper current.





Electrical current in semiconductors

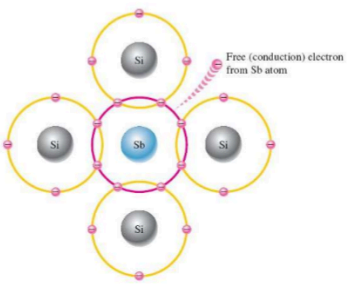
N-type and P-type semiconductors

- ***Electrons*** and ***holes*** enable semiconductors to conduct but they are generally poor conductors.
- Semiconductor conductivity can be drastically increased by the controlled addition of impurities – a process called ***doping***.
- Doping increases the number of electrons or holes.
- N-type has increased electrons, P-type has increased holes.

Electrical current in semiconductors

N-type doping

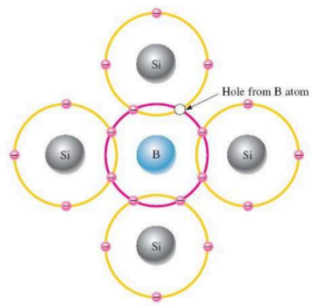
- To increase the number of electrons, ***pentavalent*** impurity atoms are added. Example: Antimony (Sb) with 5 valence electrons.
- The pentavalent atom (Sb) uses 4 valence electrons for bonds, and gives the 5th electron to conduction band. Sb in this case is called the ***donor atom***.



Source:
Floyd, Thomas L. Electronic devices: conventional current version. Pearson, 2012.

P-type doping

- To increase the number of holes, ***trivalent*** impurity atoms are added. Example: Boron (B) with 3 valence electrons.
- The trivalent atom (B) uses 4 valence electrons from adjacent Si atoms, resulting in a hole. B in this case is called the ***acceptor atom***.



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