



الجامعة السعودية الإلكترونية
SAUDI ELECTRONIC UNIVERSITY
2011-1432

College of Computing and
Informatics
Data Science Pre-Master Program
SCI 101
General Physics I



SCI 101 General Physics

Week 1

Motion in one dimension

Lecture Outlines

2.1 Position, velocity and speed of a particle

2.2 Instantaneous Velocity and Speed

Weekly Learning Outcomes

- Recall basic and derived physical quantities
- Differentiate distance and displacement, speed and velocity

Required Reading

Chapter 2 Motion in One Dimension in Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 2 Motion Along a Straight Line in Principles of Physics, 10th Edition. John Wiley & Sons

Recommended Video

- Motion along one dimension <https://www.youtube.com/watch?v=EhsEIRAIImM8&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=4>
- Motion along straight line <https://www.youtube.com/watch?v=EhsEIRAIImM8&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=3>



Position, velocity and speed of a particle

Section 2.1

Linear Speed

- **Speed** is a “scalar quantity” that does not include a direction.
- I am running at 10 mph, but I do not tell you where – this is speed.
- Speed is my distance covered divided by the time it takes me



Linear Speed

Average Speed

- It would take us a lot longer to drive downtown because of the traffic where we have to slow, stop, start, accelerate, slow, stop, etc.
- Therefore in planning a trip we think about average speed



Average Velocity

Average Velocity

Average Velocity is the Total distance (d) covered divided by the elapsed time (t)

$$v = \frac{d_2 - d_1}{t}$$



Average Velocity

Example 2-1: Runner's average velocity.

The of a runner as a function of time is plotted as moving position along the x axis of a coordinate system. During a 3.00-s time interval, the runner's position changes from $x_1 = 50.0$ m to $x_2 = 30.5$ m, as shown. What was the runner's average velocity?

$$v = \frac{x_2 - x_1}{t} = \frac{30.5 - 50.0}{3} = -6.50 \text{ m/s}$$

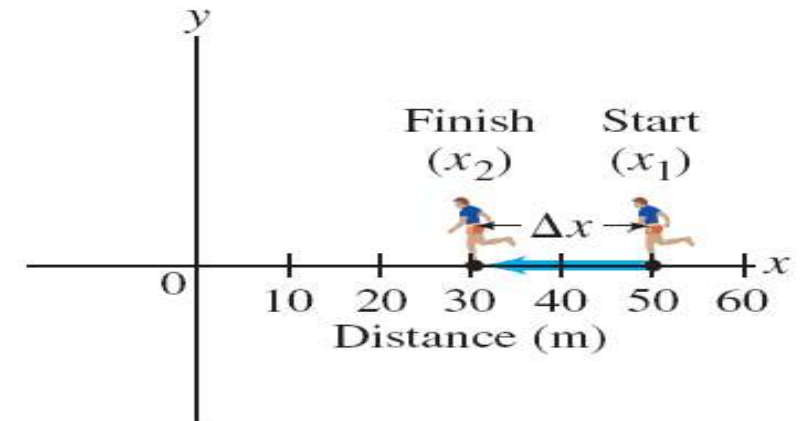


Figure 2-1 : A person runs from $x_1 = 50.0$ m to $x_2 = 30.5$ m

Instantaneous Velocity and Speed

Section 2.2

Instantaneous Velocity

- The instantaneous velocity is the average velocity in the limit as the time interval becomes infinitesimally short.
- Ideally, a speedometer would measure instantaneous velocity; in fact, it measures average velocity, but over a very short time interval.

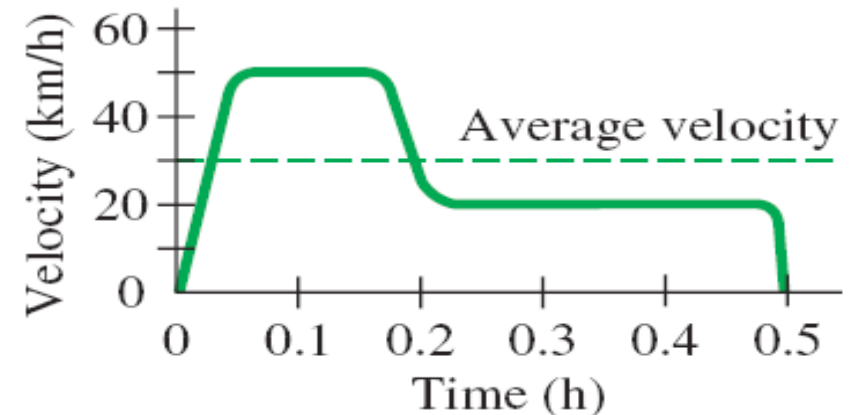
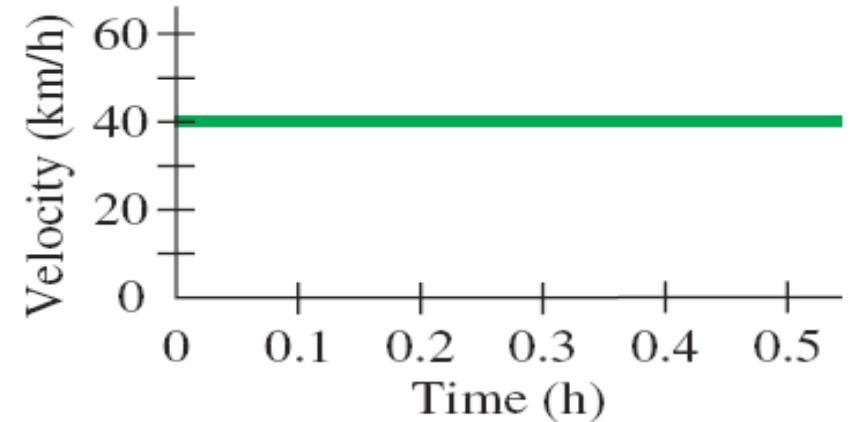
$$v = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$



Car speedometer showing mi/h in white, and km/h in orange.

Instantaneous Velocity

- The instantaneous speed always equals the magnitude of the instantaneous velocity.
- it only equals the average velocity if the velocity is constant.



Velocity of a car as a function of time:
(a) at constant velocity;
(b) with varying velocity

Instantaneous Velocity

Remark :

- Going in a straight line at the same speed is called **Constant Velocity**.
- But if we change our speed (brake at a light) or our direction (turn a corner) then we have a **Changing Velocity**
- Changing our speed or direction is **Acceleration**

Acceleration

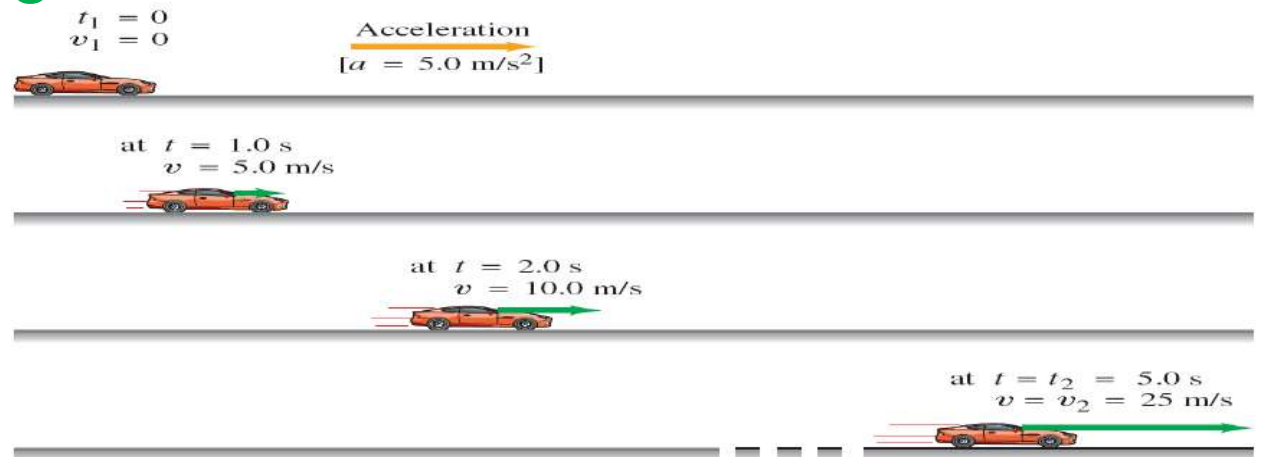
Acceleration is the rate of change of velocity.

$$\text{average acceleration} = \frac{\text{change of velocity}}{\text{time elapsed}}.$$

Example : Average acceleration.

A car accelerates along a straight road from rest to 25 m/s in 5.0 s.
What is the magnitude of its average acceleration?

$$a = \frac{v_2 - v_1}{t} = \frac{25 - 0}{5} = 5 \text{ m/s}^2$$



Acceleration

Conceptual Example : Velocity and acceleration.

- (a) If the velocity of an object is zero, does it mean that the acceleration is zero?
- (b) If the acceleration is zero, does it mean that the velocity is zero? Think of some examples.

Linear Acceleration

- **Acceleration** is how quickly velocity changes

$$a = \frac{v_2 - v_1}{t}$$

Example :

What is the acceleration if we accelerate in a car from stop to 60 km/h in 5 seconds?

$$a = \frac{v_2 - v_1}{t} = \frac{60 - 0}{5} = 12 \text{ m/s}^2$$



Thank
You





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Week 2

Motion in one dimension + Vectors

Lecture Outlines

2.7 Particles under constant acceleration

2.8 Freely Falling objects

3.0 Vectors

3.2 Vector and Scalar Quantities

3.3 Basic Vector Arithmetic

3.4 Component of Vector and Unit Vector

Weekly Learning Outcomes

- Understand motion with constant acceleration
- State freely falling motion and solve related problems
- Recall scalar and Vector quantities
- Introduce the concept of unit vector along three directions
- Outline the vector multiplications
- Estimate dot and cross product of vectors

Required Reading

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- <https://www.youtube.com/watch?v=4QnsrZV1rKw>



Particles under constant acceleration

Section 2.7

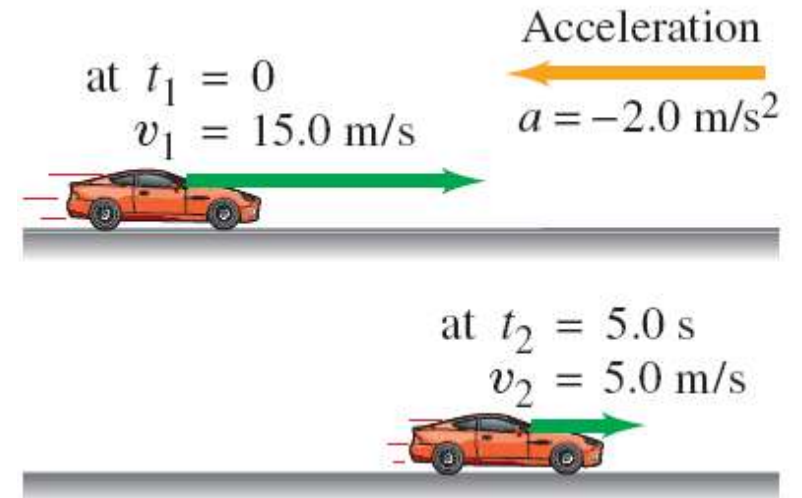
Acceleration

Example : Car slowing down.

An automobile is moving to the right along a straight highway, which we choose to be the positive x axis. Then the driver puts on the brakes. If the initial velocity (when the driver hits the brakes) is $v_1 = 15.0$ m/s, and it takes 5.0 s to slow down to $v_2 = 5.0$ m/s, what was the car's average acceleration?

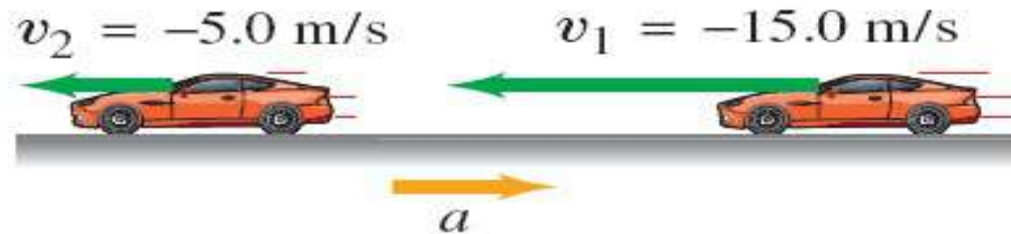
$$a = \frac{v_2 - v_1}{t} = \frac{5 - 15}{5} = -2 \text{ m/s}^2$$

Notice that the average acceleration is negative because it is in the negative x direction, and the car is slowing down



Acceleration

- There is a difference between negative acceleration and deceleration
- Negative acceleration is acceleration in the negative direction as defined by the coordinate system.
- Deceleration occurs when the acceleration is opposite in direction to the velocity.

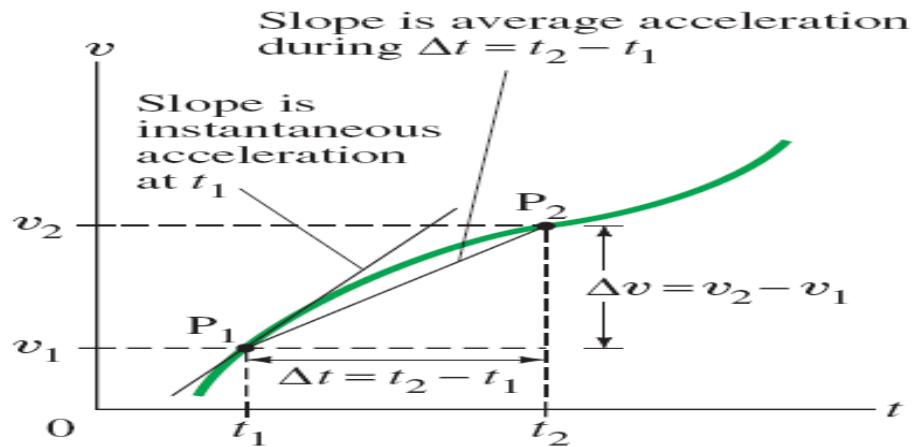


The car now moving to the *left* and decelerating. The acceleration is $+2.0 \text{ m/s}^2$.

Acceleration

The instantaneous acceleration is the average acceleration in the limit as the time interval becomes infinitesimally short.

$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$



A graph of velocity v vs. time t . The average acceleration over a time interval $\Delta t = t_2 - t_1$ is the slope of the straight line P_1P_2 : $a_{av} = \Delta v / \Delta t$. The instantaneous acceleration at time t_1 is the slope of the v vs. t curve at that instant.

Motion at Constant Acceleration

Example : A particle is moving in a straight line so that its position is given by the relation $x = (2.10 \text{ m/s}^2)t^2 + (2.80 \text{ m})$.

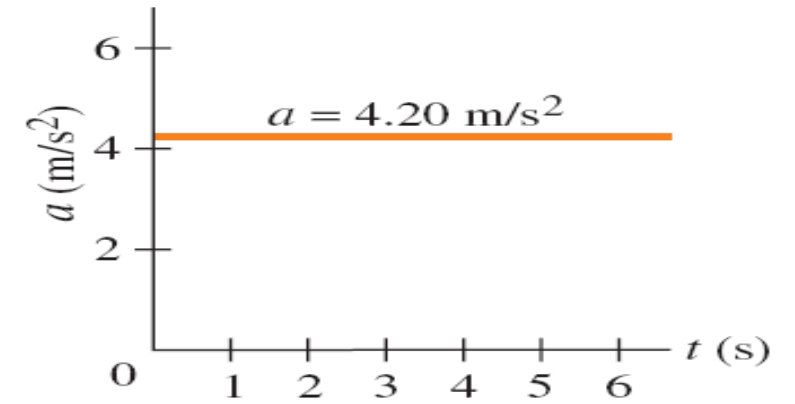
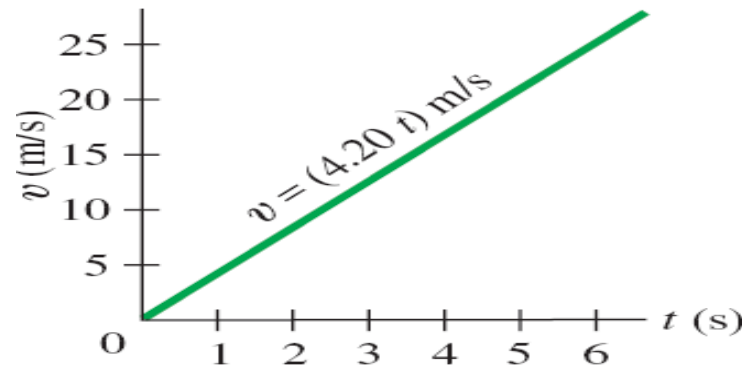
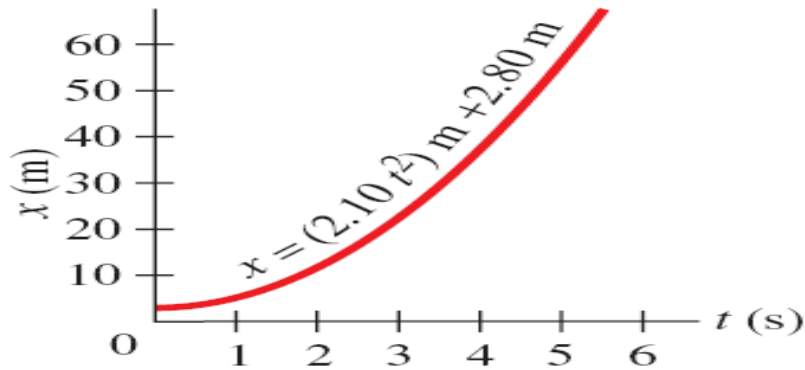
Calculate (a) its average acceleration during the time interval from $t_1 = 3.00 \text{ s}$ to $t_2 = 5.00 \text{ s}$, and

$$\begin{aligned} v(t) &= \frac{dx}{dt} = 4.20 t \\ v_1 &= v(3) = 4.20(3) \\ &= 12.6 \text{ m/s} \\ v_2 &= v(5) = 4.20(5) \\ &= 21 \text{ m/s} \\ a &= \frac{v_2 - v_1}{t_2 - t_1} = \frac{21 - 12.6}{5 - 3} \\ &= 4.20 \text{ m/s}^2 \end{aligned}$$

Motion at Constant Acceleration

(b) its instantaneous acceleration as a function of time.

$$a = \frac{dv}{dt} = \frac{d}{dt} [4.20 t] = 4.20 \text{ m/s}^2$$



Graphs of (a) x vs. t , (b) v vs. t , and (c) a vs. t for the motion $x = At^2 + B$. Note that x increases linearly with t^2 and that the acceleration a is constant. Also, v is the slope of the x vs. t curve, whereas a is the slope of the v vs. t curve.

Motion at Constant Acceleration

The average velocity of an object during a time interval t is

$$v = \frac{\Delta x}{\Delta t} = \frac{x - x_0}{t - t_0}$$

The acceleration, assumed constant, is

$$a = \frac{v - v_0}{t - t_0}$$

Motion at Constant Acceleration

In addition, as the velocity is increasing at a constant rate, we know that

$$\bar{v} = \frac{v_0 + v}{2}$$

Combining these last three equations, we find:

$$x = x_0 + v_0 t + \frac{1}{2} a t^2.$$

We can also combine these equations so as to eliminate t :

$$v^2 = v_0^2 + 2a(x - x_0).$$

Motion at Constant Acceleration

We now have all the equations we need to solve constant-acceleration problems.

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\bar{v} = \frac{v + v_0}{2}.$$

Freely Falling Objects

Section 2.8

Freely Falling Objects

- Near the surface of the Earth, all objects experience approximately the same acceleration due to gravity.
- This is one of the most common examples of motion with constant acceleration.

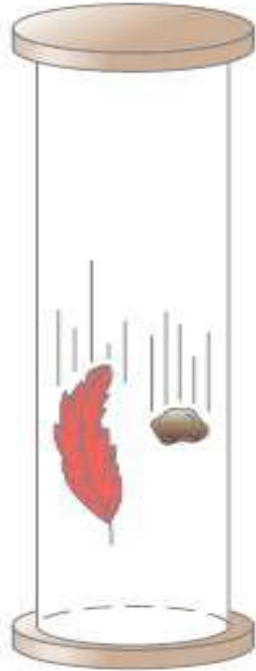


Multi-flash photograph of a falling apple, at equal time intervals. The apple falls farther during each successive interval, which means it is accelerating.

Freely Falling Objects



Air-filled tube



Evacuated tube

A rock and a feather are dropped simultaneously
(a) in air, (b) in a vacuum.

- The acceleration due to gravity at the Earth's surface is approximately 9.80 m/s^2 .
- At a given location on the Earth and in the absence of air resistance, all objects fall with the same constant acceleration.

Freely Falling Objects

Example : Falling from a tower.

Suppose that a ball is dropped ($v_0 = 0$) from a tower 70.0 m high. How far will it have fallen after a time $t_1 = 1.00$ s, $t_2 = 2.00$ s, and $t_3 = 3.00$ s? Ignore air resistance.

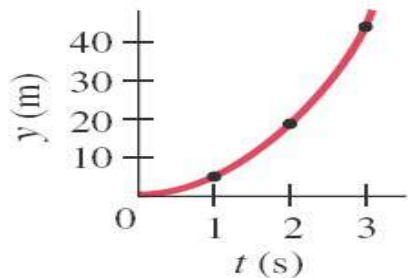
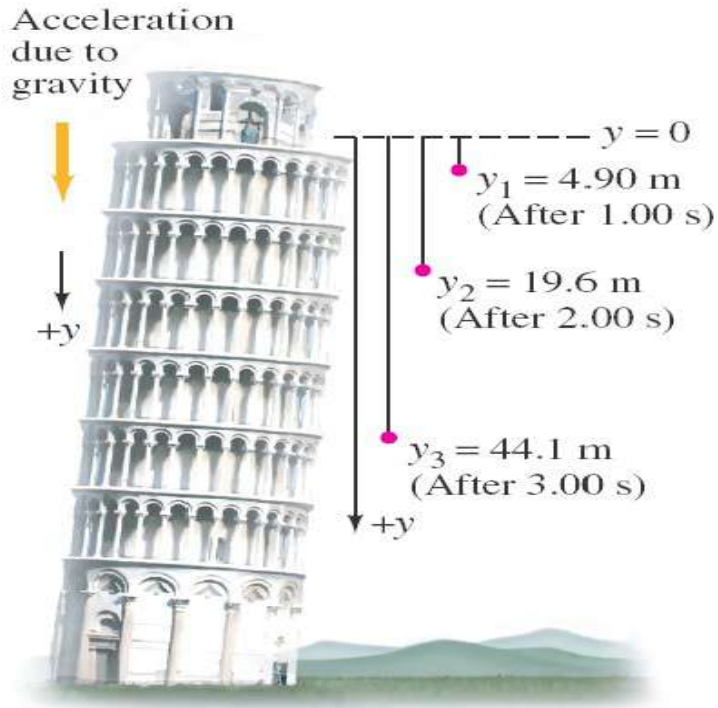
$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$x = 0 + 0 + \frac{1}{2} g t^2 = \frac{1}{2} (9.8) t^2 = 4.9 t^2 \Rightarrow$$

$$x(1) = 4.9(1^2) = 4.9 \text{ m}$$

$$x(2) = 4.9(2^2) = 19.6 \text{ m}$$

$$x(3) = 4.9(3^2) = 44.1 \text{ m}$$



Freely Falling Objects

Example : Consider a ball thrown upward with initial velocity of 15 m/s, and make more calculations. Calculate (a) how much time it takes for the ball to reach the maximum height

Notice that when the ball reaches its maximum height, its velocity becomes zero

$$v_0 = 15 \text{ m/s}$$

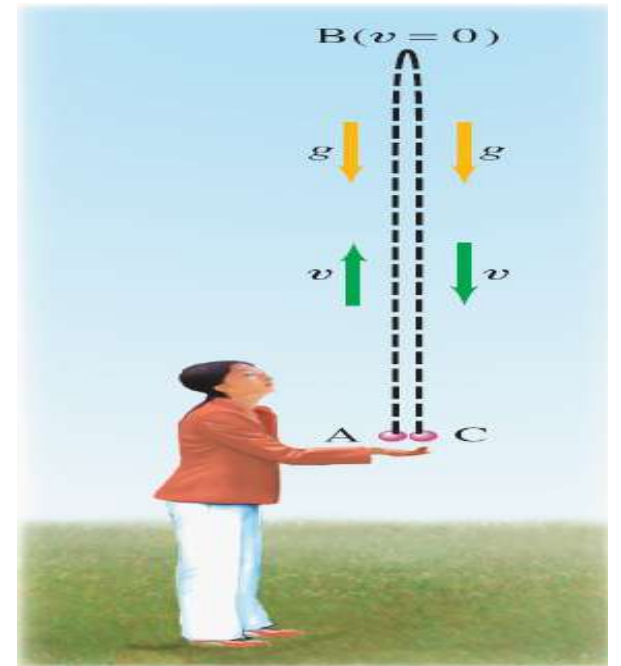
$$v = 0$$

$$v = v_0 + at$$

$$v = v_0 - gt$$

$$0 = 15 - (9.8)t$$

$$t = \frac{15}{9.8} \approx 1.53$$



Freely Falling Objects

b) The maximum height is obtained from the following formula

$$y = y_0 + v_0 t + \frac{1}{2} a t^2$$

$$y = 0 + 15(1.53) + \frac{1}{2}(-9.8)(1.53)^2$$

$$y \approx 11.48m$$

c) Notice that the initial and final position of the ball is zero so we have

$$v^2 = v_0^2 + 2a(y_f - y_i)$$

$$v^2 = (15)^2 - 2(9.8)(0 - 0)$$

$$v^2 = 225$$

$$v = -\sqrt{225} = -15m/s$$

Freely Falling Objects

Example : For a ball thrown upward at an initial speed of 15.0 m/s, calculate at what time t the ball passes a point 8.00 m above the person's hand.

$$v_0 = 15, \quad y_0 = 0, \quad y = 8, \quad a = -g = -9.8, \quad t = ?$$

$$y = y_0 + v_0 t + \frac{1}{2} a t^2 \Rightarrow$$

$$8 = 0 + 15t + \frac{1}{2}(-9.8)t^2$$

$$4.9t^2 - 15t + 8 = 0$$

Let $a = 4.9$, $b = -15$, $c = 8$ then

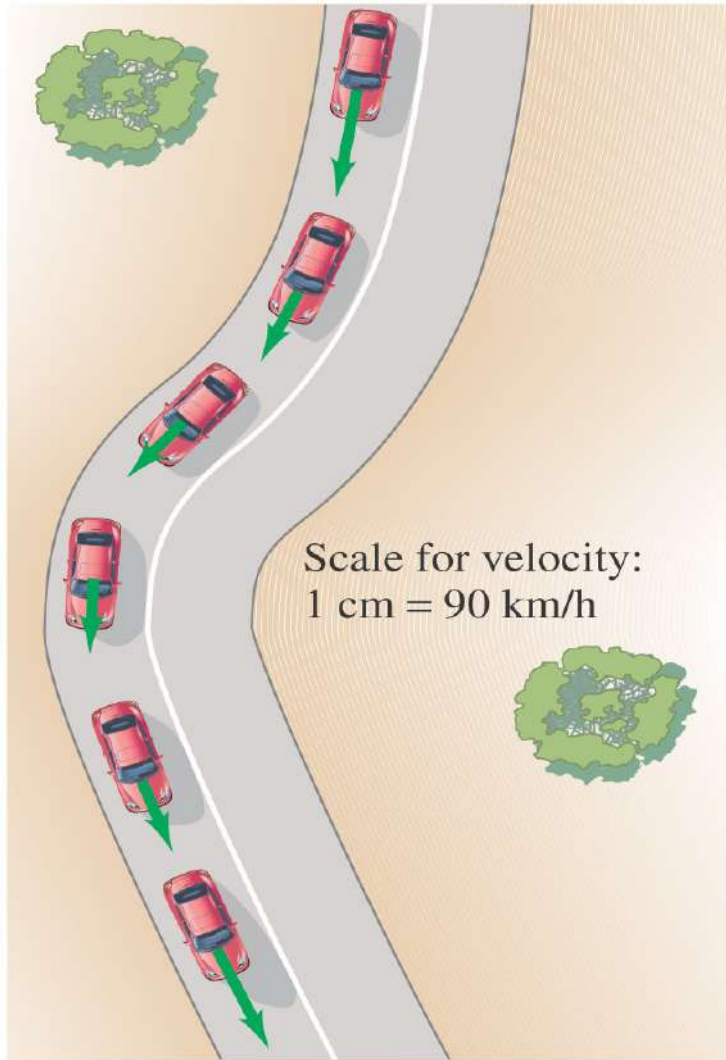
$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-(-15) \pm \sqrt{(-15)^2 - 4(4.9)(8)}}{2(4.9)} \Rightarrow$$

$$t_1 = 0.659 \text{ s} \quad \text{and} \quad t_2 = 2.375 \text{ s}$$

Vectors

Section 3.0

Vectors and Scalars



- A vector has magnitude as well as direction.

Vectors and Scalar Quantities

Section 3.2

Vectors and Scalars

- Some vector quantities:

Displacement, Velocity, Force, Momentum

A scalar has only a magnitude.

- Some scalar quantities:

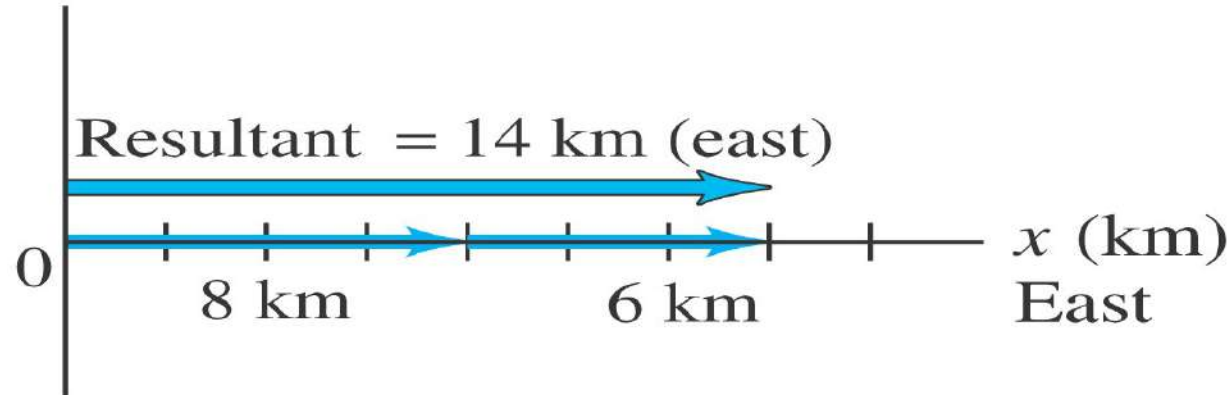
Mass, Time, Temperature

Basic Vectors Arithmetic

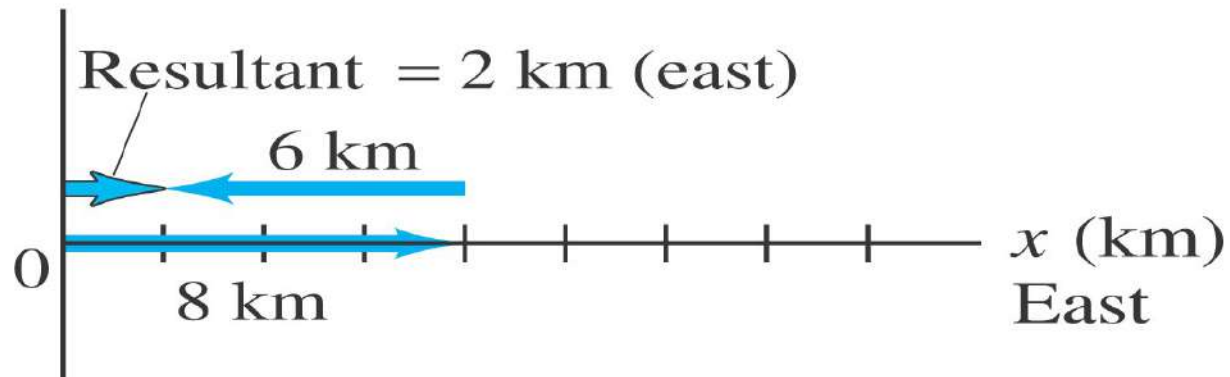
Section 3.3

Additions of Vectors – Graphical Method

Addition of vectors in one dimension,



simple addition and subtraction are all that is needed.

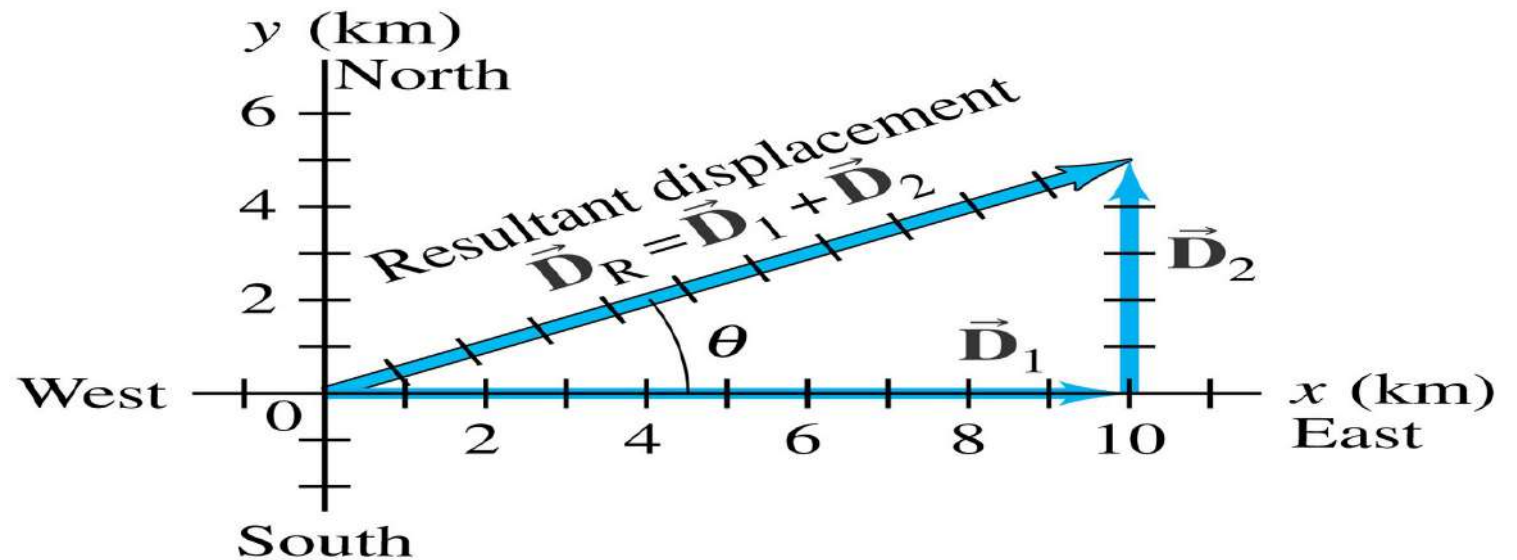


you need to be careful about the signs, as the figure indicates.

Additions of Vectors – Graphical Method

- If the motion is in two dimensions, the situation is somewhat more complicated.
- Here, the actual travel paths are at right angles to one another; we can find the displacement by using the Pythagorean Theorem.

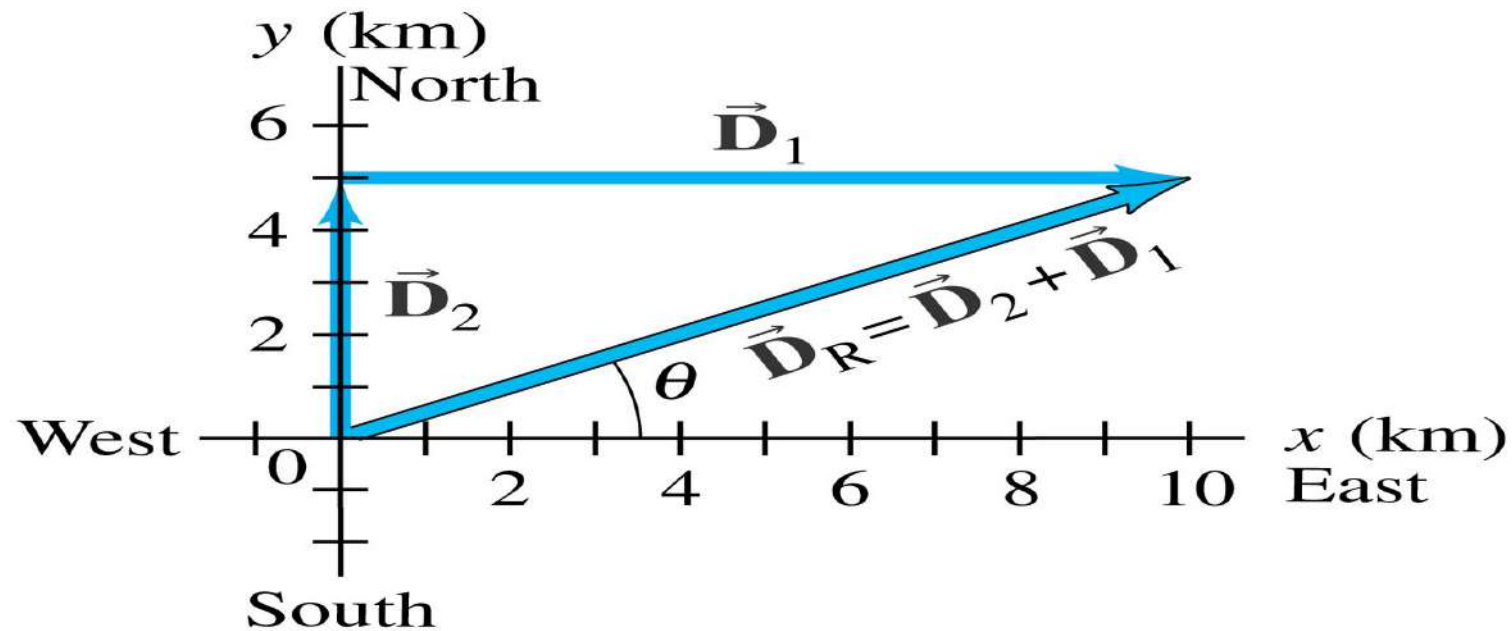
$$D_R = \sqrt{D_1^2 + D_2^2}$$



Additions of Vectors – Graphical Method

Adding the vectors in the opposite order gives the same result:

$$\vec{V}_1 + \vec{V}_2 = \vec{V}_2 + \vec{V}_1$$



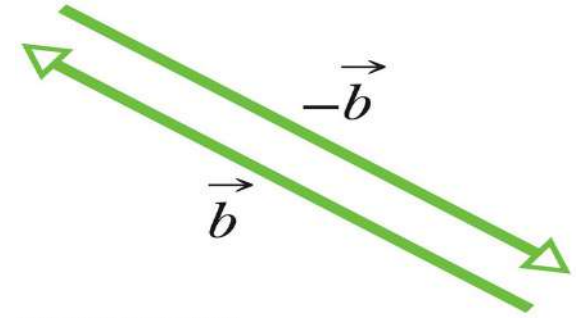
Negative of a Vectors

- A negative sign reverses vector direction

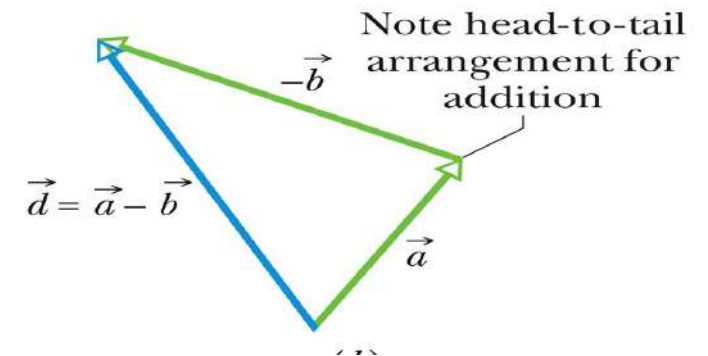
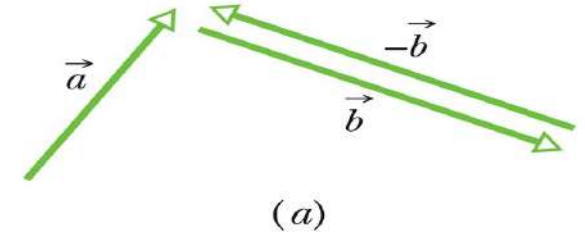
$$\vec{b} + (-\vec{b}) = 0.$$

- We use this to define vector subtraction

$$\vec{d} = \vec{a} - \vec{b} = \vec{a} + (-\vec{b})$$



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Negative of a Vectors

- The negative of a vector is defined as the vector that, when added to the original vector, gives a resultant of zero.

Represented as

- The negative of the vector will have the same magnitude, but point in the opposite direction.

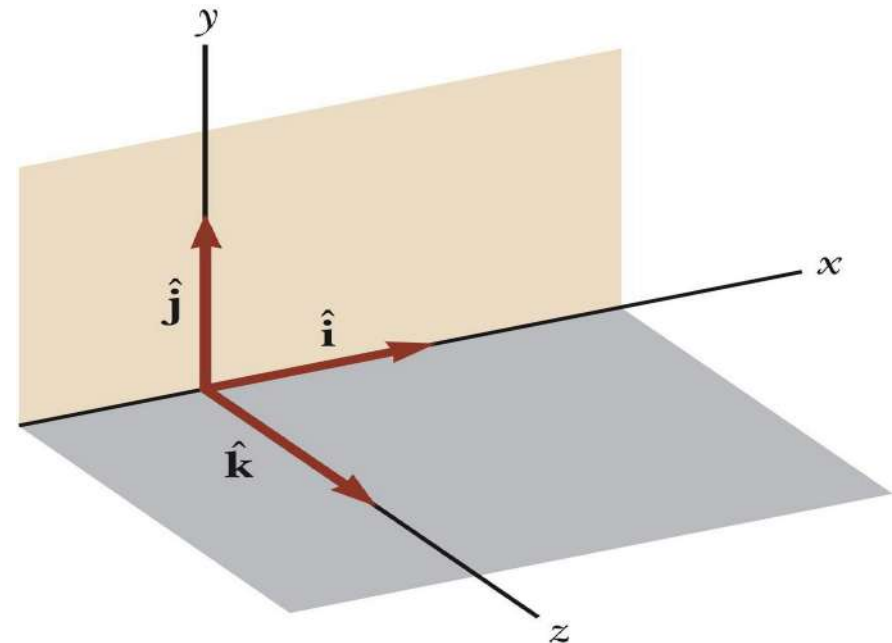
Component of Vectors and Unit Vectors

Section 3.4

Unit Vector

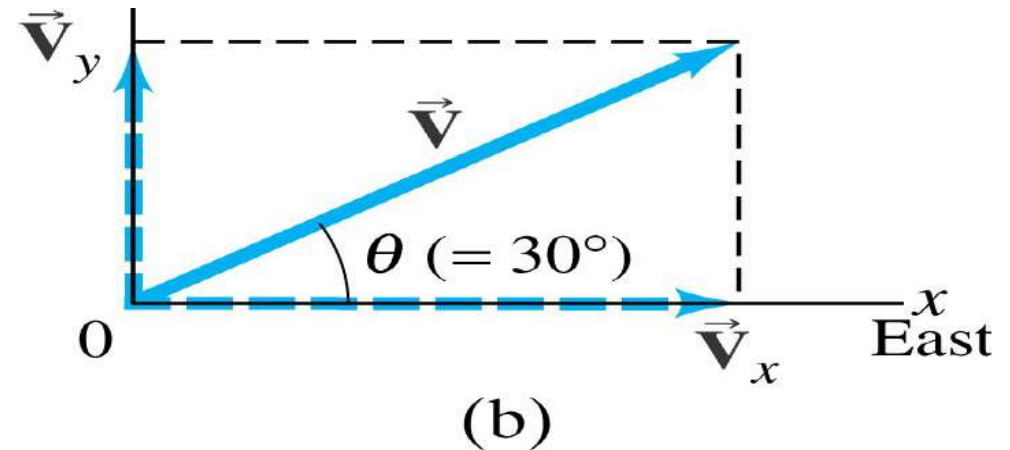
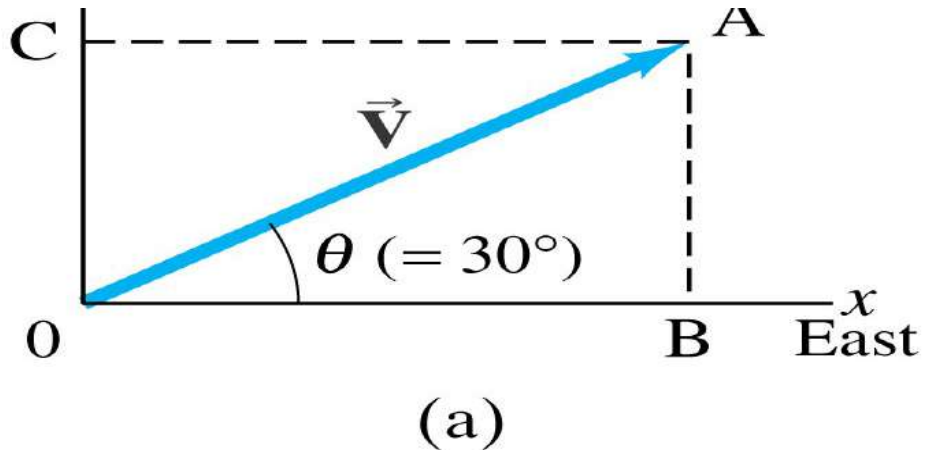
- Unit vectors form a set of mutually perpendicular vectors in a right-handed coordinate system.
- The magnitude of each unit vector is 1

$$|\hat{i}| = |\hat{j}| = |\hat{k}| = 1$$



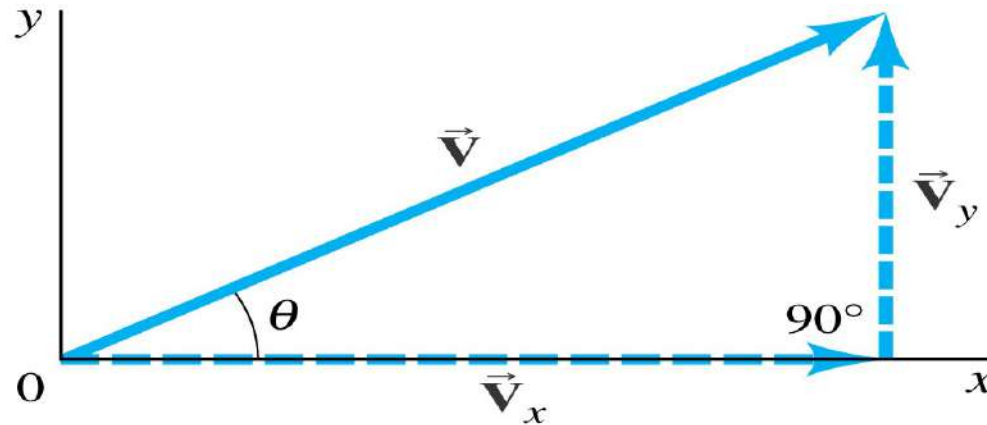
Adding Vectors by Components

- Any vector can be expressed as the sum of two other vectors, which are called its components.
- Usually the other vectors are chosen so that they are perpendicular to each other.



Adding Vectors by Components

If the components are perpendicular, they can be found using trigonometric functions.



$$\sin \theta = \frac{V_y}{V}$$

$$\cos \theta = \frac{V_x}{V}$$

$$\tan \theta = \frac{V_y}{V_x}$$

$$V^2 = V_x^2 + V_y^2$$

Vectors and Their Components

- Components in two dimension can be found by:

$$a_x = a \cos \theta \quad \text{and} \quad a_y = a \sin \theta,$$

where θ is the angle the vector makes with the positive x axis, and a is the vector length

- The length and angle can also be found if the components are known

$$a = \sqrt{a_x^2 + a_y^2} \quad \text{and} \quad \tan \theta = \frac{a_y}{a_x}$$

- Therefore, components fully define a vector

Vectors and Their Components

- Angles may be measured in degrees or radians
- Recall that a full circle is 360° , or 2π rad

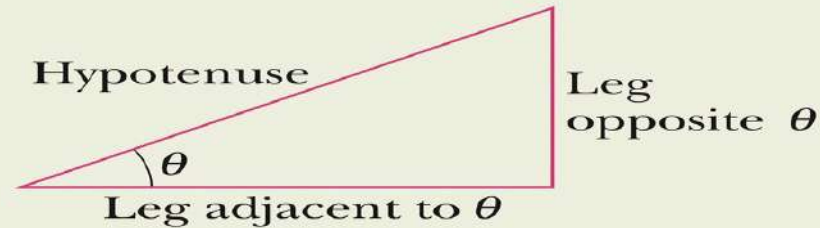
$$40^\circ \frac{2\pi \text{ rad}}{360^\circ} = 0.70 \text{ rad.}$$

- The three basic trigonometric functions

$$\sin \theta = \frac{\text{leg opposite } \theta}{\text{hypotenuse}}$$

$$\cos \theta = \frac{\text{leg adjacent to } \theta}{\text{hypotenuse}}$$

$$\tan \theta = \frac{\text{leg opposite } \theta}{\text{leg adjacent to } \theta}$$



Unit Vectors, Adding Vectors by Components

- The quantities $a_x \mathbf{i}$ and $a_y \mathbf{j}$ are **vector components**

$$\begin{aligned}\vec{a} &= a_x \hat{\mathbf{i}} + a_y \hat{\mathbf{j}} \\ \vec{b} &= b_x \hat{\mathbf{i}} + b_y \hat{\mathbf{j}}.\end{aligned}$$

- Vectors can be added using components
- The quantities a_x and a_y alone are **scalar components**

- Or just “components” as before
 $\vec{r} = \vec{a} + \vec{b},$

$$r_x = a_x + b_x$$

$$r_y = a_y + b_y$$

$$r_z = a_z + b_z.$$

Multiplying Vectors

- Multiplying a vector $\mathbf{z}$ by a scalar c results in a new vector whose magnitude is the magnitude of vector $\mathbf{z}$ times $|c|$ and Its direction is the same as vector $\mathbf{z}$, or opposite if c is negative
- To multiply a vector by a scalar, we can simply multiply each of the components of vector $\mathbf{z}$ by c
- To divide a vector by a scalar we multiply by $1/c$

Example :

Multiply vector $\mathbf{z}$ by 5 where $\mathbf{z} = -3 \mathbf{i} + 5 \mathbf{j}$

$$5 \mathbf{z} = -15 \mathbf{i} + 25 \mathbf{j}$$

Multiplying Vectors

- Multiplying two vectors: the **scalar product**, Also called the **dot product**, results in a scalar, where a and b are magnitudes and ϕ is the angle between the directions of the two vectors:

$$\vec{a} \cdot \vec{b} = ab \cos \phi,$$

- The commutative law applies, and we can do the dot product in component form

$$\vec{a} \cdot \vec{b} = (a_x \hat{i} + a_y \hat{j} + a_z \hat{k}) \cdot (b_x \hat{i} + b_y \hat{j} + b_z \hat{k}),$$

$$\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z.$$

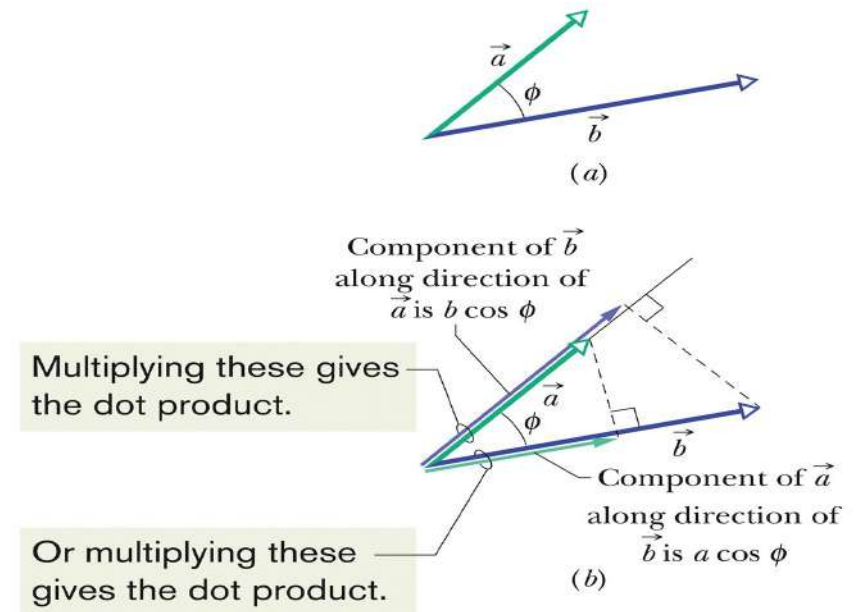
Remark : The dot product is commutative, that is $\vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a}.$

Multiplying Vectors

- A **dot product** is: the product of the magnitude of one vector times the scalar component of the other vector in the direction of the first vector

$$\vec{a} \cdot \vec{b} = (a \cos \phi)(b) = (a)(b \cos \phi).$$

- Either projection of one vector onto the other can be used
- To multiply a vector by the projection, multiply the magnitudes



Multiplying Vectors

Multiplying two vectors: the **vector product**

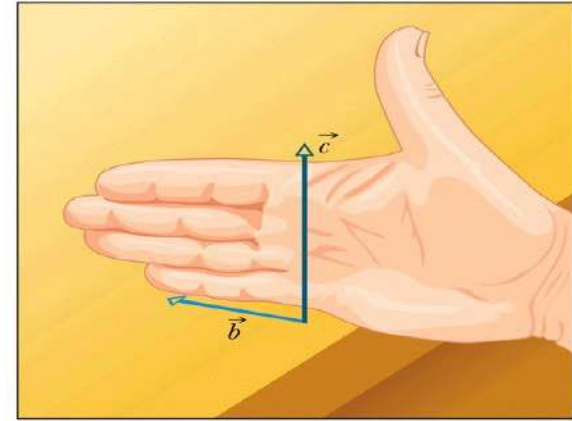
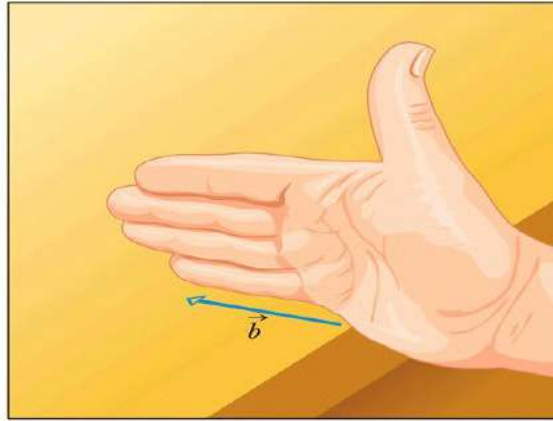
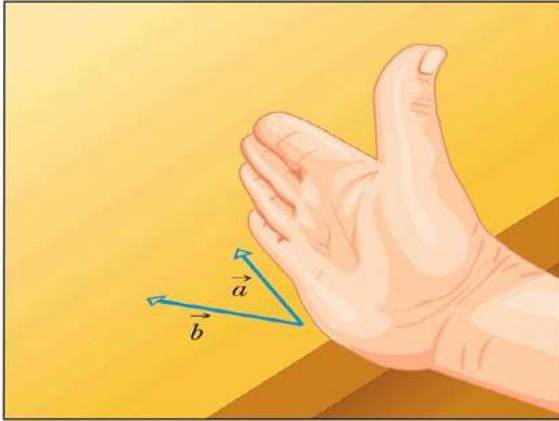
- The **cross product** of two vectors with magnitudes a & b , separated by angle ϕ , produces a vector with magnitude:

$$c = ab \sin \phi,$$

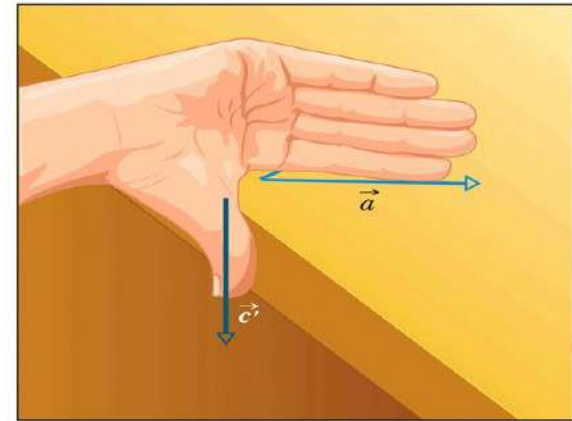
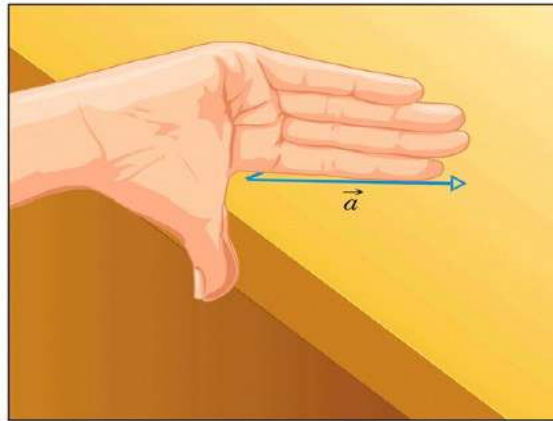
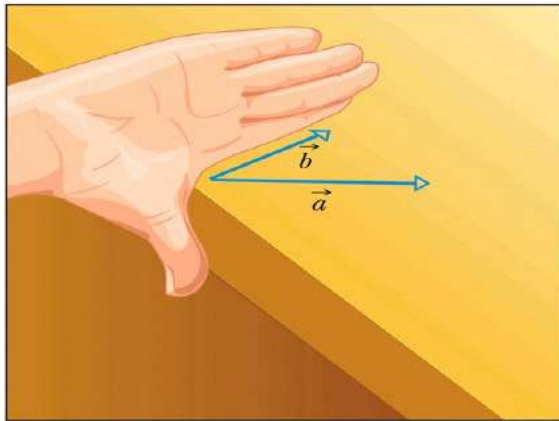
and a direction perpendicular to both original vectors

- Direction is determined by the **right-hand rule**
- Place vectors tail-to-tail, sweep fingers from the first to the second, and thumb points in the direction of the resultant vector

Multiplying Vectors



(a)



(b)

The upper shows vector a cross vector b , the lower shows vector b cross vector a

Multiplying Vectors

- The cross product is not commutative

$$\vec{b} \times \vec{a} = -(\vec{a} \times \vec{b}).$$

- To evaluate, we distribute over components:

$$\vec{a} \times \vec{b} = (a_x \hat{i} + a_y \hat{j} + a_z \hat{k}) \times (b_x \hat{i} + b_y \hat{j} + b_z \hat{k}),$$

$$a_x \hat{i} \times b_x \hat{i} = a_x b_x (\hat{i} \times \hat{i}) = 0,$$

$$a_x \hat{i} \times b_y \hat{j} = a_x b_y (\hat{i} \times \hat{j}) = a_x b_y \hat{k}.$$

- Therefore, by expanding (3-26):

$$\vec{a} \times \vec{b} = (a_y b_z - b_y a_z) \hat{i} + (a_z b_x - b_z a_x) \hat{j} + (a_x b_y - b_x a_y) \hat{k}.$$

If $\vec{a}$ and $\vec{b}$ are parallel or antiparallel, $\vec{a} \times \vec{b} = 0$. The magnitude of $\vec{a} \times \vec{b}$, which can be written as $|\vec{a} \times \vec{b}|$, is maximum when $\vec{a}$ and $\vec{b}$ are perpendicular to each other.

Multiplying Vectors

Example :

Find the cross product $A \times B$ where the vectors $A=(1,0,1)$ and $B=(-1,0,1)$

$$\begin{aligned} A \times B &= \begin{vmatrix} i & j & k \\ 1 & 0 & 1 \\ -1 & 0 & 1 \end{vmatrix} = \\ & \begin{vmatrix} 0 & 1 \\ 0 & 1 \end{vmatrix} i - \begin{vmatrix} 1 & 1 \\ -1 & 1 \end{vmatrix} j + \begin{vmatrix} 1 & 0 \\ -1 & 0 \end{vmatrix} k = \\ & 0i - 2j + 0k = -2j \\ A \times B &= (0, -2, 0) \end{aligned}$$

Thank
You



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College of Computing and
Informatics
Data Science Pre-Master Program
SCI 101
General Physics I



SCI 101 General Physics

Week 3

Motion in Two Dimension

Lecture Outlines

4.0 Motion in Two Dimensions

4.1 Position, velocity and acceleration

4.2 Two dimensional motion with constant acceleration

4.3 Projectile Motion

4.4 Analysis Model: Particle in Uniform Circular Motion

Weekly Learning Outcomes

- Recall Vectors and properties
- Describe Position, Velocity, and Acceleration Vectors
- Differentiate between displacement and distance, velocity and speed
- Analyze projectile motion and calculation of related physical quantities
- Analyze uniform circular motion and calculation of centripetal acceleration

Required Reading

Chapter 4 : Motion in Two Dimensions in in Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 4 : Motion in two and three dimensions in Principles of Physics, 10th Edition. John Wiley & Sons

Recommended Video

- Projectile Motion

<https://www.youtube.com/watch?v=8NLzuURxFwY>

Motion in Two Dimension

Section 4.0

Motion in Two Dimension

- Vectors can be implemented to study motion in two dimensions
- Two important types of two dimensional motions are
 - Projectile motion such as throwing baseball
 - Circular motion such as the motion of planet around the sun

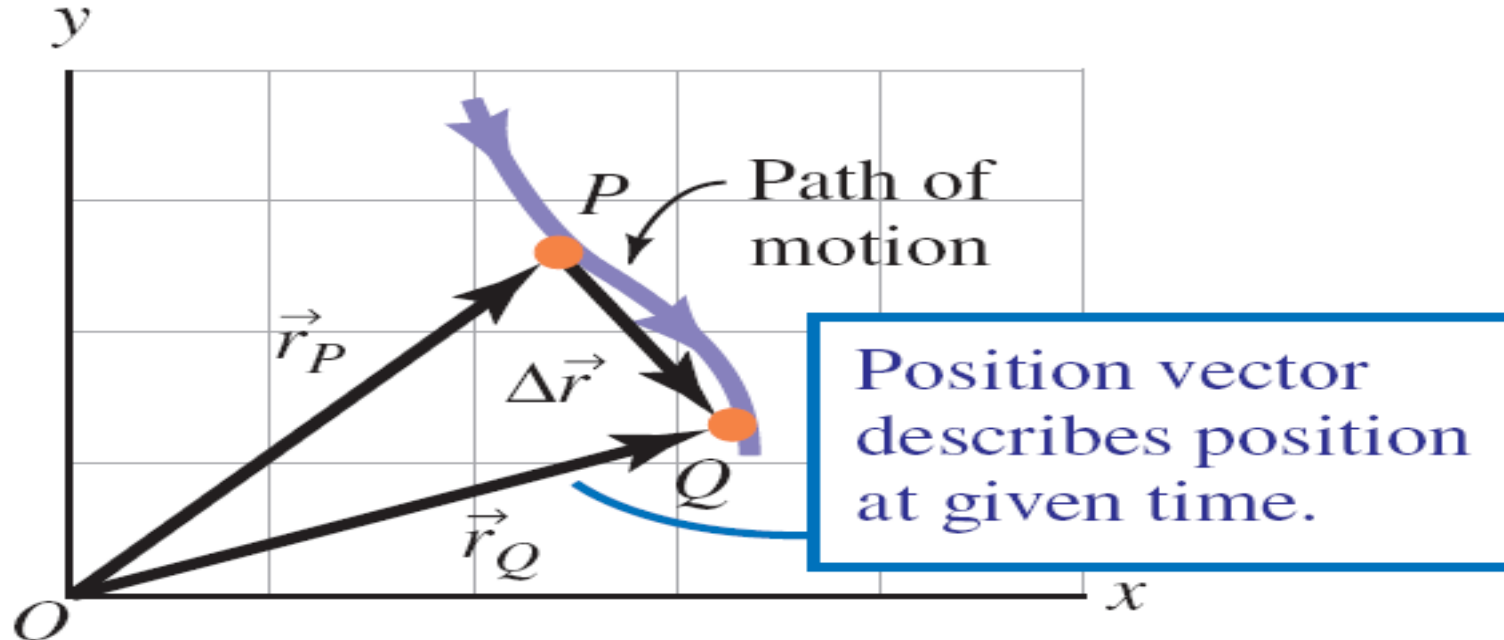
Position, velocity and acceleration

Section 4.1

Position and Displacement

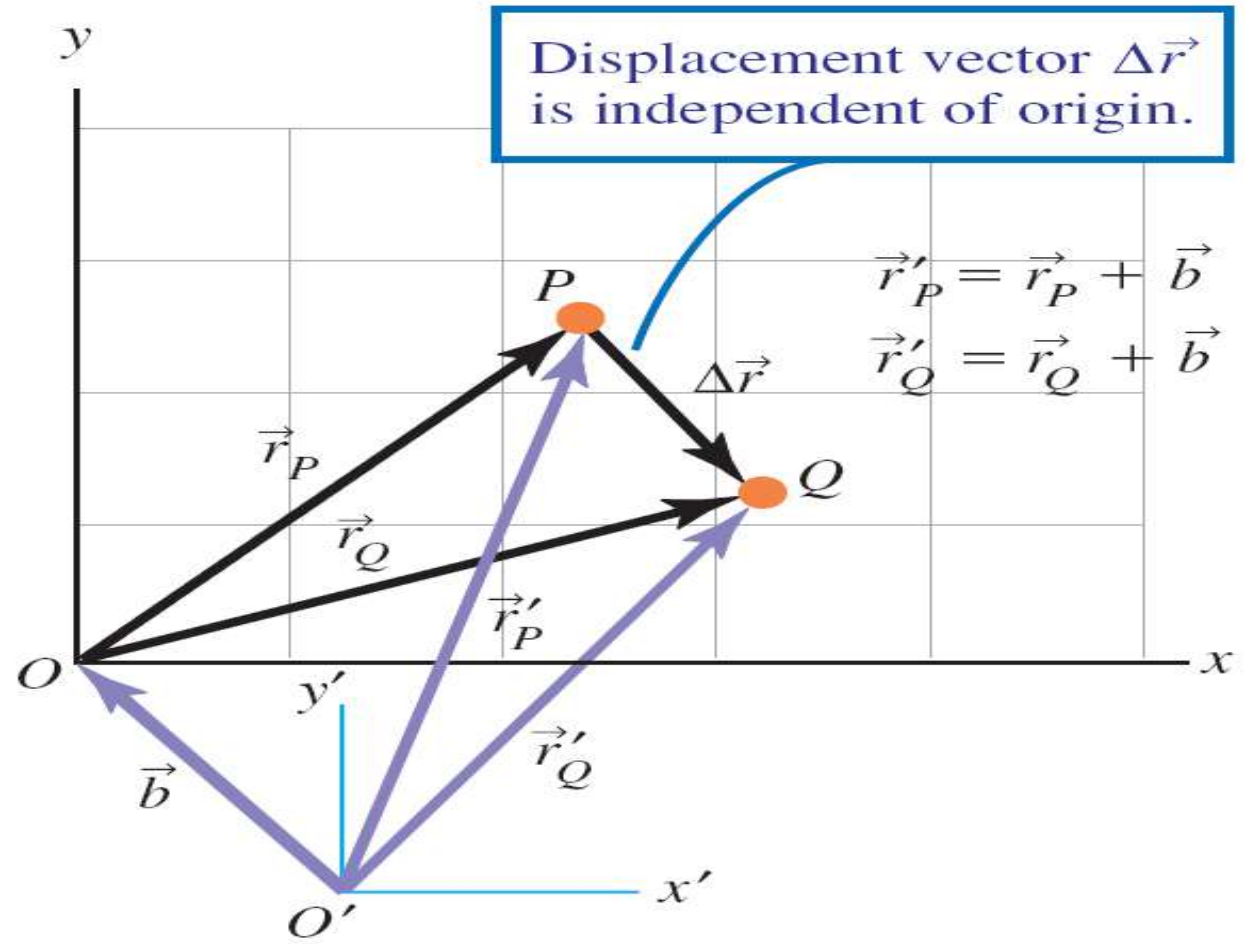
- We can measure position from the origin of coordinate system
- Displacement vector is difference of two position vectors

$$\Delta \vec{r} \equiv \vec{r}_Q - \vec{r}_P$$



Position and Displacement

Position vectors depend on the origin of a coordinate system, but displacement vector does not



Position and Displacement

- Change in position vector is **displacement**

$$\Delta \vec{r} \equiv \vec{r}_Q - \vec{r}_P$$

- We can rewrite this as:

$$\Delta \vec{r} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k},$$

Or express it in terms of changes in each coordinate:

$$\Delta \vec{r} = \Delta x \hat{i} + \Delta y \hat{j} + \Delta z \hat{k}.$$

Average Velocity and Instantaneous Velocity

- **Average velocity** is a displacement divided by its time interval
- We can write this in component form:

$$\vec{v}_{\text{avg}} = \frac{\Delta \vec{r}}{\Delta t}.$$

$$\vec{v}_{\text{avg}} = \frac{\Delta x \hat{i} + \Delta y \hat{j} + \Delta z \hat{k}}{\Delta t} = \frac{\Delta x}{\Delta t} \hat{i} + \frac{\Delta y}{\Delta t} \hat{j} + \frac{\Delta z}{\Delta t} \hat{k}.$$

Example

A particle moves through displacement $(12 \text{ m})\hat{i} + (3.0 \text{ m})\hat{k}$ in 2.0 s:

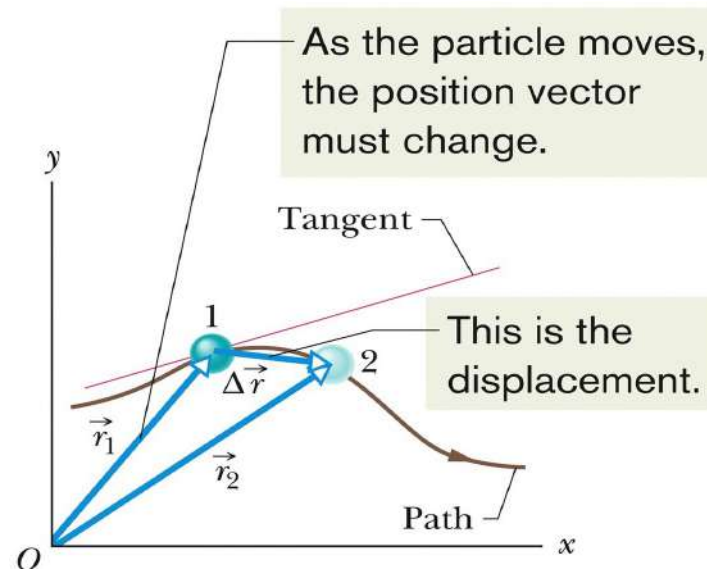
$$\vec{v}_{\text{avg}} = \frac{\Delta \vec{r}}{\Delta t} = \frac{(12 \text{ m})\hat{i} + (3.0 \text{ m})\hat{k}}{2.0 \text{ s}} = (6.0 \text{ m/s})\hat{i} + (1.5 \text{ m/s})\hat{k}.$$

Average Velocity and Instantaneous Velocity

- **Instantaneous velocity** is defined as the velocity of a particle at a single point in time

$$\vec{v} = \frac{d\vec{r}}{dt}.$$

- The limit of avg. velocity as the time interval shrinks to 0



Visualize displacement and instantaneous velocity

Average Velocity and Instantaneous Velocity

- The direction of instantaneous velocity of a particle is always tangent to the particle's path at the particle's position

$$\vec{v} = \frac{d}{dt} (x\hat{i} + y\hat{j} + z\hat{k}) = \frac{dx}{dt} \hat{i} + \frac{dy}{dt} \hat{j} + \frac{dz}{dt} \hat{k}.$$

- In unit-vector notation:

$$v_x = \frac{dx}{dt}, \quad v_y = \frac{dy}{dt}, \quad \text{and} \quad v_z = \frac{dz}{dt}.$$

$$\vec{v} = v_x \hat{i} + v_y \hat{j} + v_z \hat{k},$$

- A velocity vector shows direction and magnitude

Average Velocity and Instantaneous Velocity

- Average acceleration is defined as change in velocity divided by its time interval

$$\vec{a}_{\text{avg}} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{\Delta \vec{v}}{\Delta t}.$$

$$\vec{a} \equiv \lim_{\Delta t \rightarrow 0} \frac{\vec{v}(t + \Delta t) - \vec{v}(t)}{\Delta t} = \frac{d\vec{v}}{dt}$$

- Instantaneous acceleration is acceleration at a given moment

$$\vec{a} = \frac{d\vec{v}}{dt}.$$

Average Velocity and Instantaneous Velocity

- Acceleration in unit-vector form

$$\begin{aligned}\vec{a} &= \frac{d}{dt} (v_x \hat{i} + v_y \hat{j} + v_z \hat{k}) \\ &= \frac{dv_x}{dt} \hat{i} + \frac{dv_y}{dt} \hat{j} + \frac{dv_z}{dt} \hat{k}.\end{aligned}$$

- To get the components of acceleration, we differentiate the components of velocity with respect to time

$$a_x = \frac{dv_x}{dt}, \quad a_y = \frac{dv_y}{dt}, \quad \text{and} \quad a_z = \frac{dv_z}{dt}.$$

$$\vec{a} = a_x \hat{i} + a_y \hat{j} + a_z \hat{k},$$

Two Dimension Motion With Constant Acceleration

Section 4.2

Motion with Constant Acceleration

- Trajectory for projectile motion lies in the plane formed by the initial velocity vector and the acceleration vector
- Position and velocity for constant acceleration are given respectively by

$$\vec{r} = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2} \vec{a} t^2$$

$$\vec{v} = \vec{v}_0 + \vec{a} t$$

Motion with Constant Acceleration

Example : A particle moves in the xy plane, starting from the origin at $t = 0$ with an initial velocity having an x component of 20 m/s and a y component of -15 m/s. The particle experiences an acceleration in the x direction, given by $a_x = 4.0 \text{ m/s}^2$

(A) Determine the total velocity vector at any later time.

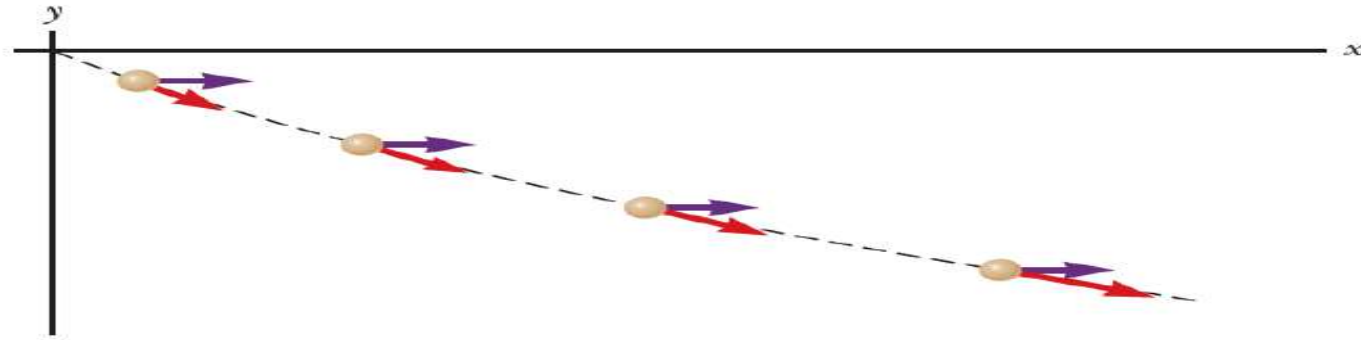


Figure 4.7 (Example 4.1) Motion diagram for the particle. Velocity vectors are shown in red and acceleration vectors in purple.

Motion with Constant Acceleration

$$v_{xi} = 20, \quad v_{yi} = -15, \quad a_x = 4, \quad a_y = 0, \quad \vec{v}(t) = ?$$

$$v_x = v_{x0} + a_x t \Rightarrow$$

$$v_x = 20 + 4t$$

$$v_y = v_{y0} + a_y t \Rightarrow$$

$$v_y = -15 + 0 = -15$$

$$\vec{v} = v_x \hat{i} + v_y \hat{j} \Rightarrow$$

$$\vec{v} = (20 + 4t)\hat{i} - 15\hat{j}$$

Motion with Constant Acceleration

(B) Calculate the velocity of the particle at $t=5.0$ s and the angle the velocity vector makes with the x-axis

Substituting in part (a) gives

$$\vec{v}(5) = (20 + 4 \times 5)\hat{i} - 15\hat{j} = 40\hat{i} - 15\hat{j}$$

To find the angle θ the velocity vector makes we use the following formula :

$$\tan\theta = \frac{v_y}{v_x} = \frac{-15}{40} \Rightarrow \theta = \tan^{-1}\left(\frac{-15}{40}\right) = -21^\circ$$

Motion with Constant Acceleration

(C) Evaluate the speed of the particle

Notice that the speed is the magnitude of the velocity vector $\vec{v}$ so
$$\text{speed} = |\vec{v}| = \sqrt{40^2 + (-15)^2} = 43 \text{ m/s}$$

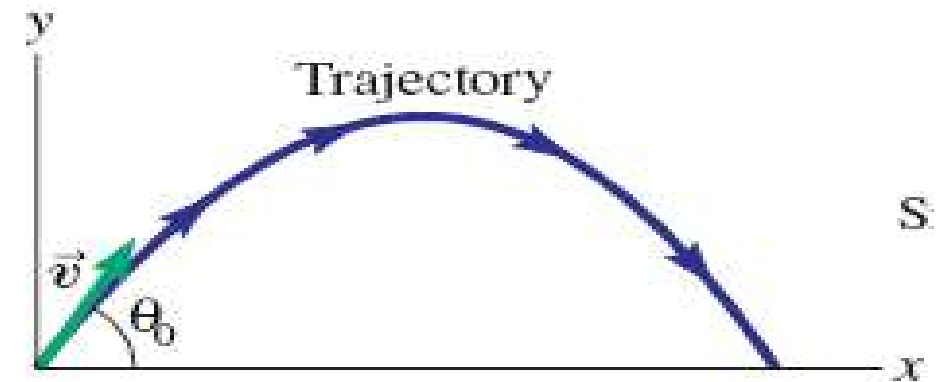
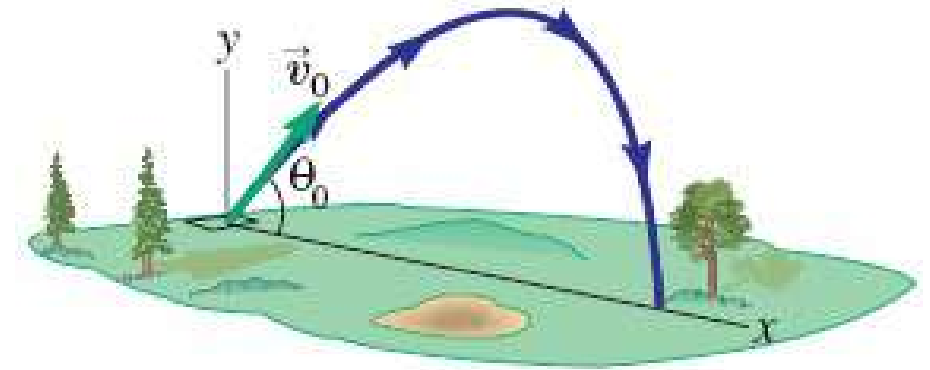
Projectile Motion

Section 4.3

Projectile Motion

Projectile:

- Object moving with the acceleration of gravity
- Path lies in a plane
- x -component of the velocity is constant
- y -component is found using equations for constant acceleration
- Projectile is launched with initial speed v_0 at an angle θ_0 .



Projectile Motion

- A **projectile** is a particle moving in the vertical plane with some initial velocity whose acceleration is always free-fall acceleration (g)
- The motion of a projectile is **projectile motion** launched with an initial velocity v_0

$$\vec{v}_0 = v_{0x}\hat{i} + v_{0y}\hat{j}.$$

$$v_{0x} = v_0 \cos \theta_0 \quad \text{and} \quad v_{0y} = v_0 \sin \theta_0.$$

- In projectile motion, the horizontal motion and the vertical motion are

Projectile Motion

- Horizontal motion: No acceleration, so velocity is constant:

$$x - x_0 = v_{0x}t.$$

$$x - x_0 = (v_0 \cos \theta_0)t.$$

- Vertical motion: Acceleration is always -g:

$$\begin{aligned} y - y_0 &= v_{0y}t - \frac{1}{2}gt^2 \\ &= (v_0 \sin \theta_0)t - \frac{1}{2}gt^2, \end{aligned}$$

$$v_y = v_0 \sin \theta_0 - gt$$

$$v_y^2 = (v_0 \sin \theta_0)^2 - 2g(y - y_0).$$

Projectile Motion

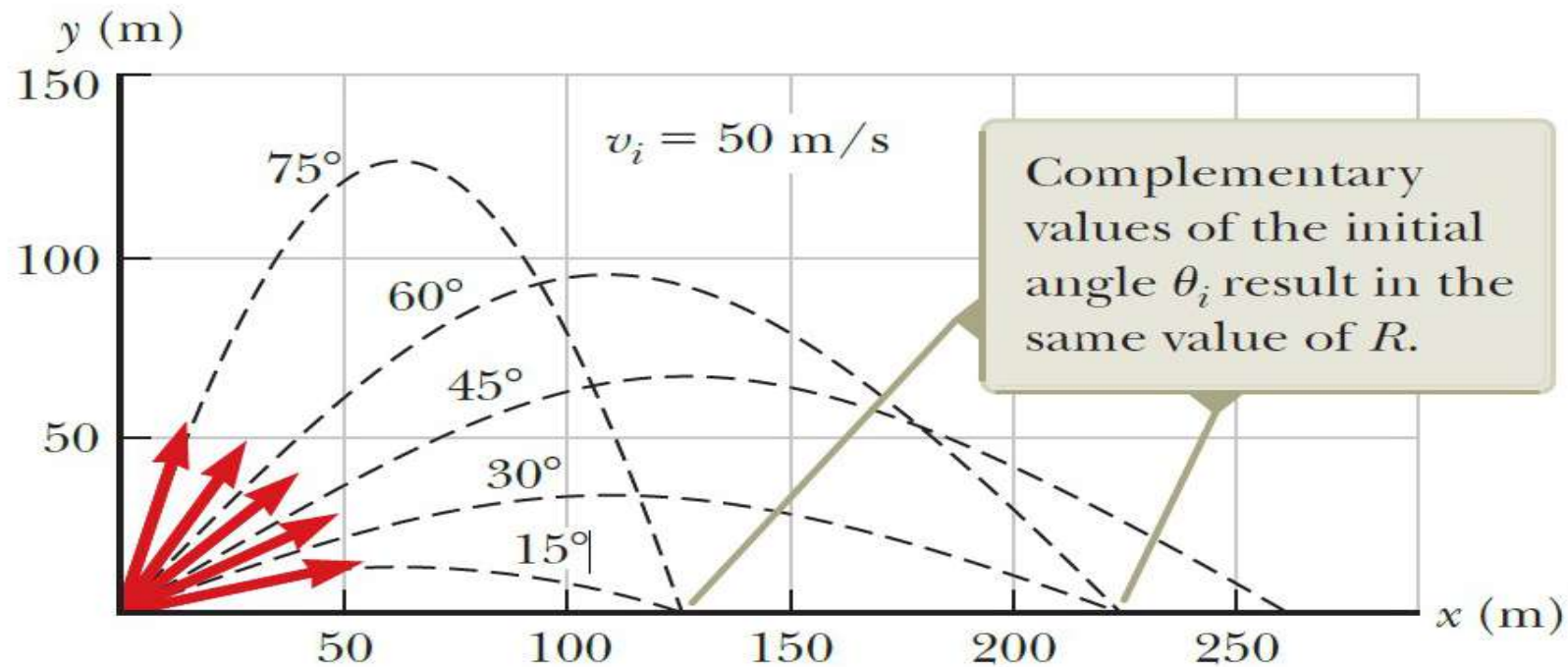
Horizontal range

- The distance the projectile travels in x by the time it returns to its initial height

$$R = \frac{v_0^2}{g} \sin 2\theta_0.$$

- The Horizontal range R is maximum when the launch angle is 45°

Range Vs Angle of projection



A projectile launched over a flat surface from the origin with an initial speed of 50 m/s at various angle of projection

Range Vs Angle of projection

Example : A long jumper leaves the ground at an angle of 20.0° above the horizontal and at a speed of 11.00 m/s.

(A) How far he jump in the horizontal direction?

$$R = \frac{v_i^2 \sin 2\theta_i}{g} = \frac{(11.0 \text{ m/s})^2 \sin 2(20.0^\circ)}{9.80 \text{ m/s}^2} = 7.94 \text{ m}$$

(B) What is the maximum height reached by the jumper ?

$$h = \frac{v_i^2 \sin^2 \theta_i}{2g} = \frac{(11.0 \text{ m/s})^2 (\sin 20.0^\circ)^2}{2(9.80 \text{ m/s}^2)} = 0.722 \text{ m}$$



ADRIAN DENNIS/AFP/Getty Images

Range Vs Angle of projection

Example :

A stone is thrown from the top of a building upward at an angle of 30.0° to the horizontal with an initial speed of 20.0 m/s as shown in Figure 4.14. The height from which the stone is thrown is 45.0 m above the ground.

(A) How long does it take the stone to reach the ground?

$$y_i = 45, \quad y = 0, \quad v_i = 20, \quad a = -g = -9.8, \quad \theta_i = 30, \quad t = ?$$

$$v_{yi} = v_i \sin \theta_i = 20 \sin 30 = 10$$

$$y = y_i + v_{yi}t + \frac{1}{2}at^2 \Rightarrow$$

$$0 = 45 + 10t + \frac{1}{2}(-9.8)t^2 \Rightarrow$$

$$4.9t^2 - 10t - 45 = 0$$

$$\text{Let } A = 4.9, \quad B = -10, \quad C = -45$$

$$t = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} = \frac{-(-10) \pm \sqrt{(-10)^2 - 4(4.9)(-45)}}{2(4.9)}$$

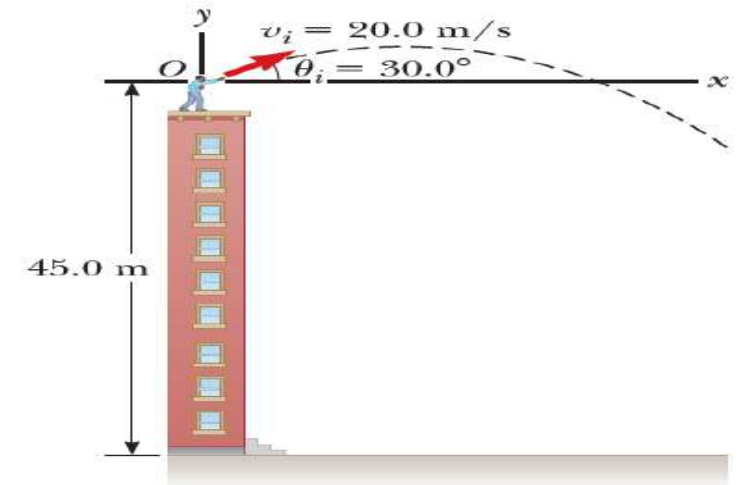


Figure 4.14 A stone is thrown from the top of a building

Range Vs Angle of projection

If we ignore the negative solution we get the following value of t : $t=4.22$ s

(B) What is the speed of the stone just before it strikes the ground?

$$\text{Use } v_y = v_{yi} + a_y t \Rightarrow v_y = v_{yi} - gt$$

$$v_y = 10 - 9.8(4.22) = -31.3$$

$$\text{Recall also that } v_{xi} = v_i \cos \theta_i = 20 \cos 30 = 17.3$$

Since the stone is not accelerating in the horizontal direction we take $a_x = 0$

$$\text{Thus, } v_x = v_{xi} + a_x t = 17.3 + 0(4.22) = 17.3$$

$$\text{Therefore, } \vec{v} = 17.3\hat{i} - 31.3\hat{j}$$

Since the speed is the magnitude of the velocity vector we have

$$\text{speed} = \sqrt{17.3^2 + (-31.3)^2} = 35.8 \text{ m/s}$$

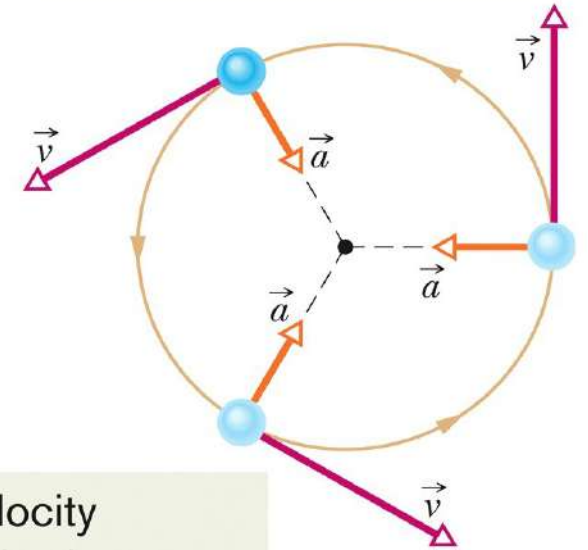
Analysis Model: Particle in Uniform Circular Motion

Section 4.4

Uniform Circular Motion

- A particle is in **uniform circular motion** if it travels around a circle or circular arc at a constant speed
- Since the velocity changes, the particle is accelerating!
- Velocity and acceleration have constant magnitude and changing direction

The acceleration vector always points toward the center.



The velocity vector is always tangent to the path.

Uniform Circular Motion

- Acceleration of a particle undergoing uniform circular motion is called centripetal acceleration Means “center seeking”

$$a = \frac{v^2}{r}$$

- The acceleration is directed radially inward
- The period of revolution is: the time it takes for the particle go around the closed path exactly once

$$T = \frac{2\pi r}{v}$$

- Angular speed of the particle is $\omega = \frac{2\pi}{T}$

Uniform Circular Motion

Example :

What is the angular velocity of a particle in a circular orbit, rotating at the rate of 200 times per minute?

$$T = \frac{60}{200} = 0.3s$$

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.3} = 20.93rad / s$$

Thank
You





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SCI 101 General Physics

Week 4

Newton's laws of motion

Lecture Outlines

5.0 The Laws of Motion

5.1 Concept of Force

5.2 Newton's First Law and Inertial Frames

5.4 Newton's Second Law

5.6 Newton's third Law

5.7 Analysis Models using Newton's second law

5.8 Forces of Friction

Weekly Learning Outcomes

- Recall motion of an object and related physical quantities
- State Newton's first law of motion and define inertia
- Introduce concept of force
- Recognize Newton's second law of motion and solve related problems
- Understand action reaction couple
- State Newton's third law
- Recognize Newton's second law and relation with mass and acceleration
- Understand frictional force and list types of friction
- Solve problems related to Newton's laws of motion and friction

Required Reading

Chapter 4 : The Laws of Motion in Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 5 : Force and Motion I in Principles of Physics,
10th Edition. John Wiley & Sons

Chapter 6 : Force and Motion II in *Principles of Physics*,
10th Edition. John Wiley & Sons

Recommended Video

- <https://www.youtube.com/watch?v=kgLeZuQkyuo&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=7>
- Newton's third law
https://www.youtube.com/watch?v=q31sgw_wuAs&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=8



The Laws of Motion

Section 5.0

The Laws of Motion

- The description of an object in motion included its position, velocity, and acceleration.
- There was no consideration of what might influence that motion.
- Two main factors need to be addressed to answer questions about why the motion of an object will change.
 - Forces acting on the object
 - The mass of the object
- Dynamics studies the causes of motion.
- We Will start with three basic laws of motion formulated by Sir Isaac Newton

The Laws of Motion

Issac Newton 1642 – 1727 major
Contribution to science includes

- Basic laws of mechanics
- Law of Universal Gravitation
- Calculus
- Light and optics



Concept of Force

Section 5.1

Force

- A **force**: Is a “push or pull” acting on an object and it causes acceleration
- We will focus on Newton's three laws of motion:
- Newtonian mechanics is valid for everyday situations
- It is *not* valid for speeds which are an appreciable fraction of the speed of light
- It is *not* valid for objects on the scale of atomic structure
- Newtonian mechanics is viewed as an approximation of general relativity

Force

Characteristics of forces:

- Unit: N, the newton; $1 \text{ N} = 1 \text{ kg m/s}^2$
- Acceleration of a mass is proportional to the exerted force
- Forces are vectors
- Net force is the *vector sum* of all forces on an object

Principle of superposition for forces:

A net force has the same impact as a single force with identical magnitude and direction

Newton's First Law of Motion and Inertial Frames

Section 5.2

Newton's First Law

- In the absence of external forces and when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line).
- Newton's first law is not true in all frames

Inertial frames

- An inertial reference frame is one in which Newton's laws hold
- A frictionless puck, pushed from the north pole, viewed from space
- The same situation, viewed from the ground
- Over *long* distances, the ground is a **non inertial frame**
- A fictitious force would be needed to explain deflection

Newton's Second Law

Section 5.4

Newton's second law

- This law relate mass of the object with net force acts on it and acceleration
- Mass : *“the mass of a body is the characteristic that relates a force on the body to the resulting acceleration”*
- Mass is a measure of a body's resistance to a change in motion (change in velocity)
- It is *not* the same as weight, density, size etc.
- Mass is inversely proportional to acceleration

Newton's second law

Example :

Find the resulting acceleration if we apply an 8.0 N force to various bodies of the following masses:

a) 1 kg b) 2 kg c) 0.5 kg

a) Mass: 1kg $\rightarrow$ acceleration: 8 m/s²

b) Mass: 2kg $\rightarrow$ acceleration: 4 m/s²

c) Mass: 0.5kg $\rightarrow$ acceleration: 16 m/s²

Newton's second law

Newton's Second Law:

The net force on a body is equal to the product of the body's mass and acceleration.

- As an equation, we write: $\vec{F}_{\text{net}} = m\vec{a}$
- Identify the body in question, and *only* include forces that act *on* that body!
- Separate the problem axes (they are independent):

$$F_{\text{net},x} = ma_x, \quad F_{\text{net},y} = ma_y, \quad \text{and} \quad F_{\text{net},z} = ma_z.$$

Newton's second law

If the net force on a body is zero then:

- Its acceleration is zero
- The forces and the body are in *equilibrium*
- *But* there may still be forces!

Newton's second law

SI (System International) unit of force is Newton

Abbreviation : N

System	Force	Mass	Acceleration
SI	newton (N)	kilogram (kg)	m/s ²
CGS ^a	dyne	gram (g)	cm/s ²
British ^b	pound (lb)	slug	ft/s ²

^a1 dyne = 1 g · cm/s².

^b1 lb = 1 slug · ft/s².

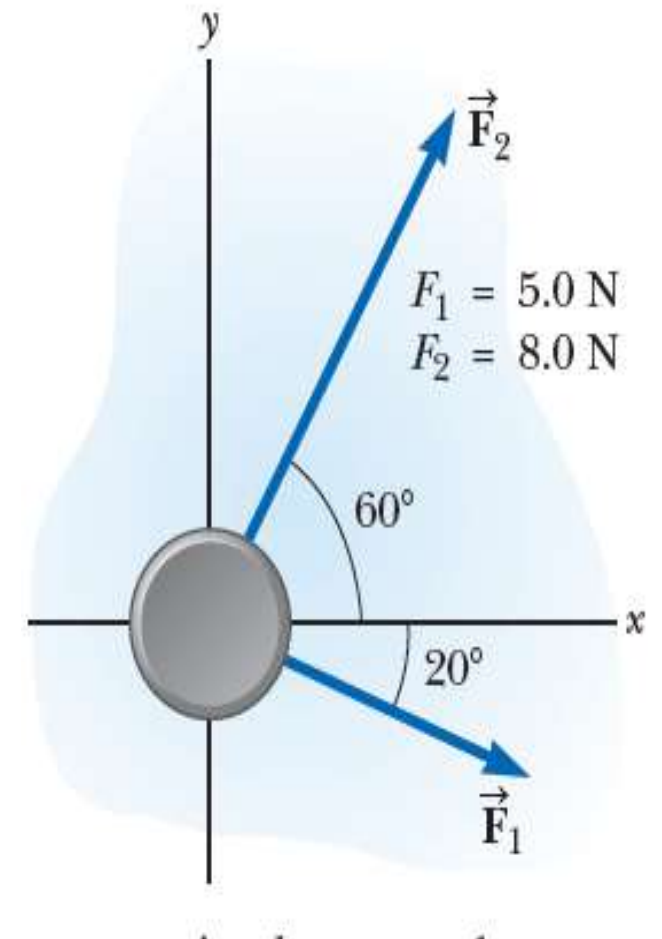
Newton's second law

- A **system** consists of one or more bodies
- Any force on the bodies inside a system exerted by bodies outside the system is an **external force**
- Net force on a system = sum of external forces
- Forces between bodies in a system are called **internal forces** and not included in a FBD *of the system* since internal forces cannot accelerate the system

Newton's second law

Example :

A hockey puck having a mass of 0.30 kg slides on the frictionless, horizontal surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting the forces on the puck shown in Figure 5.4. The force $\vec{F}_1$ has a magnitude of 5.0 N, and is directed at $\theta = 20^\circ$ below the x axis. The force $\vec{F}_2$ has a magnitude of 8.0 N and its direction is $\phi = 60^\circ$ above the x axis. Determine both the magnitude and the direction of the puck's acceleration.



Newton's second law

The component of the net force acting on the puck in the x direction

$$\sum F_x = F_{1x} + F_{2x} = F_1 \cos \theta + F_2 \cos \phi$$

The component of the net force acting on the puck in the y direction:

$$\sum F_y = F_{1y} + F_{2y} = F_1 \sin \theta + F_2 \sin \phi$$

Use Newton's second law in component form (Eq. 5.3) to find the x and y components of the puck's acceleration:

$$a_x = \frac{\sum F_x}{m} = \frac{F_1 \cos \theta + F_2 \cos \phi}{m} \qquad a_y = \frac{\sum F_y}{m} = \frac{F_1 \sin \theta + F_2 \sin \phi}{m}$$

Newton's second law

Substitute numerical values:

$$a_x = \frac{(5.0 \text{ N}) \cos(-20^\circ) + (8.0 \text{ N}) \cos(60^\circ)}{0.30 \text{ kg}} = 29 \text{ m/s}^2$$

$$a_y = \frac{(5.0 \text{ N}) \sin(-20^\circ) + (8.0 \text{ N}) \sin(60^\circ)}{0.30 \text{ kg}} = 17 \text{ m/s}^2$$

The magnitude of the acceleration:

$$a = \sqrt{(29 \text{ m/s}^2)^2 + (17 \text{ m/s}^2)^2} = 34 \text{ m/s}^2$$

The direction of the acceleration relative to the positive x axis:

$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right) = \tan^{-1}\left(\frac{17}{29}\right) = 31^\circ$$

Gravitational force

- Gravitational force is a pull that acts on a body, directed toward a second body.
- Generally we consider situations where the second body is Earth
- In free fall (y direction, with no drag from the air):

$$F_g = mg.$$

- This force still acts on a body at rest!
- In vector form $\vec{F}_g = -F_g \hat{j} = -mg \hat{j} = m \vec{g},$

Weight

- All objects are attracted to the Earth.
- The attractive force exerted by the Earth on an object is called the **gravitational force** .
- This force is directed toward the center of the Earth, and its magnitude is called the **weight** of the object

$$W = F_g \quad (\text{weight, with ground as inertial frame}).$$

Weight

To relate weight to mass, consider an apple in free fall. The only force on the apple is the gravitational force which results in an acceleration of g . Applying Newton's 2nd Law

$$F_{\text{net}} = ma \quad \text{where } F_{\text{net}} = F_g = W \quad \text{and } a = g$$

$$F_g = W = mg$$

Thus,

$$W = mg \quad (\text{mass - weight relationship})$$

Weight

Measuring weight:

- Use a balance to compare a body to known masses, find its mass, and compute its weight
- Use a spring scale that measures weight on a calibrated scale
- Weight is not the same as mass: a pan balance will read the same for different values of g , a scale will read differently for different values of g
- Weight must be measured when the body is not accelerating vertically

E.g., in your bathroom, or on a train but not in an elevator

SI (System International) unit of weight is Newton (N)

Weight

Example:

What is the weight of a person with a mass of 70.0 kg on the earth

$$\text{Weight} = \text{mass} \times 9.8 \text{ m/s}^2$$

$$\text{Weight} = 70.0 \text{ kg} \times 9.8 \text{ m/s}^2$$

$$\text{Weight} = 686 \text{ N}$$

$$\text{Remember that } 1 \text{ N} = (1 \text{ kg}) (1 \text{ m/s}^2)$$

Difference between mass and weight

- Mass is the amount of matter in an object. This does not change in an object as it moves away from the earth.
- Weight is caused by gravity. Therefore, the greater the distance, the less the force of attraction. The less the distance the greater the force of attraction.
- Your weight is dependent upon the mass of the earth. If you were able to go to the planet, Jupiter, your weight would be 27 times greater, because the mass of Jupiter is 27 times greater.

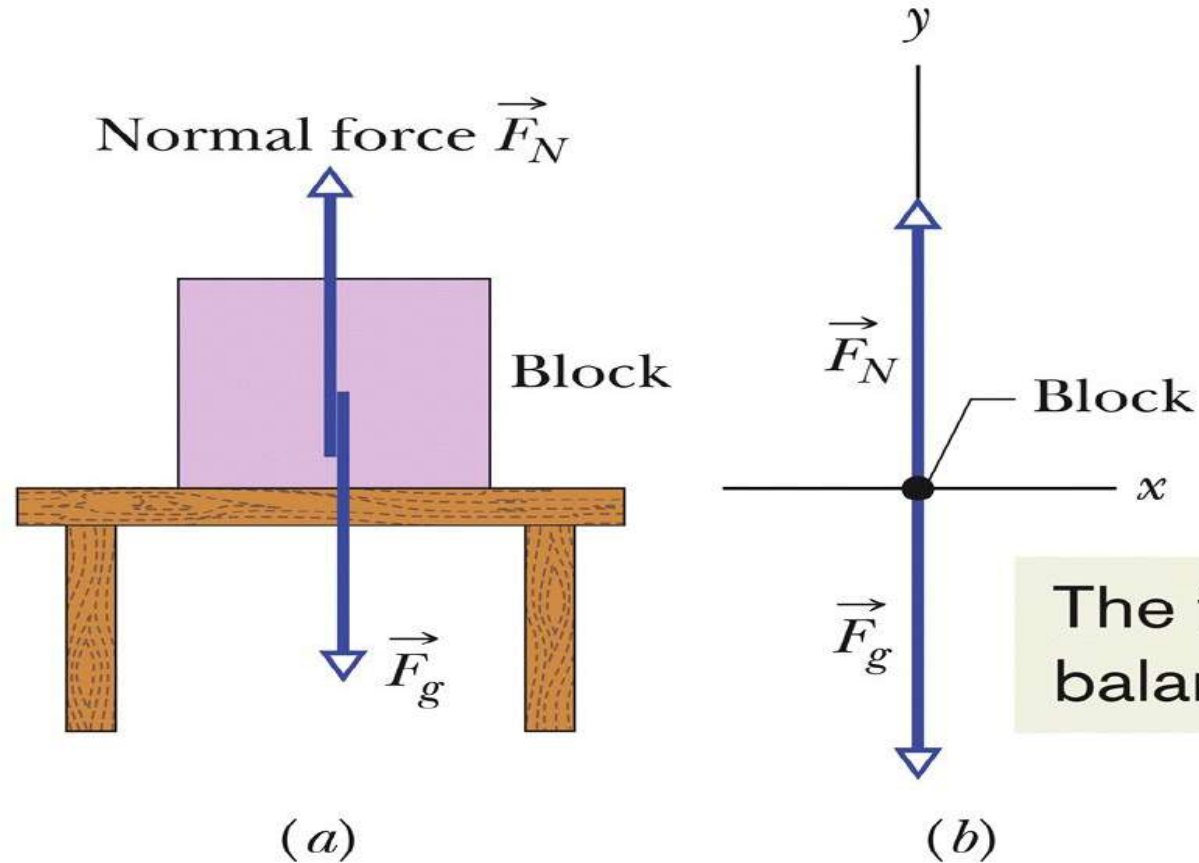
The Normal Force

- If you are standing on a surface, the push back **on** you from the surface (due to deformation) is the normal force
- Normal means perpendicular
- When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a normal force that is perpendicular to the surface

The Normal Force

The normal force is the force on the block from the supporting table.

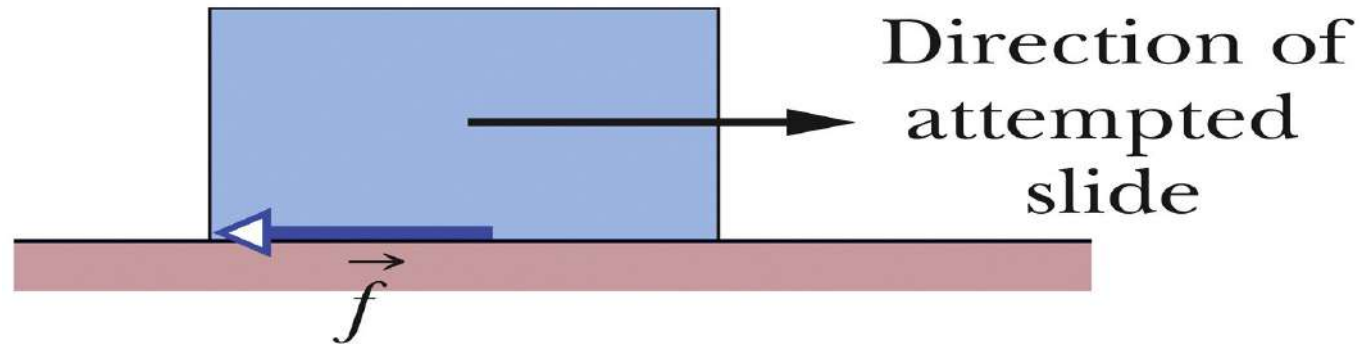
The gravitational force on the block is due to Earth's downward pull.



The forces balance.

Frictional force or friction

- Friction occurs when one object slides or attempts to slide over another .
- Friction is directed along the surface, opposite to the direction of intended motion



Tension force

- A cord (or rope, etc.) is attached to a body and pulled taut
- Cord pulls on the body with force T directed along the cord
- The cord is said to be *under tension*
- The tension in the cord is T

Tension force

- A *massless* and *an stretchable* cord exists only as a connection between two bodies.
- It pulls on both with the same force, T
- True even if the bodies and cord are accelerating, and even if the cord runs around a *massless, frictionless pulley*
- These are useful simplifying assumptions

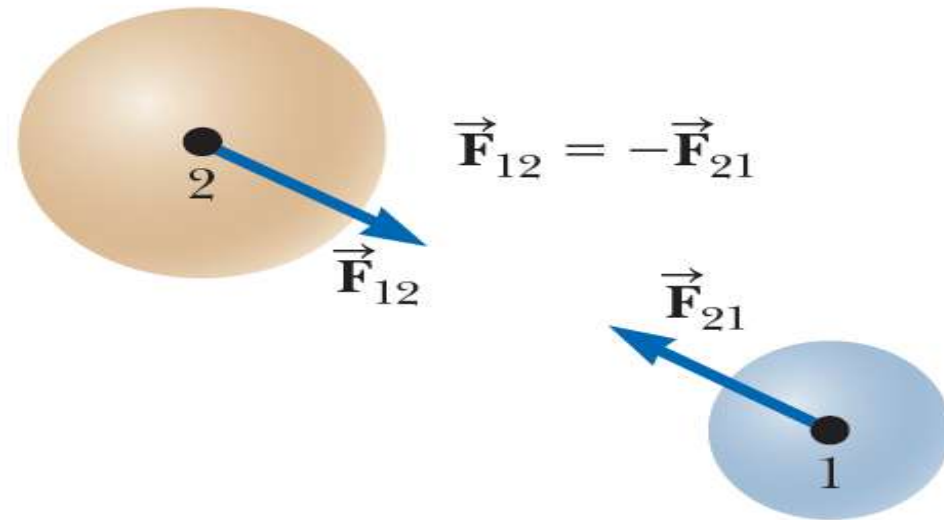
Newton's Third Law

Section 5.6

Newton's Third Law

If two objects interact, the force exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force exerted by object 2 on object 1

$$\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$$



The Particle in Equilibrium

- If the acceleration of an object modeled as a particle is zero, the object is treated with the **particle in equilibrium** model.
- In this model, the net force on the object is zero:

$$\sum \vec{F} = 0$$

The Particle Under a Net Force

- If an object experiences an acceleration, its motion can be analyzed with the **particle under a net force** model.
- The appropriate equation for this model is Newton's second law,

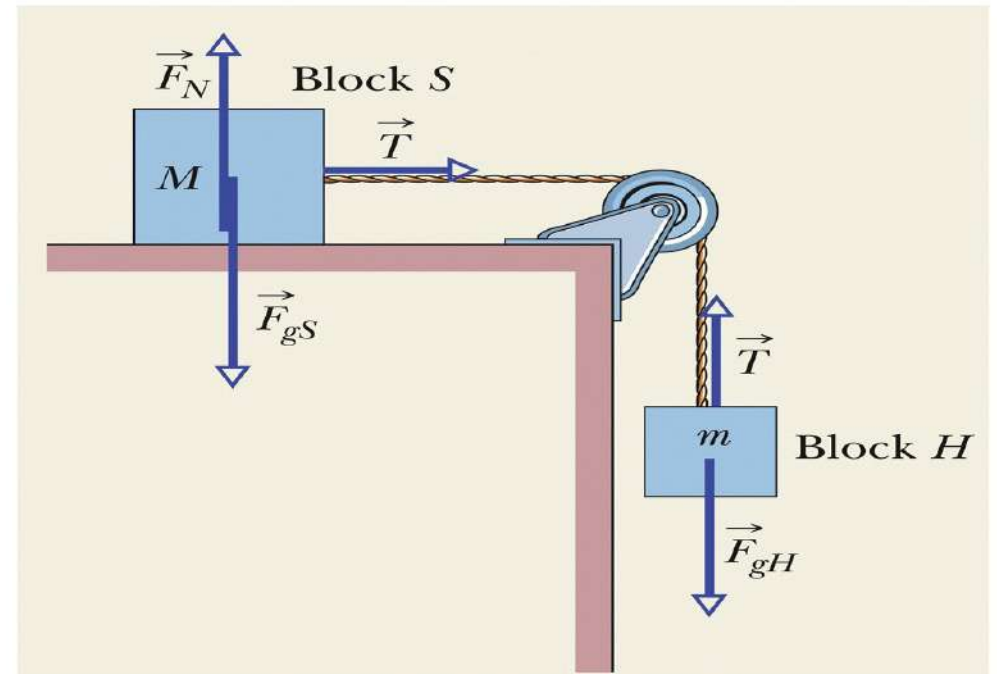
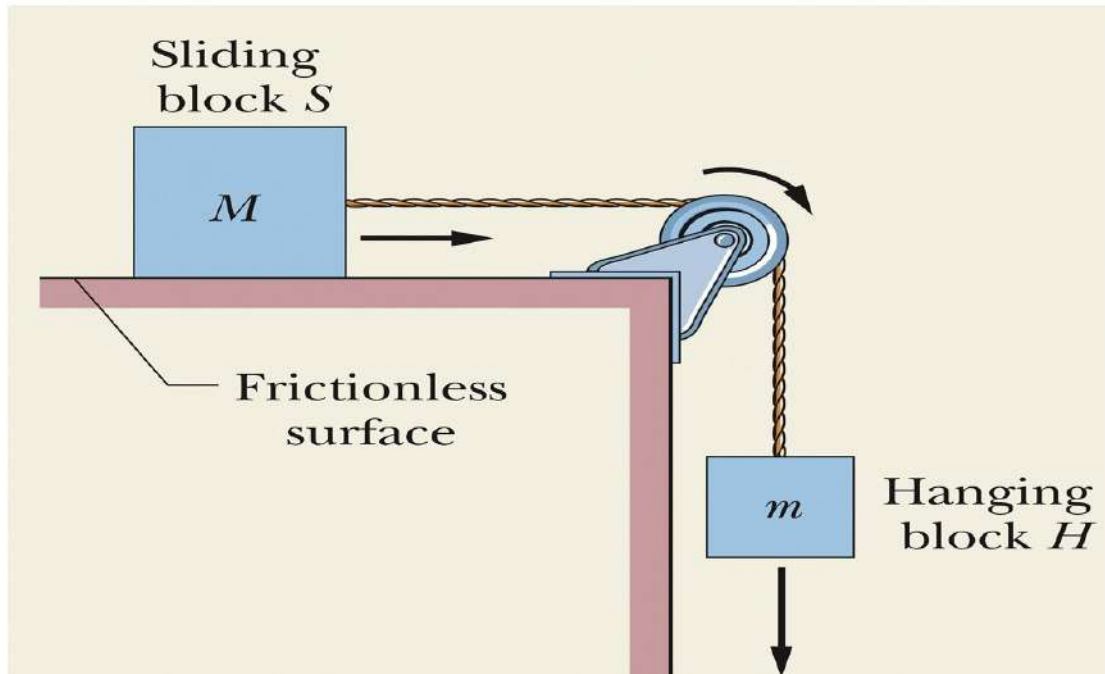
$$\sum \vec{F} = m \vec{a}$$

Analysis Models Using Newton's Second Law

Section 5.7

Applying Newton's Laws

Example : A block of mass $M = 3.3$ kg, connected by a cord and pulley to a hanging block of mass $m = 2.1$ kg, slides across a frictionless surface. Find the acceleration of the block and tension in the string



Applying Newton's Laws

For the sliding block:

$$T = Ma.$$

For the hanging block:

$$T - mg = -ma.$$

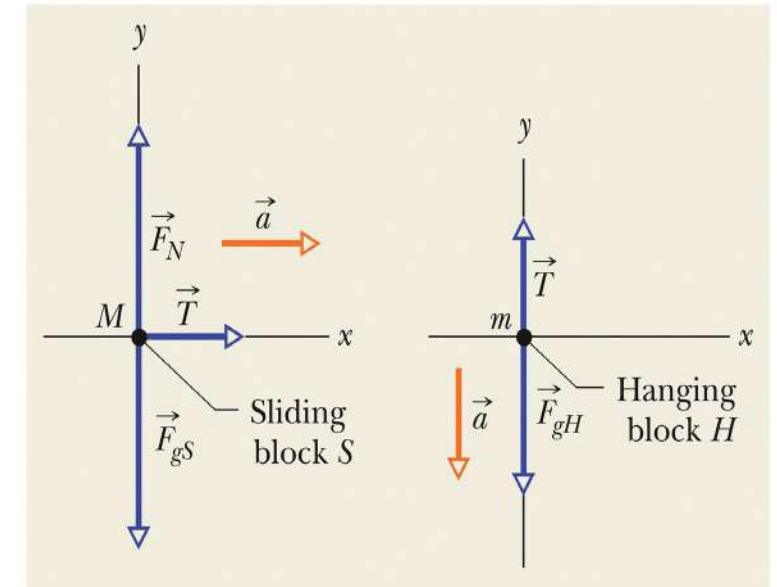
Combining we get:

$$T = \frac{Mm}{M + m} g.$$

$$a = \frac{m}{M + m} g.$$

Plugging in we find $a = 3.8 \text{ m/s}^2$ and $T = 13 \text{ N}$

Does this make sense? Check that dimensions are correct, check that $a < g$, check that $T < mg$ (otherwise acceleration would be upward), check limiting cases (e.g., $g = 0$, $M = 0$, $m = \infty$)



Applying Newton's Laws

Example :

A hockey puck on a frozen pond is given an initial speed of 20.0 m/s. If the puck always remains on the ice and slides 115 m before coming to rest, determine the coefficient of kinetic friction between the puck and ice.

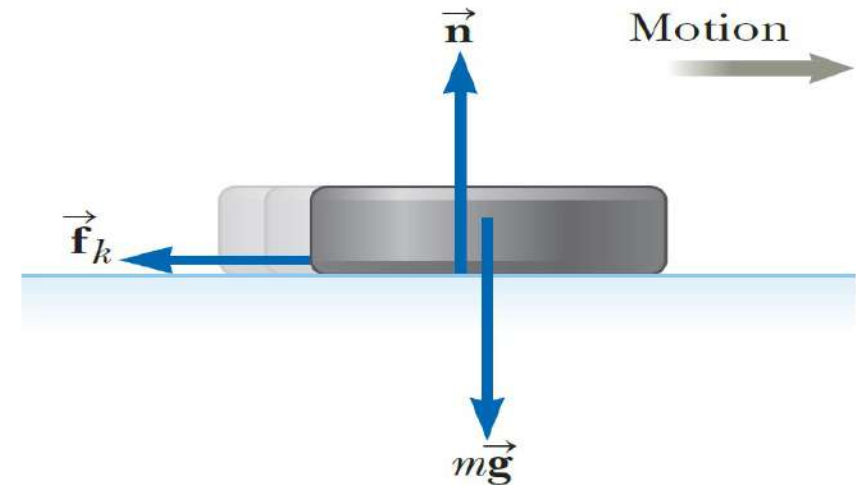
$$v_f^2 = v_o^2 + 2a\Delta x$$

$$0 = 20^2 + 2a(115)$$

$$0 = 400 + 230a$$

$$-230a = 400$$

$$a = \frac{400}{-230} \Rightarrow a = -1.74 \text{ m/s}^2$$



Applying Newton's Laws

We know that the only force acting on the puck in the x direction is the force of friction. Since friction always opposes motion, we see that:

$$f_k = \mu_k N = \mu_k mg$$

$$f_k = -ma \quad (1)$$

Notice also that the normal force in this case can be set equal to the force of gravity because we know that no other forces besides those two are acting on the puck in

the y direction. Since gravity acts in the negative direction, the normal force will be positive.

$$N = mg$$

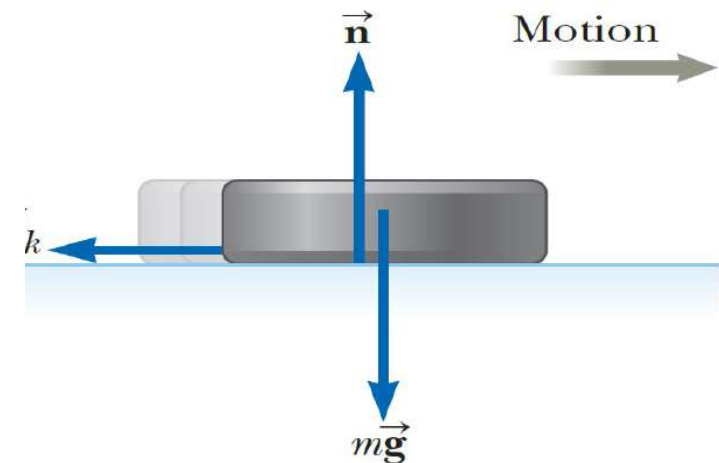
$$f_k = \mu_k N = \mu_k mg \quad (2)$$

From (1) and (2) we conclude

$$-ma = \mu_k mg \Rightarrow$$

$$a = -\mu_k g \Rightarrow$$

$$\mu_k = -\frac{a}{g} = -\frac{-1.74}{9.8} \approx 0.18$$



Forces of Friction

Section 5.8

Friction

- Friction forces are essential
- Examples of friction forces are : Picking things up, walking, biking, driving anywhere, writing with a pencil, building with nails and weaving clothes
- Overcoming friction forces is also important because it improves:
 - Efficiency in engines (20% of the gasoline used in an automobile goes to counteract friction in the drive train)
- Anything that we want to remain in motion

Friction

- If you slide a book across a counter, it will slow and stop, so there must be an acceleration parallel to the surface and opposite the direction of motion.
- If you push a book at a constant speed across the counter, there must be an equal and opposite force opposing you, otherwise the book would accelerate.

Friction

There are two types of friction

The static frictional force:

- The opposing force that prevents an object from moving
- Can have any magnitude from 0 N up to a maximum
- Once the maximum is reached, forces are no longer in equilibrium and the object slides

The kinetic frictional force:

- The opposing force that acts on an object in motion
- Has only one value
- Generally smaller than the maximum static frictional force

Friction

The properties of friction

1. If the body does not move, then the applied force and frictional force balance along the direction parallel to the surface: equal in magnitude, opposite in direction
2. The magnitude of f_s has a maximum $f_{s,max}$ given by:

$$f_{s,max} = \mu_s F_N,$$

where μ_s is the **coefficient of static friction**. If the applied force increases past $f_{s,max}$, sliding begins.

Friction

3. Once sliding begins, the frictional force decreases to f_k given by:

$$f_k = \mu_k F_N,$$

where μ_k is the **coefficient of kinetic friction**.

- Magnitude F_N of the normal force measures how strongly the surfaces are pushed together
- The values of the friction coefficients are unitless and must be determined experimentally

Friction

TABLE 5.1 Coefficients of Friction

	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

Thank
You





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College of Computing and
Informatics
Data Science Pre-Master Program
SCI 101
General Physics I



SCI 101 General Physics
Week 5
Work and Energy

Lecture Outlines

7.0 Energy of a system

7.2 Work Done by a Constant Force

7.5 Kinetic Energy and the Work – Kinetic Energy Theorem

7.6 Potential Energy of a System

8.2 Analysis Model: Isolated System (Energy)

Weekly Learning Outcomes

- Recall energy and types of energy
- Describe work done by force and its nature
- Differentiate between kinetic energy and potential energy of a body
- Understand conservation of energy and solving problems

Required Reading

Chapter 7 and 8 : Energy of a system and Conservation of energy in Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 7 and 8 : Kinetic energy and work, potential energy and conservation of energy in Principles of Physics, 10th Edition. John Wiley & Sons

Recommended Video

- Energy and work :

<https://www.youtube.com/watch?v=QdUVQ922JzQ&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=8>

- Conservation of energy :

<https://www.youtube.com/watch?v=gLbMjkaleJc&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=9>



Energy of a system

Section 7.0

System

- A *system* is a small portion of the Universe.
- When we consider a system, we ignore the details of the rest of the Universe.
- **A valid system:**
 - May be a single object or particle
 - May be a collection of objects or particles
 - May be a region of space
 - May vary with time in size and shape

Energy

- Energy is required for any sort of motion and it has the following properties :
 - It is a scalar quantity assigned to an object or a system of objects
 - It can be changed from one form to another
 - It is *conserved* in a closed system, that is the total amount of energy of all types is always the same
- In this chapter we discuss one type of energy (kinetic energy) and also discuss one method of transferring energy (work)

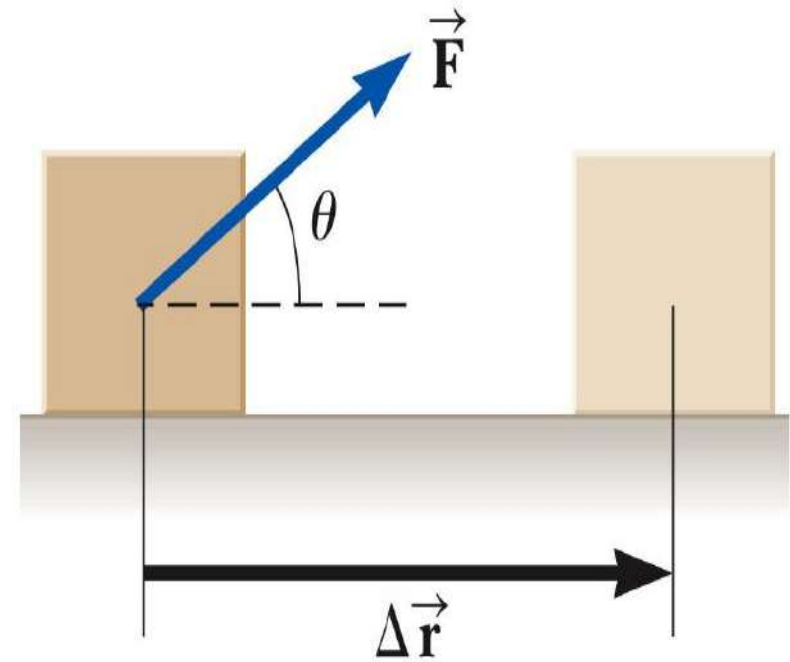
Work

- The **work**, W , done on a system by an agent exerting a constant force on the system is the product of the magnitude F of the force, the magnitude Δr of the displacement of the point of application of the force, and $\cos \theta$, where θ is the angle between the force and the displacement vectors.
- The meaning of the term *work* is distinctly different in physics than in everyday meaning.
- Work is done *by* some part of the environment that is interacting directly with the system.

$$W = F \Delta r \cos \theta$$

Work

- The displacement is that of the point of application of the force.
- A force does no work on the object if the force does not move through a displacement.
- The work done by a force on a moving object is zero when the force applied is perpendicular to the displacement of its point of application.



Work

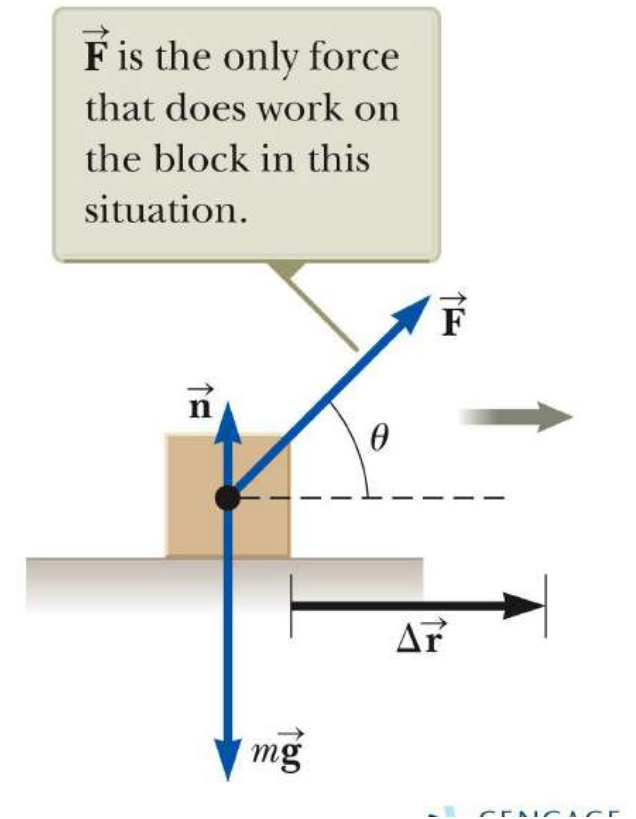
- The displacement is that of the point of application of the force.
- If the force is applied to a rigid object that can be modeled as a particle, the displacement is the same as that of the particle.
- For a deformable system, the displacement of the object generally is not the same as the displacement associated with the forces applied.

Work

The normal force and the gravitational force do no work on the object.

$$\cos \theta = \cos 90^\circ = 0$$

The force is the only force that does work on the object

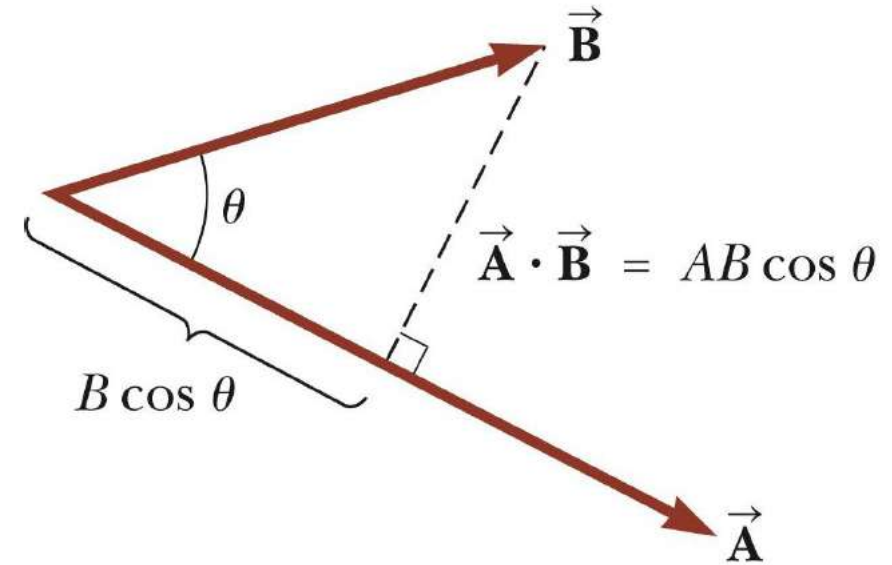


Work

- The sign of the work depends on the direction of the force relative to the displacement.
- Work is positive when projection of $\vec{F}$ onto $\vec{d}$ is in the same direction as the displacement.
- Work is negative when the projection is in the opposite direction.
- Work is a scalar quantity.
- The unit of work is a joule (J)
- $1 \text{ joule} = 1 \text{ newton} \cdot 1 \text{ meter} = \text{kg} \cdot \text{m}^2 / \text{s}^2$
i.e $J = N \cdot m$

The Scalar Product of Two Vectors

- The scalar product of two vectors is written as
- It is also called the dot product.
- θ is the angle *between* A and B
- If we apply this to work, we get:



Work

Example : A man cleaning a floor pulls a vacuum cleaner with a force of magnitude $F = 50.0 \text{ N}$ at an angle of 30.0° with the horizontal (Fig. 7.5). Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced 3.00 m to the right

$$W = F \Delta r \cos \theta = (50.0 \text{ N})(3.00 \text{ m})(\cos 30.0^\circ) \\ = 130 \text{ J}$$



Figure 7.5: A vacuum cleaner being pulled at an angle of 30° from the horizontal

Work done by a constant force

Section 7.2

Work done by a constant force

Example :

A particle moving in the xy plane undergoes a displacement given by $\Delta \vec{r} = (2.0\hat{i} + 3.0\hat{j}) \text{ m}$ as a constant force $\vec{F} = (5.0\hat{i} + 2.0\hat{j}) \text{ N}$ acts on the particle. Calculate the work done by $\vec{F}$ on the particle?

$$\begin{aligned} W &= \vec{F} \cdot \Delta \vec{r} = [(5.0\hat{i} + 2.0\hat{j}) \text{ N}] \cdot [(2.0\hat{i} + 3.0\hat{j}) \text{ m}] \\ &= (5.0\hat{i} \cdot 2.0\hat{i} + 5.0\hat{i} \cdot 3.0\hat{j} + 2.0\hat{j} \cdot 2.0\hat{i} + 2.0\hat{j} \cdot 3.0\hat{j}) \text{ N} \cdot \text{m} \\ &= [10 + 0 + 0 + 6] \text{ N} \cdot \text{m} = 16 \text{ J} \end{aligned}$$

Work done by a constant force

Kinetic energy:

- The faster an object moves, the greater its kinetic energy
- Kinetic energy is zero for a stationary object
- For an object with v well below the speed of light:

$$K = \frac{1}{2}mv^2$$

- The unit of kinetic energy is a **joule** (J)

$$1 \text{ joule} = 1 \text{ J} = 1 \text{ kg} \cdot \text{m}^2/\text{s}^2.$$

Work done by a constant force

Example : What is the kinetic energy released by 2 colliding trains with given weight of $1.2 \times 10^6 \text{ N}$ and acceleration from rest given by $a = 0.26 \text{ m/s}^2$, if the displacement is given by $(3.2 \times 10^3) \text{ m}$?

The final velocity of each locomotive

$$v^2 = v_0^2 + 2a(x - x_0).$$

$$\begin{aligned} v^2 &= 0 + 2(0.26 \text{ m/s}^2)(3.2 \times 10^3 \text{ m}), \\ v &= 40.8 \text{ m/s} = 147 \text{ km/h.} \end{aligned}$$

Convert weight to mass

$$m = \frac{1.2 \times 10^6 \text{ N}}{9.8 \text{ m/s}^2} = 1.22 \times 10^5 \text{ kg.}$$

The kinetic energy

$$\begin{aligned} K &= 2\left(\frac{1}{2}mv^2\right) = (1.22 \times 10^5 \text{ kg})(40.8 \text{ m/s})^2 \\ &= 2.0 \times 10^8 \text{ J.} \end{aligned} \quad (\text{Answer})$$

Kinetic Energy and the Work – Kinetic Energy Theorem

Section 7.5

Work kinetic energy theorem

When work is done on a system and the only change in the system is in the speeds of its members, the net work done on the system equals the change in kinetic energy of the system, as expressed by

$$W = \Delta K$$

Total work done by force = Change in Kinetic Energy

Work kinetic energy theorem

- The **work-kinetic energy theorem** states:

$$\text{change in kinetic energy} = (\text{the } \underline{\text{net}} \text{ work done})$$

Or we can write it as:

$$(\text{final } KE) = (\text{initial } KE) + (\text{net work})$$

- The work-kinetic energy theorem holds for positive and negative work

Work kinetic energy theorem

Example :

If the kinetic energy of a particle is initially 5 J then find the final kinetic energy if :

a) A net transfer of 2 J to the particle (positive work)

$$\text{Final KE} = 5 + 2 = 7 \text{ J}$$

b) A net transfer of 2 J from the particle (negative work)

- $\text{Final KE} = 5 - 2 = 3 \text{ J}$

Work kinetic energy theorem

Example :

A 6.0-kg block initially at rest is pulled to the right along a frictionless, horizontal surface by a constant horizontal force of magnitude 12 N. Find the block's speed after it has moved through a horizontal distance of 3.0 m?.

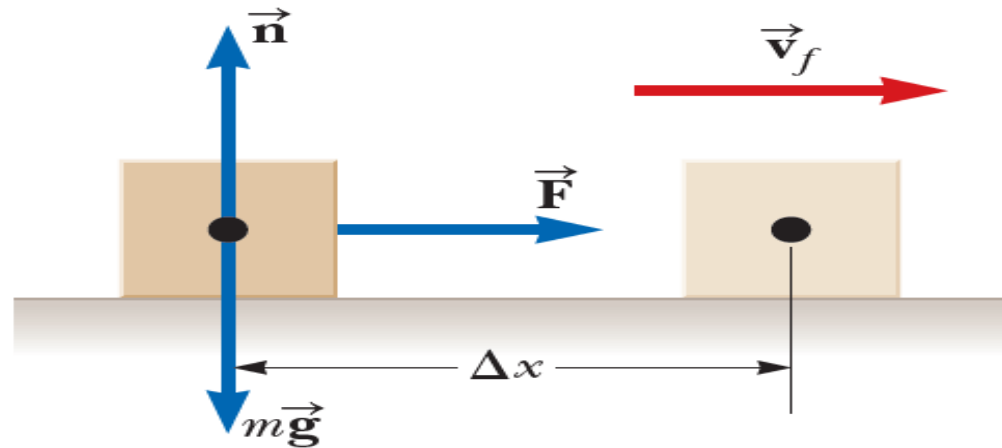


Figure 7.14 A block pulled to the right on a frictionless surface by a constant horizontal force

Work kinetic energy theorem

The net external force acting on the block is the horizontal 12-N force.

$$W_{\text{ext}} = \Delta K = K_f - K_i = \frac{1}{2}mv_f^2 - 0 = \frac{1}{2}mv_f^2$$

Use the work–kinetic energy theorem for the block, noting that its initial kinetic energy is zero:

$$v_f = \sqrt{\frac{2W_{\text{ext}}}{m}} = \sqrt{\frac{2F\Delta x}{m}}$$

Solve for v_f and use for the work done on the block by $\mathbf{F}$:

$$v_f = \sqrt{\frac{2(12 \text{ N})(3.0 \text{ m})}{6.0 \text{ kg}}} = 3.5 \text{ m/s}$$

Potential Energy of a system

Section 7.6

Potential Energy

Potential energy

Potential energy U is the energy that can be associated with the configuration of a system of objects that exert forces on one another

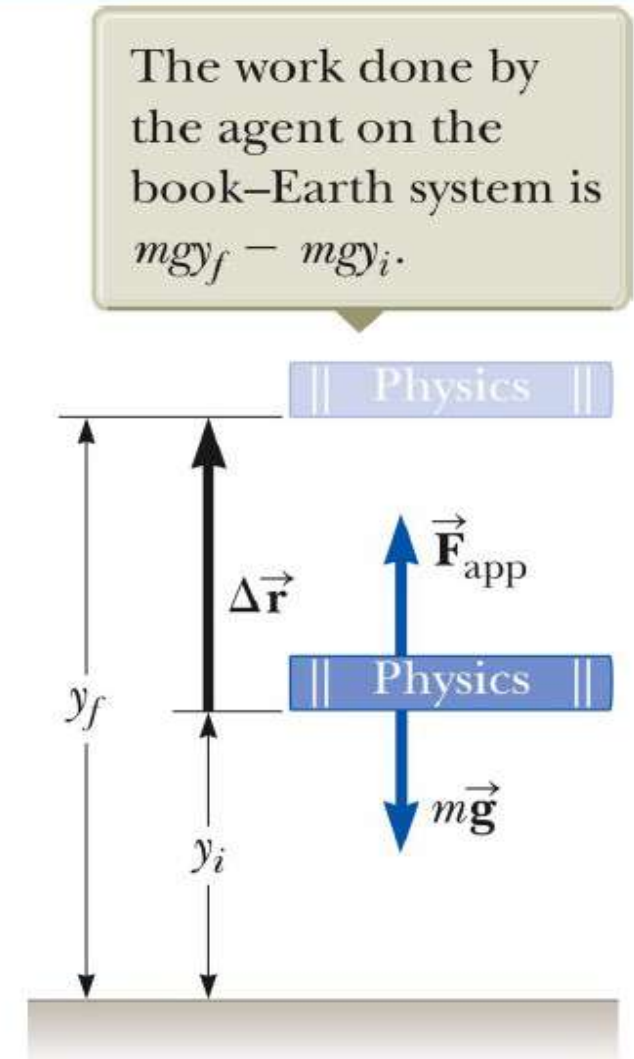
Gravitational potential energy

It accounts for kinetic energy increase during the fall

- Physics determines how potential energy is calculated, to account for stored energy

Gravitational Potential Energy

- The system is the Earth and the book.
- Do work on the book by lifting it slowly through a vertical displacement.
- The work done on the system must appear as an increase in the energy of the system.
- The energy storage mechanism is called *potential energy*



Gravitational Potential Energy

Gravitational potential energy is the energy associated with an object at a given location above the surface of the Earth.

- The quantity mgy is identified as the gravitational potential energy, U_g .
$$U_g = mgy$$
- The unit of gravitational potential energy is joule (J)

Gravitational Potential Energy

Example : A trophy being shown off by a careless athlete slips from the athlete's hands and drops on his foot.

a) Choosing floor level as the $y = 0$ point of your coordinate system, estimate the change in gravitational potential energy of the trophy–Earth system as the trophy falls.

Calculate the gravitational potential energy of the trophy– Earth system just before the trophy is released.

$$U_i = mgy_i = (2 \text{ kg})(9.80 \text{ m/s}^2)(1.4 \text{ m}) = 27.4 \text{ J}$$

Calculate the gravitational potential energy of the trophy– Earth system when the trophy reaches the athlete's foot:

Gravitational Potential Energy

$$U_f = mgy_f = (2 \text{ kg})(9.80 \text{ m/s}^2)(0.05 \text{ m}) = 0.98 \text{ J}$$

Evaluate the change in gravitational potential energy of the trophy–Earth system:

$$\Delta U_g = 0.98 \text{ J} - 27.4 \text{ J} = -26.4 \text{ J}$$

Gravitational Potential Energy

b) Repeat the calculation, using the top of the athlete's head as the origin of coordinates

$$U_i = mgy_i = (2 \text{ kg})(9.80 \text{ m/s}^2)(-0.6 \text{ m}) = -11.8 \text{ J}$$

$$U_f = mgy_f = (2 \text{ kg})(9.80 \text{ m/s}^2)(-1.95 \text{ m}) = -38.2 \text{ J}$$

$$\Delta U_g = -38.2 \text{ J} - (-11.8 \text{ J}) = -26.4 \text{ J} \approx -26 \text{ J}$$

Types of Systems

Non-isolated systems

- Energy can cross the system boundary in a variety of ways.
- Total energy of the system changes

Isolated systems

- Energy does not cross the boundary of the system
- Total energy of the system is constant

Conservation of energy

Conservation of energy can be used if no non-conservative forces act within the isolated system

Conservation of Energy

Energy is conserved

This means that energy cannot be created nor destroyed.

- If the total amount of energy in a system changes, it can only be due to the fact that energy has crossed the boundary of the system by some method of energy transfer.

Conservation of Energy

Isolated System

- For an isolated system, $\Delta E_{\text{mech}} = 0$

$$E_{\text{mech}} = K + U$$

This is *conservation of energy* for an isolated system with no non-conservative forces acting.

- The changes in energy can be written out and rearranged.

$$K_f + U_f = K_i + U_i$$

- Remember, this applies only to a system in which conservative forces act.

Conservation of Energy

If **non-conservative forces** are acting, some energy is transformed into internal energy.

Conservation of Energy becomes $\Delta E_{\text{system}} = 0$

E_{system} is all kinetic, potential, and internal energies

This is the most general statement of the isolated system model.

Problem Solving Strategy

Conservation of Mechanical Energy for an Isolated System with No Non-conservative Forces

Imagine what types of energy are changing in the system

Categorize

- Define the system
- It may consist of more than one object and may or may not include springs or other sources of storing potential energy.
- Determine if any energy transfers occur across the boundary of your system.
If there are transfers, use the non-isolated system model
If there are no transfers, use
- Determine if there are any non-conservative forces acting.
If not, use the principle of conservation of mechanical energy.

Problem Solving Strategy

Analyze

- Choose configurations to represent initial and final configuration of the system.
- For each object that changes elevation, identify the zero configuration for gravitational potential energy.
- For each object on a spring, the zero configuration for elastic potential energy is when the object is in equilibrium.
- If more than one conservative force is acting within the system, write an expression for the potential energy associated with each force.
- Write expressions for total initial mechanical energy and total final mechanical energy.
- Set them equal to each other.

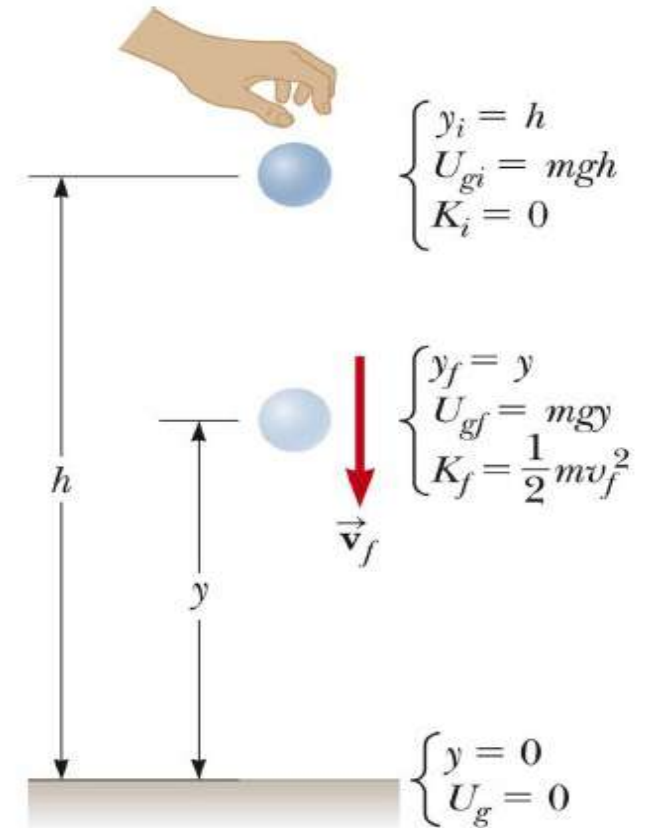
Problem Solving Strategy

Example :

A ball of mass m is dropped from a height h above the ground as shown in the figure. Determine the speed of the ball at a height y above the ground?

Conceptualize

- Use energy instead of motion Categorize
- System is the ball and the Earth
- System is isolated
- Use the isolated system model
- Only force is gravitational which is conservative



Problem Solving Strategy

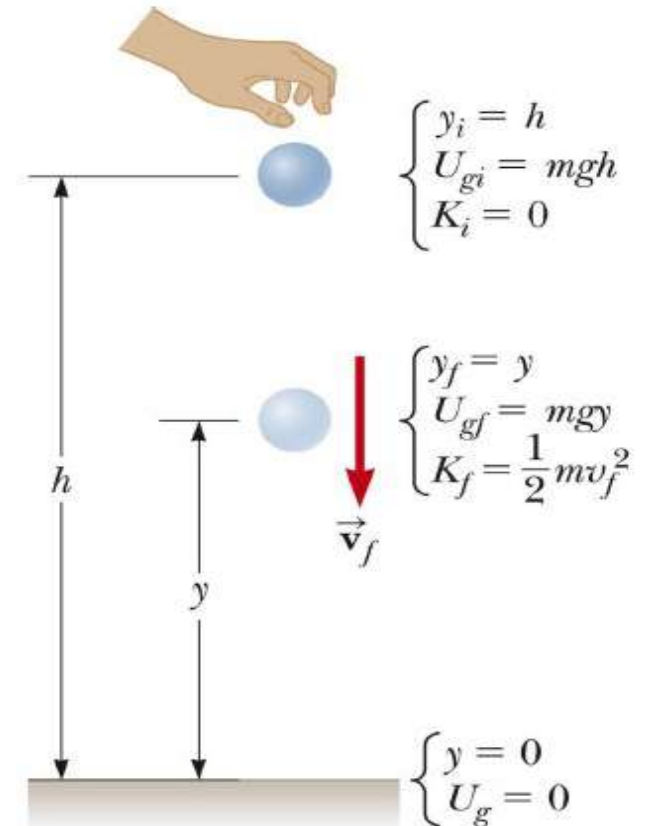
Apply the principle of Conservation of Mechanical Energy

$$K_f + U_{gf} = K_i + U_{gi}$$

$K_i = 0$, the ball is dropped

Solve for

Notice that the equation for is consistent with the results obtained from the particle under constant acceleration model for a falling object.



Thank
You





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College of Computing and
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Data Science Pre-Master Program
SCI 101
General Physics I



SCI 101 General Physics
Week 7
Linear Momentum

Lecture Outlines

9.0 Linear Momentum and Collisions

9.1 Linear Momentum

9.2 Analysis Model : Isolated System (Momentum)

9.3 Analysis Model : Non Isolated System (Momentum)

Weekly Learning Outcomes

- Understand Linear momentum and its units
- Recall Newton's second law motion and rewriting in terms of momentum
- Differentiate between Elastic collision and inelastic collision
- Solving problems related to isolated system and non-isolated system

Required Reading

Chapter 9 : Linear Momentum and collisions in Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 9 : Center of mass and Linear momentum in Principles of Physics, 10th Edition. John Wiley & Sons

Recommended Video

Momentum : <https://www.youtube.com/watch?v=RGCyZnoQdZE&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=10>



Linear Momentum and Collisions

Section 9.0

Linear Momentum

- The **linear momentum** of a particle or an object that can be modeled as a particle of mass m moving with a velocity is defined to be the product of the mass and velocity:

$$p = m \cdot v$$

- Linear momentum is a vector quantity.
- Its direction is the same as the direction of the velocity.
- The SI units of momentum is $\text{kg} \cdot \text{m} / \text{s}$.
- The components of the momentum of a particle are:

$$p_x = m \cdot v_x \quad p_y = m \cdot v_y \quad p_z = m \cdot v_z$$

Newton's First and Second Laws

- Newton's first law states that if a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a force.
- Newton's second law states that the acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object.

$$\vec{F} = m \vec{a}$$

Newton's Second Law and Momentum

- Newton's Second Law can be used to relate the momentum of a particle to the resultant force acting on it.

with constant mass

- The time rate of change of the linear momentum of a particle is equal to the net force acting on the particle.
- This is the form in which Newton presented the Second Law which is a more general form than the one we used previously.
- This form also allows for mass changes.

Conservation of momentum

- Conservation of momentum refers to the fact that the total momentum of any physical system remains constant, and it can be expressed mathematically as
- This is the mathematical statement of a new analysis model, the isolated system (momentum).
- It means that the total momentum of isolated system of two particles must remain constant.

and are initial values, and are the final values of the momenta for 2 particles system and for the time interval during which the particles interact.

Conservation of momentum

- In component form, the total momenta in each direction are independently conserved.

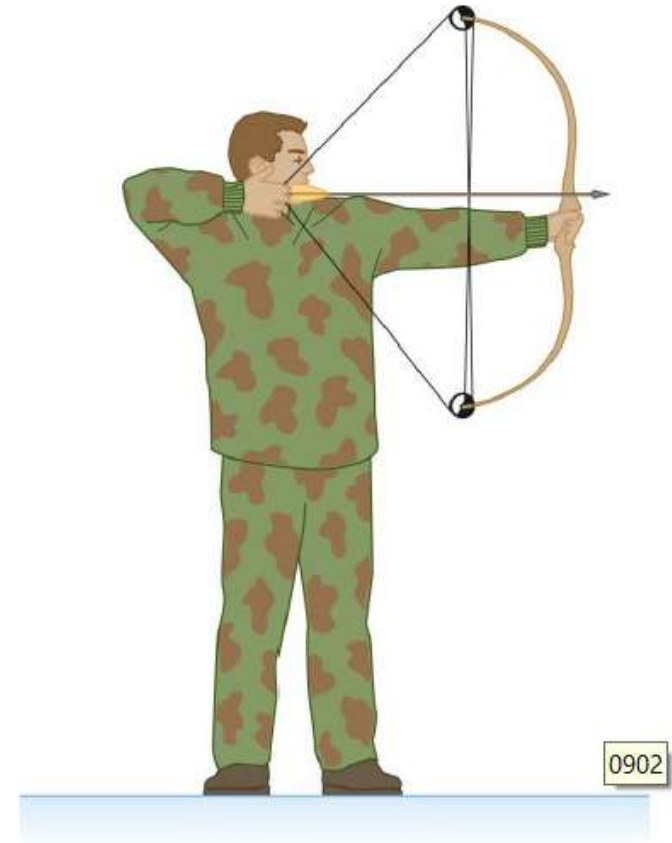
$$p_{1ix} + p_{2ix} = p_{1fx} + p_{2fx}, \quad p_{1iy} + p_{2iy} = p_{1fy} + p_{2fy}, \quad p_{1iz} + p_{2iz} = p_{1fz} + p_{2fz}$$

- This is known as the law of conservation of linear momentum and it can be applied to systems with any number of particles.
- The momentum version of the isolated system model states whenever two or more particles in an isolated system interact, the total momentum of the system remains constant.

Conservation of momentum

The archer is standing on a frictionless surface (ice). Approaches:

- Motion – no
- No information about velocities, etc.
- Newton's Second Law – no
- No information about F or a
- Energy approach – no
- No information about work or energy
- Momentum – yes



The archer Problem 1

Conceptualize

The arrow is fired one way and the archer recoils in the opposite direction.

Categorize

Momentum

- Let the system be the archer with bow (particle 1) and the arrow (particle 2).
- It is not an isolated system in the y -direction because the gravitational force and the normal force act on it.
- There are no external forces in the x -direction, so it is isolated in terms of momentum in the x -direction.
- Apply the isolated system (momentum) model in terms of momentum components in the x -direction.

The archer Problem 1

Total momentum before releasing the arrow is 0

The total momentum after releasing the arrow is

$$=0$$

Finalize

The final velocity of the archer is negative.

Indicates he moves in a direction opposite the arrow.

Archer has much higher mass than arrow, so velocity is much lower.

The archer Problem 1

Example 1 : The archer is standing on a frictionless surface (ice). The arrow is fired one way and the archer recoils in the opposite direction. If the mass of the archer is $m_1 = 60$ kg and the mass of the arrow is $m_2 = 0.030$ kg, then find the archer velocity after firing the arrow if the velocity of the arrow is

$$m_1 = 60, \quad m_2 = 0.030, \quad v_{1i} = v_{2i} = 0, \quad v_{2f} = 85 \text{ i}, \quad v_{1f} = ?$$

$$\Delta \vec{P} = 0 \Rightarrow \vec{P}_f - \vec{P}_i = 0 \Rightarrow$$

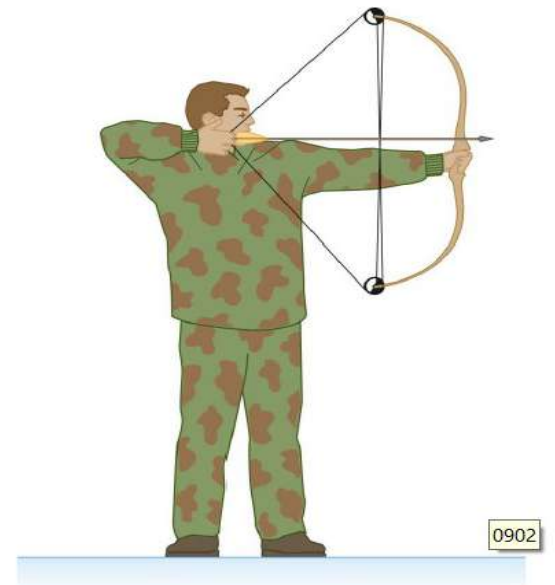
$$\vec{P}_f = \vec{P}_i$$

$$m_1 v_{1f} + m_2 v_{2f} = m_1 v_{1i} + m_2 v_{2i} \Rightarrow$$

$$60 v_{1f} + 0.030 \times 85 \text{ i} = 0 + 0 \Rightarrow$$

$$60 v_{1f} = -0.030 \times 85 \text{ i} \Rightarrow$$

$$v_{1f} = \frac{-0.030 \times 85 \text{ i}}{60} = -0.042 \text{ i m/s}$$



Impulse and Momentum

- The momentum of a system changes if a net force from the environment acts on the system.
- For momentum considerations, a system is non-isolated if a net force acts on the system for a time interval.

From Newton's second law ,

Solving for $\vec{p}$ gives

Integrating to find the change in momentum over some time interval

.

- The integral is called the impulse , , of the force acting on an object over Δt

Impulse and Momentum

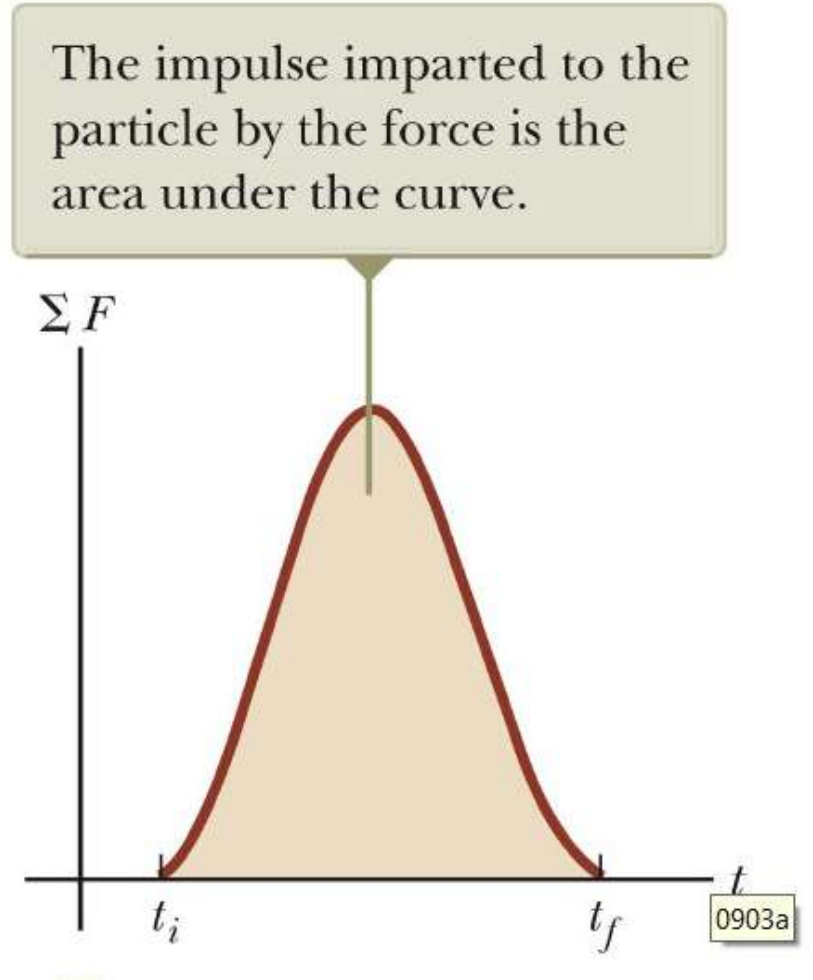
- The change in the momentum of a particle is equal to the impulse of the net force acting on the particle:

This is equivalent to Newton's Second Law.

- This is identical in form to the conservation of energy equation.
- This is the most general statement of the principle of conservation of momentum and is called the conservation of momentum equation.
- This form applies to non-isolated systems.
- This is the mathematical statement of the **non-isolated system (momentum) model**.

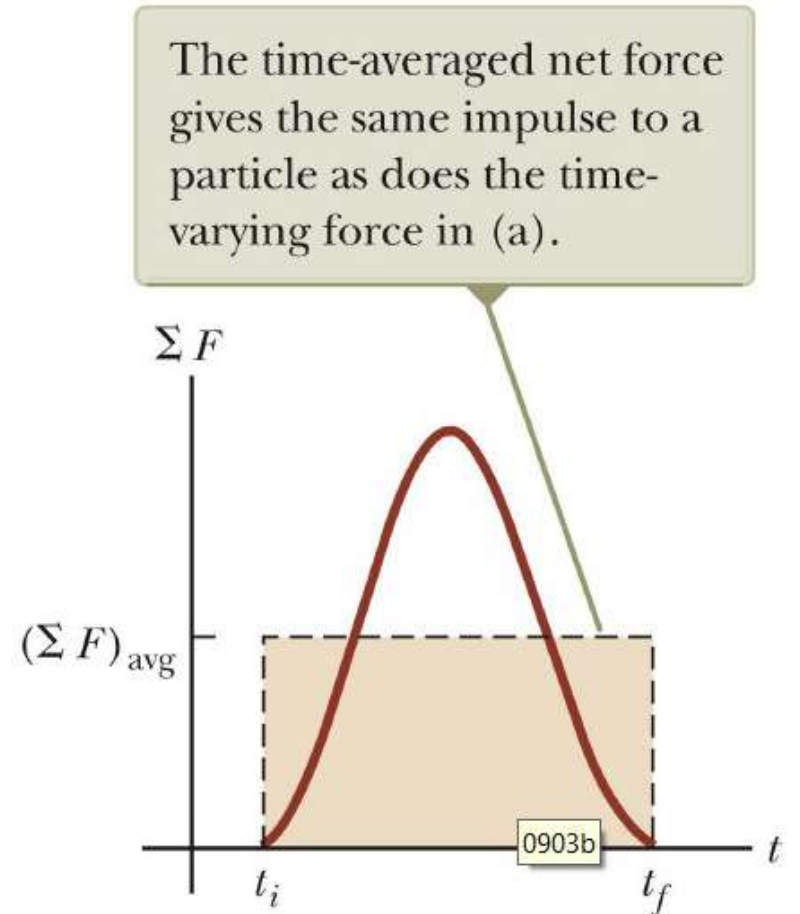
Impulse

- Impulse is a vector quantity.
- The magnitude of the impulse is equal to the area under the force-time curve.
- The force may vary with time.
- Dimensions of impulse are $M L / T$
- Impulse is not a property of the particle, but a measure of the change in momentum of the particle.



Calculation of Impulse

- The impulse can also be found by using the time averaged force.
- This would give the same impulse as the time-varying force does.



Impulse Approximation

- In many cases, one force acting on a particle acts for a short time, but is much greater than any other force present.
- Using the Impulse Approximation is useful in treating collisions because the duration of collision is very short.
- If we use this approximation, the single force will be called the *impulsive* force.
- The particle is assumed to move very little during the collision.
- and represent the momenta *immediately* after and before the collision.

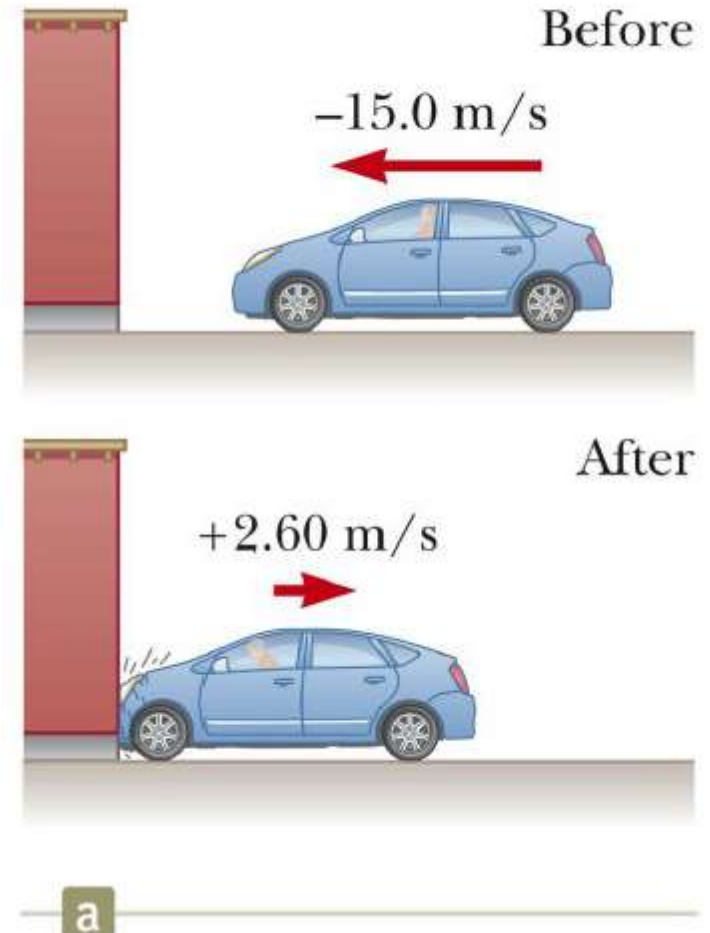
Impulse-Momentum: Crash Test Example

Conceptualize

- The collision time is short.
- We can image the car being brought to rest very rapidly and then moving back in the opposite direction with a reduced speed.

Categorize

- Assume net force exerted on the car by wall on the car is large compared with other forces on the car such as (air friction and air resistance)
- Gravitational and normal forces are perpendicular and so do not effect the horizontal momentum.



Impulse-Momentum: Crash Test Example

- We can apply impulse approximation
- The car's change in momentum is due to an impulse from the environment.
- Therefore, the non-isolated system (momentum) model can be applied.

Analyze

The momenta before and after the collision between the car and the wall can be determined .

Find

- Initial and final momenta
- Impulse
- Average force

Impulse-Momentum: Crash Test Example

Finalize

- The net force is a combination of the normal force on the car from the wall and any friction force between the tires and the ground as the front of the car crumples.
- Check signs on velocities to be sure they are reasonable

Impulse-Momentum: Crash Test Example

Example 2 : In a particular crash test, a car of mass 1500 kg collides with a wall as shown in Figure 9.5. The initial and final velocities of the car are and are , respectively.

a) If the collision lasts 0.150 s, find the impulse on the car during the collision and the average net force exerted on the car?



Figure 9.5 (Example 9.3) (a) This car's momentum changes as a result of its collision with the wall. (b) In a crash test, much of the car's initial kinetic energy is transformed into energy associated with the damage to the car.

$$m = 1500 \text{ kg}, \quad v_i = -15 \hat{i}, \quad v_f = 2.6 \hat{i}, \quad I = ? \quad \sum F_{\text{avg}} = ?$$

$$\vec{I} = \Delta \vec{p} = \vec{p}_f - \vec{p}_i = m\vec{v}_f - m\vec{v}_i = m(\vec{v}_f - \vec{v}_i)$$

$$= (1500 \text{ kg})[2.60\hat{i} \text{ m/s} - (-15.0\hat{i} \text{ m/s})] = 2.64 \times 10^4 \hat{i} \text{ kg} \cdot \text{m/s}$$

Impulse-Momentum: Crash Test Example

$$(\sum \vec{F})_{\text{avg}} = \frac{\vec{I}}{\Delta t} = \frac{2.64 \times 10^4 \hat{i} \text{ kg} \cdot \text{m/s}}{0.150 \text{ s}} = 1.76 \times 10^5 \hat{i} \text{ N}$$

b) What if the car did not rebound from the wall? Suppose the final velocity of the car is zero and the time interval of the collision remains at 0.150 s. Would that represent a larger or a smaller net force on the car?

In this case, $v_f = 0$

$$\text{So } I = \Delta \vec{P} = \vec{P}_f - \vec{P}_i = mv_f - mv_i \Rightarrow$$

$$I = 0 - 1500 \times (-15\hat{i}) = 2.25 \times 10^4 \hat{i} \text{ kg.m/s.}$$

$$(\sum \vec{F})_{\text{avg}} = \frac{\vec{I}}{\Delta t} = \frac{2.25 \times 10^4 \hat{i} \text{ kg} \cdot \text{m/s}}{0.150 \text{ s}} = 1.50 \times 10^5 \hat{i} \text{ N}$$

Obviously, that represent a smaller net force on the car

Thank
You





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General Physics I



SCI 101 General Physics

Week 8

Collision in one and two dimension

Lecture Outlines

9.4 Collisions in One Dimension

9.5 Collisions in two Dimensions

9.6 The Center of Mass

Weekly Learning Outcomes

- Recall collision between two object
- Understand types of collision in one dimension and two dimensions
- Apply conservation of momentum conservation of energy to solve problems in collisions in one dimension
- Understand center of mass and its location in an object

Required Reading

Chapter 9 : Linear Momentum and collisions in Physics
for scientists and engineers with modern physics

Recommended Reading

Chapter 9 : Center of mass and Linear momentum in
Principles of Physics, 10th Edition. John Wiley & Sons

Recommended Video

Collision

<https://www.youtube.com/watch?v=8OB8eIPgEkQ>

Collision in two dimension : <https://www.youtube.com/watch?v=9YRgHikdcqs>

Center of mass : <https://www.youtube.com/watch?v=B0Ard8jDiHM>



Collisions in One Dimension

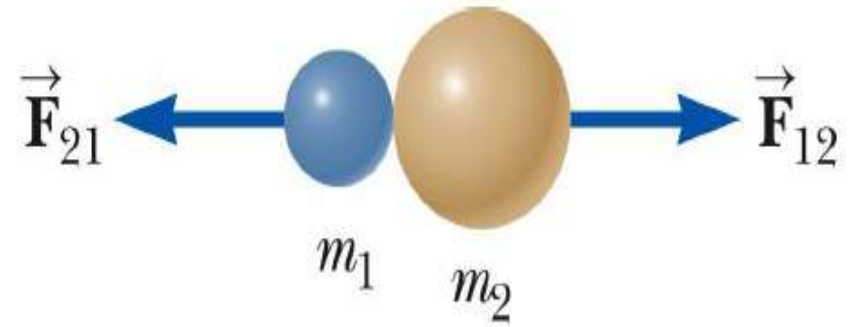
Section 9.4

Collisions

- The term **collision** represents an event during which two particles come close to each other and interact by means of forces.
- Collision may involve physical contact, but must be generalized to include cases with interaction without physical contact
- The interaction forces are assumed to be much greater than any external forces present.
- This means the impulse approximation can be used.

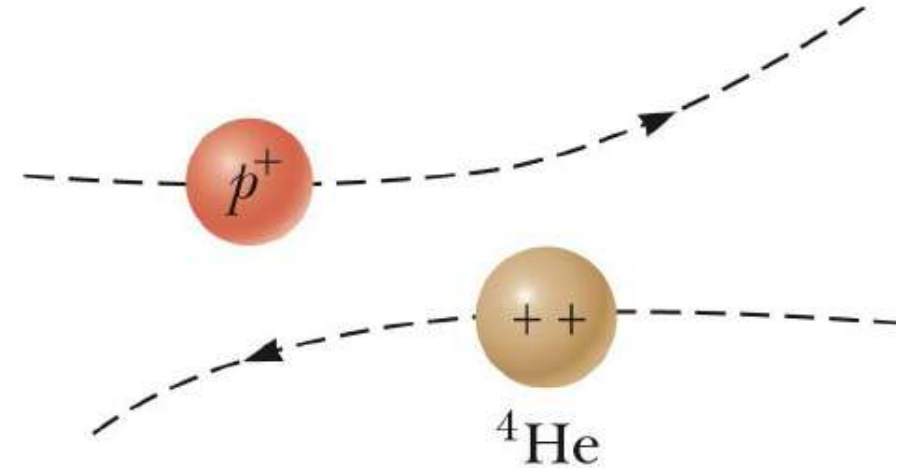
Collisions

- Collisions may be the result of direct contact.
- The impulsive forces may vary in time in complicated ways.
- This force is internal to the system.



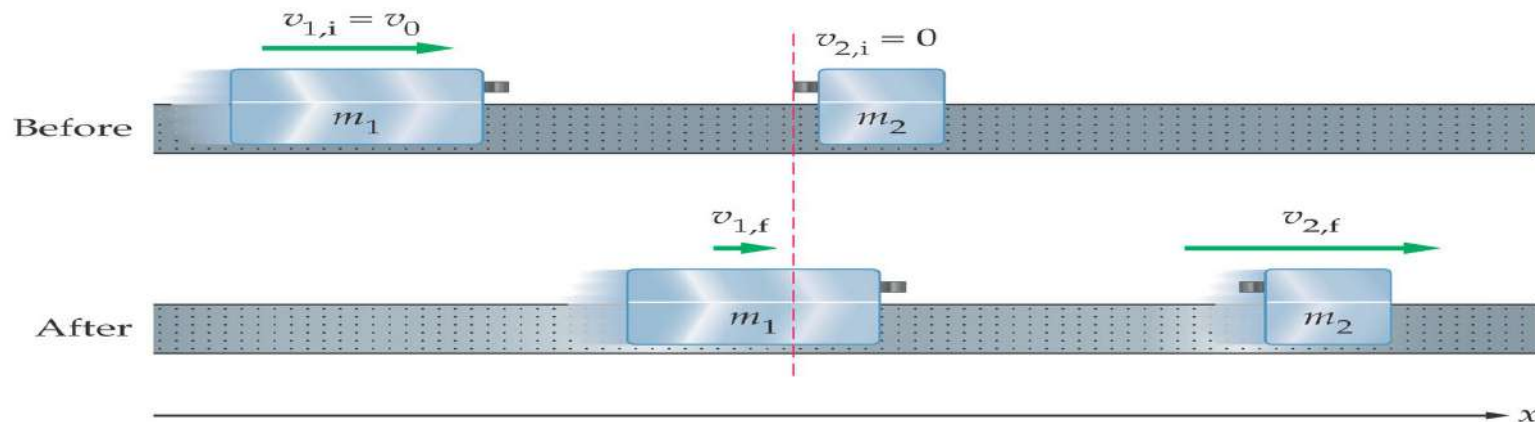
Collisions

- The collision need not include physical contact between the objects.
- There are still forces between the particles even there is no Physical contact as in the figure.
- There is a strong repulsive force between the He charge and the particle.
- This type of collision can be analyzed in the same way as those that include physical contact. Section



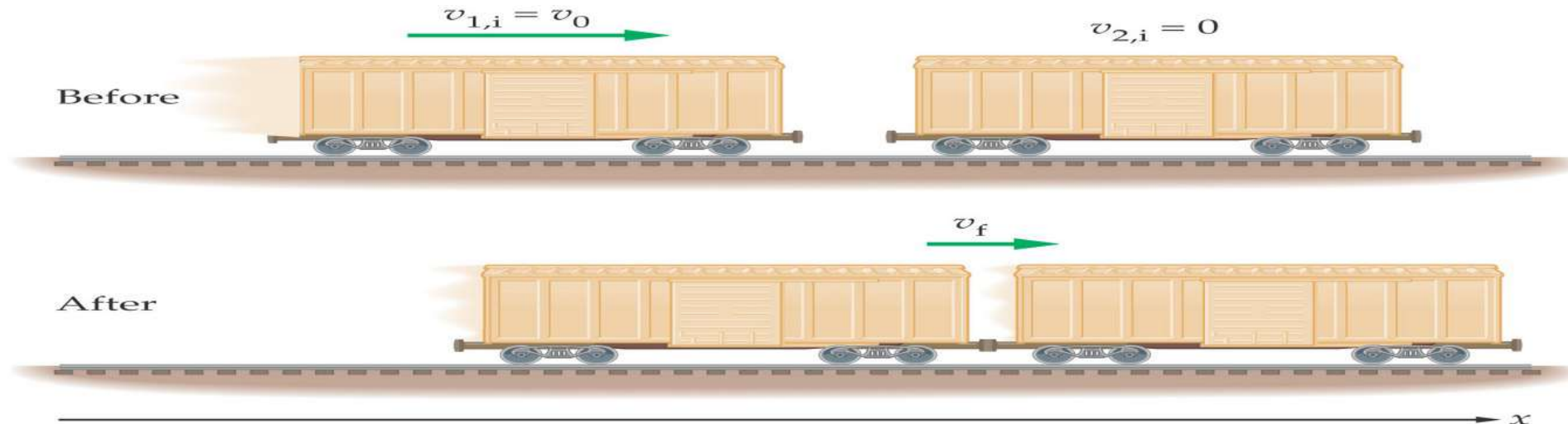
Types of Collisions

- In an *elastic* collision, momentum and kinetic energy are conserved.
- Perfectly elastic collisions occur on a microscopic level.
- In macroscopic collisions, only approximately elastic collisions actually occur.
- There must be no transformation of kinetic energy into other types of energy within the system.



Types of Collisions

- In an *inelastic* collision, kinetic energy is not conserved, although momentum is still conserved.
- If the objects stick together after the collision, it is a *perfectly inelastic* collision.
- In an inelastic collision, some kinetic energy is lost,
- Momentum is conserved in all collisions type



Elastic Collisions

- Both momentum and kinetic energy are conserved.

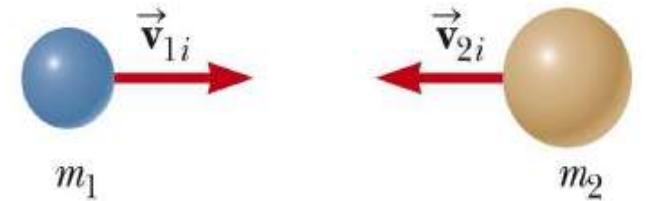
- The conservation of momentum

$$m_1 \vec{v}_{1i} + m_2 \vec{v}_{2i} = m_1 \vec{v}_{1f} + m_2 \vec{v}_{2f}$$

- The conservation of kinetic energy

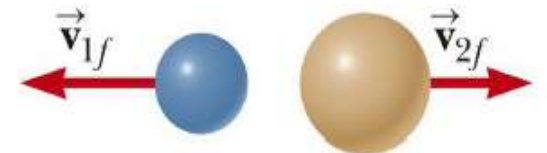
$$\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2$$

Before the collision, the particles move separately.



a

After the collision, the particles continue to move separately with new velocities.

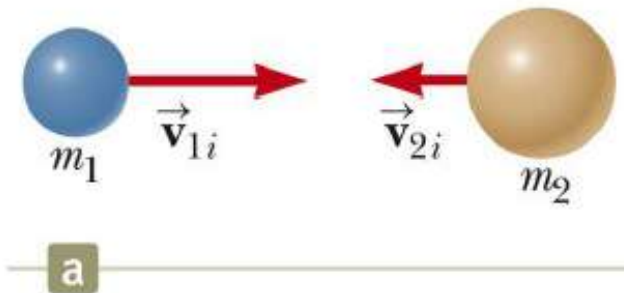


Perfectly Inelastic Collisions

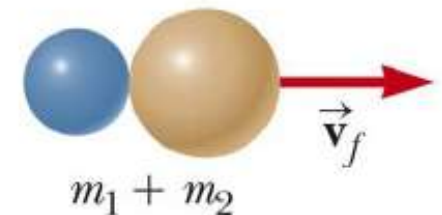
- Collisions Momentum of an isolated system is conserved in any collision, so the total momentum before the collision is equal to the total momentum of the composite system after the collision.
- Since the objects stick together, they share the same velocity after the collision.

$$m_1 \vec{v}_{1i} + m_2 \vec{v}_{2i} = (m_1 + m_2) \vec{v}_f$$

Before the collision, the particles move separately.



After the collision, the particles move together.



Problem-Solving Strategy

One-Dimensional Collisions

Conceptualize

- Image the collision occurring in your mind.
- Draw simple diagrams of the particles before and after the collision.
- Include appropriate velocity vectors.

Categorize

- Is the system of particles isolated?
- Is the collision elastic, inelastic or perfectly inelastic?

Problem-Solving Strategy

One-Dimensional Collisions

Analyze

- Set up the mathematical representation of the problem.
- Solve for the unknown(s).

Finalize

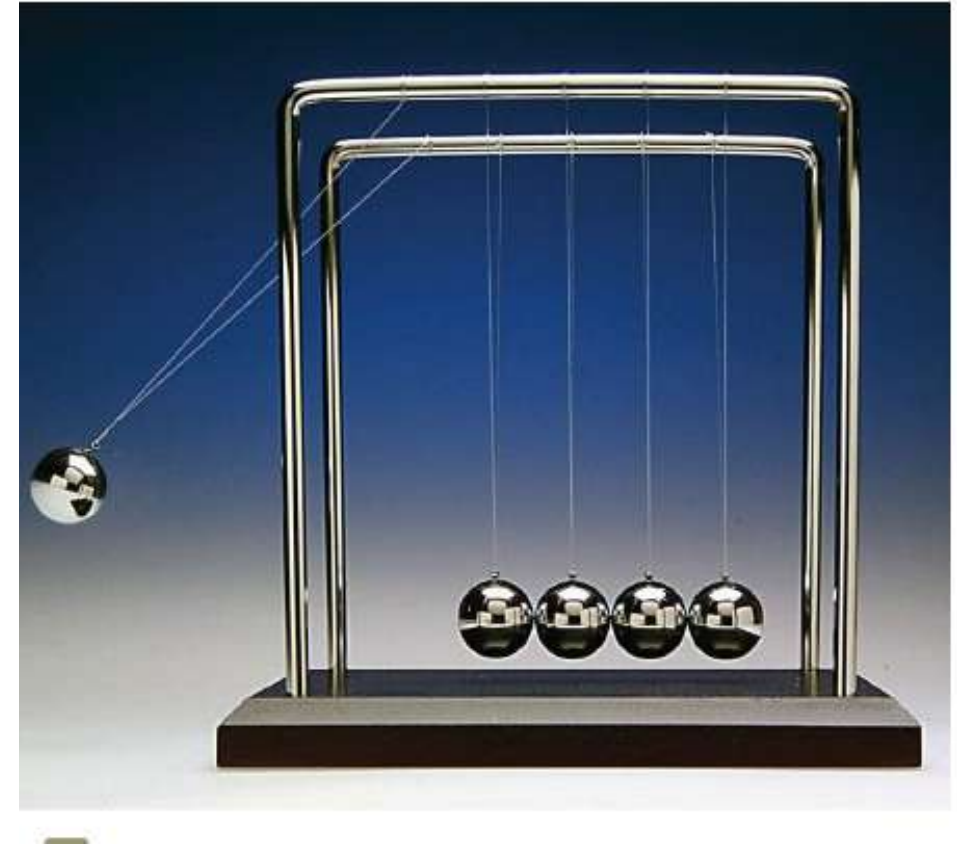
- Check to see if the answers are consistent with the mental and pictorial representations.
- Check to be sure your results are realistic.

Problem-Solving Strategy

Example : In the figure, assume all the identical five balls have the same mass. If one ball is coming in from the left and collides with other balls, is it possible that two balls exit from the right.

Due to shortness of time, the impulse approximation can be used. We can categorize the system as isolated in terms of both momentum and energy.

Elastic collisions (collision occurs between two hard balls and they have similar mass)



Problem-Solving Strategy

Before the collision

The momentum of the system is , where is the speed of ball 1.

After the collision

We imagine that ball 1 stops and balls 4 and 5 swing out.. Each moving with speed . The momentum of each ball is

The total momentum of the system after the collision is:

Which is equal to the momentum before the collision..

Then, momentum is conserved.

Problem-Solving Strategy

Check to see if kinetic energy is conserved.

Before the collision

The of the system is , of ball 1.

After the collision

We find that

The kinetic energy of the system is not conserved which is inconsistent with our assumption that collisions are elastic .

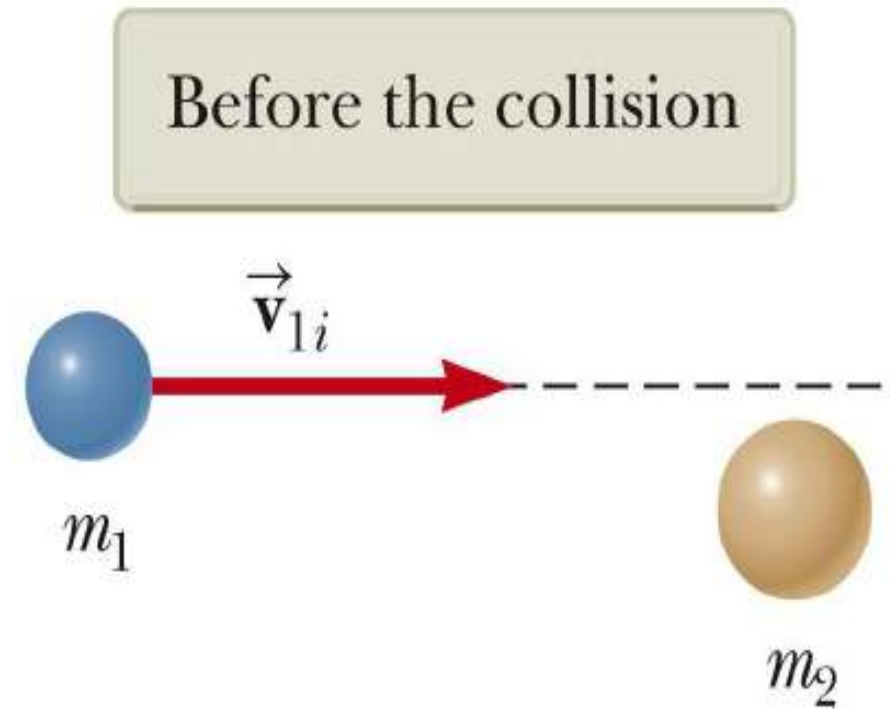
Therefore, having two balls exit was not possible if only one ball is released

Two-Dimensional Collisions

- The momentum is conserved in all directions.
- Use subscripts for
 - Identifying the object
 - Indicating initial or final values
 - The velocity components
- If the collision is elastic, use conservation of kinetic energy as a second equation.
- Remember, the simpler equation can only be used for one-dimensional situations.

Two-Dimensional Collisions

- Particle 1 is moving at velocity and particle 2 is at rest.
- In the x -direction, the initial momentum is $m_1 v_{1i}$.
- In the y -direction, the initial momentum is 0.



Two-Dimensional Collisions

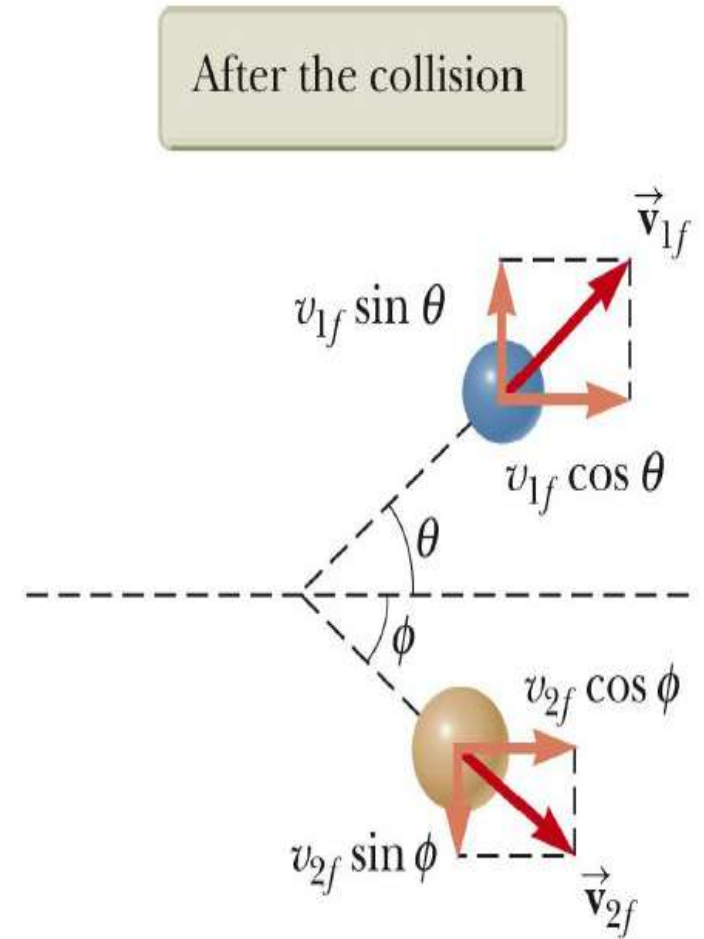
- After the collision, the momentum in the x -direction is

$$m_1 v_{1f} \cos \theta + m_2 v_{2f} \cos \phi$$

- After the collision, the momentum in the y -direction is

$$m_1 v_{1f} \sin \theta - m_2 v_{2f} \sin \phi$$

- The negative sign is due to the component of the velocity being downward.
- If the collision is elastic, apply the kinetic energy equation.
- This is an example of a *glancing collision*.



Problem-Solving Strategies

Two-Dimensional Collisions Conceptualize

- ▣ Imagine the collision.
- ▣ Predict approximate directions the particles will move after the collision.
- ▣ Set up a coordinate system and define your velocities with respect to that system.
- ▣ It is usually convenient to have the x -axis coincide with one of the initial velocities.
- ▣ In your sketch of the coordinate system, draw and label all velocity vectors and include all the given information.

Categorize

Is the system isolated? If so, categorize the collision as elastic, inelastic or perfectly inelastic.

Problem-Solving Strategies

Analyze

- Write expressions for the x- and y-components of the momentum of each object before and after the collision.
- Remember to include the appropriate signs for the components of the velocity vectors.
- Write expressions for the total momentum of the system in the x-direction before and after the collision and equate the two. Repeat for the total momentum in the y-direction.
- If the collision is inelastic, kinetic energy of the system is not conserved, and additional information is probably needed.
- If the collision is perfectly inelastic, the final velocities of the two objects are equal. Solve the momentum equations for the unknowns.

Problem-Solving Strategies

Analyze

- If the collision is elastic, the kinetic energy of the system is conserved.
- Equate the total kinetic energy before the collision to the total kinetic energy after the collision to obtain more information on the relationship between the velocities.

Finalize

- Check to see if your answers are consistent with the mental and pictorial representations.
- Check to be sure your results are realistic.

Problem-Solving Strategies

Example 9.8 : A 1500-kg car traveling east with a speed of 25.0 m/s collides at an intersection with a 2500-kg truck traveling north at a speed of 20.0 m/s as shown in Figure.

Find the direction and magnitude of the velocity of the wreckage after the collision, assuming the vehicles stick together after the collision.

Apply the isolated system model for momentum in the x direction

$$\Delta p_x = 0 \rightarrow \sum p_{xi} = \sum p_{xf} \rightarrow (1) \quad m_1 v_{1i} = (m_1 + m_2) v_f \cos \theta$$

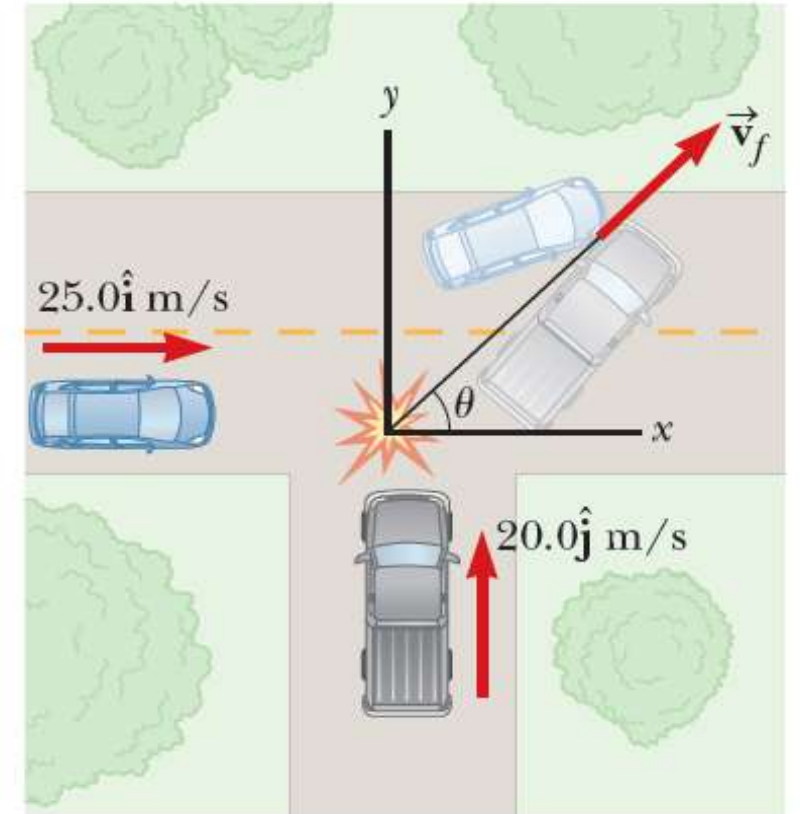


Figure 9.13 (Example 9.8) An eastbound car colliding with a northbound truck.

Problem-Solving Strategies

Apply the isolated system model for momentum in the y direction:

$$\Delta p_y = 0 \rightarrow \sum p_{yi} = \sum p_{yf} \rightarrow (2) \quad m_2 v_{2i} = (m_1 + m_2) v_f \sin \theta$$

Divide Equation (2) by Equation (1):

$$\frac{m_2 v_{2i}}{m_1 v_{1i}} = \frac{\sin \theta}{\cos \theta} = \tan \theta$$

Solve for θ and substitute numerical values:

$$\theta = \tan^{-1} \left(\frac{m_2 v_{2i}}{m_1 v_{1i}} \right) = \tan^{-1} \left[\frac{(2\,500 \text{ kg})(20.0 \text{ m/s})}{(1\,500 \text{ kg})(25.0 \text{ m/s})} \right] = 53.1^\circ$$

Problem-Solving Strategies

$$\theta = \tan^{-1}\left(\frac{m_2 v_{2i}}{m_1 v_{1i}}\right) = \tan^{-1}\left[\frac{(2\,500\text{ kg})(20.0\text{ m/s})}{(1\,500\text{ kg})(25.0\text{ m/s})}\right] = 53.1^\circ$$

$$v_f = \frac{m_2 v_{2i}}{(m_1 + m_2) \sin \theta} = \frac{(2\,500\text{ kg})(20.0\text{ m/s})}{(1\,500\text{ kg} + 2\,500\text{ kg}) \sin 53.1^\circ} = 15.6\text{ m/s}$$

The Center of Mass

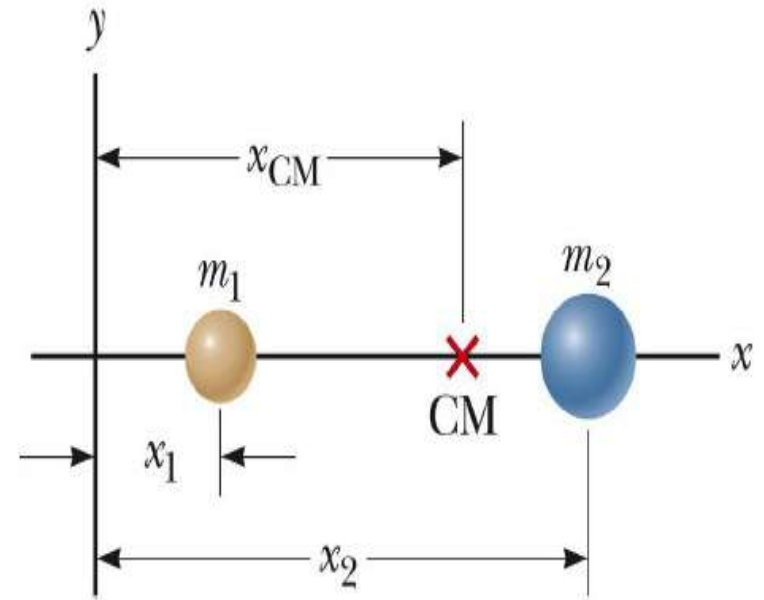
- There is a special point in a system or object, called the *center of mass*, that moves as if all of the mass of the system is concentrated at that point.
- The system will move as if an external force were applied to a single particle of mass M located at the center of mass.
- This behavior is independent of other motion, such as rotation or vibration, or deformation of the system.
- This is the particle model.

The Center of Mass

Coordinates The coordinates of the center of mass are

$$x_{\text{CM}} = \frac{\sum_i m_i x_i}{M} \quad y_{\text{CM}} = \frac{\sum_i m_i y_i}{M}$$
$$z_{\text{CM}} = \frac{\sum_i m_i z_i}{M}$$

where M is the total mass of the system.



The Center of Mass

- The center of mass in three dimensions can be located by its position vector,
- For a system of particles,

where $\mathbf{r}_i$ is the position of the i_{th} particle, defined by

The Center of Mass

- For two particles separated by a distance d , where the origin is chosen at the position of particle 1:

$$x_{\text{com}} = \frac{m_2}{m_1 + m_2} d.$$

- For two particles, for an arbitrary choice of origin:

$$x_{\text{com}} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}.$$

The Center of Mass

For many particles, we can generalize the equation,

where $M = m_1 + m_2 + \dots + m_n$:

$$\begin{aligned}x_{\text{com}} &= \frac{m_1x_1 + m_2x_2 + m_3x_3 + \dots + m_nx_n}{M} \\&= \frac{1}{M} \sum_{i=1}^n m_i x_i.\end{aligned}$$

More concisely, we can write in terms of vectors:

$$\vec{r}_{\text{com}} = \frac{1}{M} \sum_{i=1}^n m_i \vec{r}_i,$$

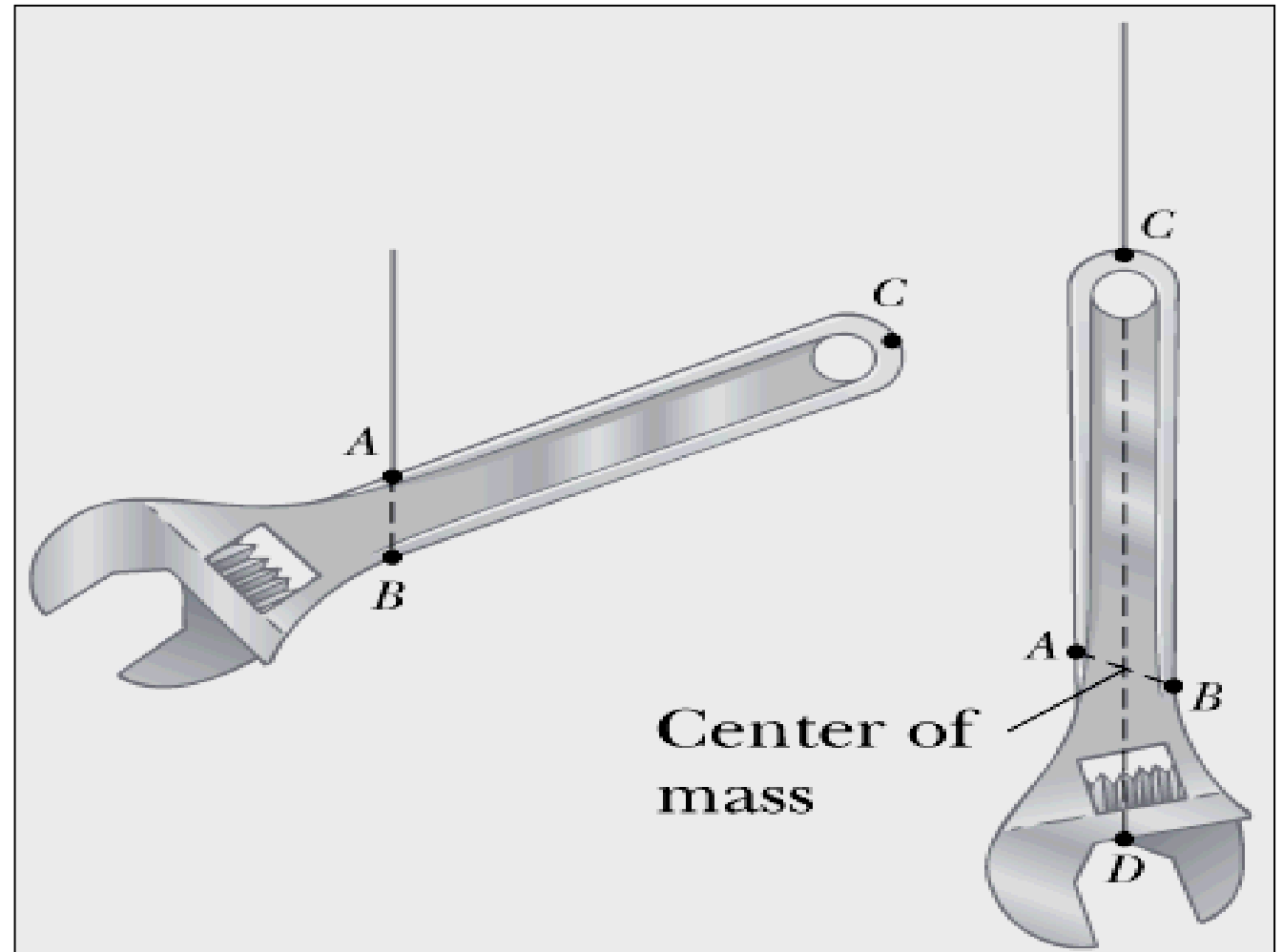
The Center of Mass

Example : Two bodies of masses 5 kg and 15 kg are located in the Cartesian plane at (1,0) and (0,1) respectively. What is the location of their Center of mass?

Therefore, the center of mass is (,)

A method for finding the center of mass of any object

- Hang object from two or more points.
- Draw extension of suspension line.
- Center of mass is at intercept of these lines.



Thank
You





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General Physics I



SCI 101 General Physics
Week 9
Rotational Motion

Lecture Outlines

10.0 Rotation of a Rigid Object about a Fixed Axis

10.1 Angular position, Velocity, and Acceleration

10.2 Rigid Object under Constant Angular Acceleration

10.4 Torque, Rigid Object Under a Net Torque

Weekly Learning Outcomes

- Recall motion and types of motion
- Introduce Rotational Motion and angular physical quantities
- Analysis Object under Constant Angular Acceleration
- Understand torque and calculate torque
- Use conservation of angular momentum to solve problems related to rotational motion

Required Reading

Chapter 10 : Rotation of a Rigid Object About a Fixed Axis in
Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 10 : Rotation in Principles of Physics, 10th
Edition. John Wiley & Sons

Recommended Video

- Rotation of Rigid Body

<https://www.youtube.com/watch?v=e1IFDZQ566k&list=PLkuVD5NmHtHfEUA4hNycY-YqPFEK5dugn&index=20>



Rotation of a Rigid Object about a Fixed Axis

Section 10.0

Rotational Variables

- The same laws apply for motion of **rotation** but we need new quantities to express them such as torque and rotational inertia
 - A rigid body rotates as a unit, locked together
 - We look at rotation about a fixed axis
 - These requirements exclude from consideration:
 - The Sun, where layers of gas rotate separately
 - A rolling bowling ball, where rotation and translation occur



Rotational Variables

- Measure using **radians** (rad): dimensionless

$$\theta = \frac{s}{r} \quad (\text{radian measure}).$$

$$1 \text{ rev} = 360^\circ = \frac{2\pi r}{r} = 2\pi \text{ rad},$$

- Do not reset θ to zero after a full rotation
- We know all there is to know about the kinematics of rotation if we have $\theta(t)$ for an object

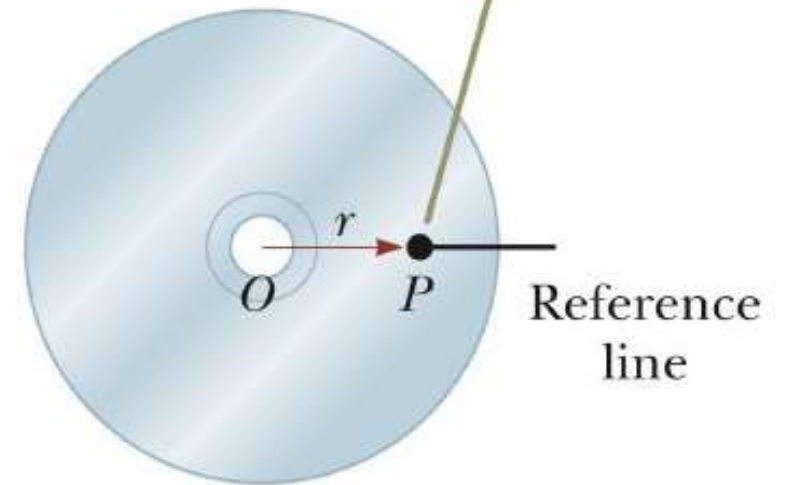
Angular position, Velocity, and Acceleration

Section 10.1

Angular Position

- Axis of rotation is the center of the disc
- Choose a fixed reference line where the point P is at a fixed distance r from the origin.
- A small element of the disc can be modeled as a particle at P .
- Polar coordinates are convenient to represent the position of P (or any other point).
- P is located at (r, θ) where r is the distance from the origin to P and θ is the measured counterclockwise from the reference line.

To define angular position for the disc, a fixed reference line is chosen. A particle at P is located at a distance r from the rotation axis through O .

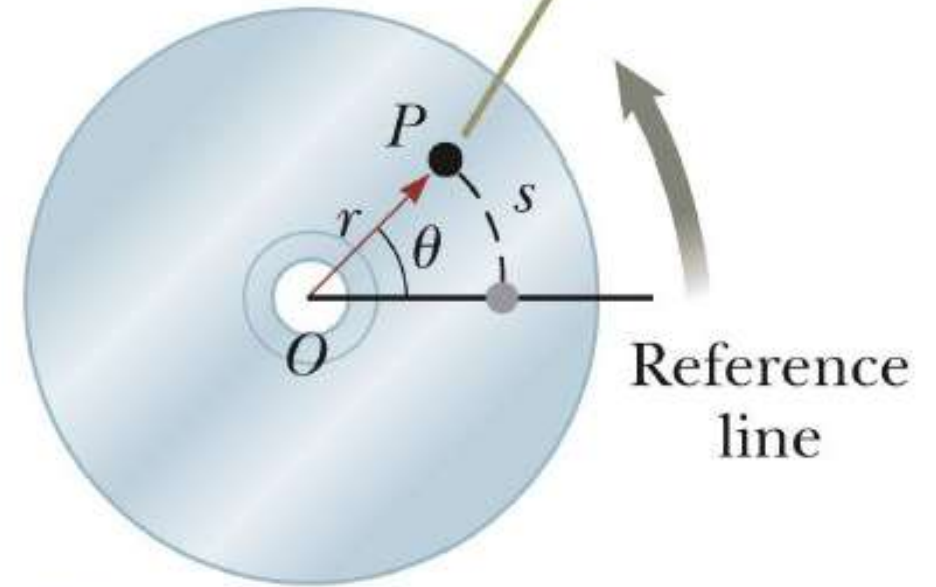


Angular Position

- As the particle moves, the only coordinate that changes is θ
- When the particle moves through θ , it moves through an arc length s .
- The arc length and r are related:

$$s = \theta r$$

As the disc rotates, a particle at P moves through an arc length s on a circular path of radius r .

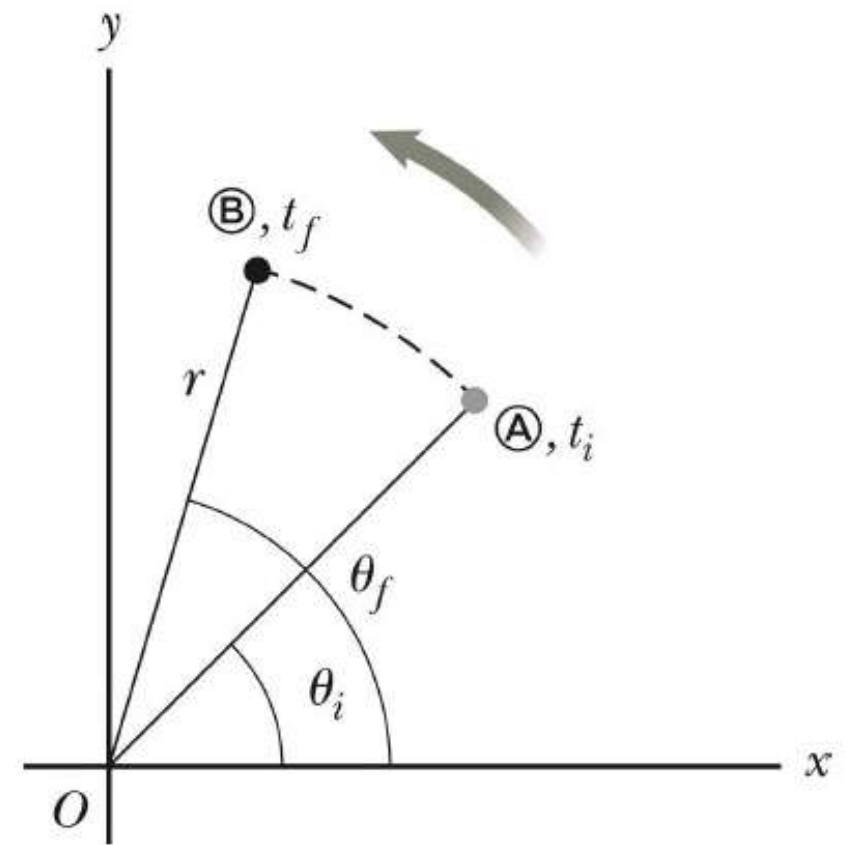


Angular Displacement

- The *angular displacement* is defined as the angle the object rotates through during some time interval.

$$\Delta\theta = \theta_f - \theta_i$$

- This is the angle that the reference line of length r sweeps out.



Rotational Variables

Average angular velocity: angular displacement during a time interval

$$\omega_{\text{avg}} = \frac{\theta_2 - \theta_1}{t_2 - t_1} = \frac{\Delta\theta}{\Delta t},$$

Instantaneous angular velocity: limit as $\Delta t \rightarrow 0$

$$\omega = \lim_{\Delta t \rightarrow 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt}.$$

- If the body is rigid, these equations hold for all points on the body
- Magnitude of angular velocity = **angular speed**

Angular Speed

- The *instantaneous* angular speed is defined as the limit of the average speed as the time interval approaches zero.

$$\omega \equiv \lim_{\Delta t \rightarrow 0} \frac{\Delta \theta}{\Delta t} = \frac{d\theta}{dt}$$

- This is analogous to translational speed.
- Units of angular speed are radians/sec.
- Angular speed will be positive if θ is increasing (counterclockwise) and negative if θ is decreasing (clockwise)

Angular Acceleration

- The average angular acceleration, α_{avg} , of an object is defined as the ratio of the change in the angular speed to the time it takes for the object to undergo the change.

$$\alpha_{avg} = \frac{\omega_f - \omega_i}{t_f - t_i} = \frac{\Delta\omega}{\Delta t}$$

- The instantaneous angular acceleration is defined as the limit of the average angular acceleration as the time goes to 0.

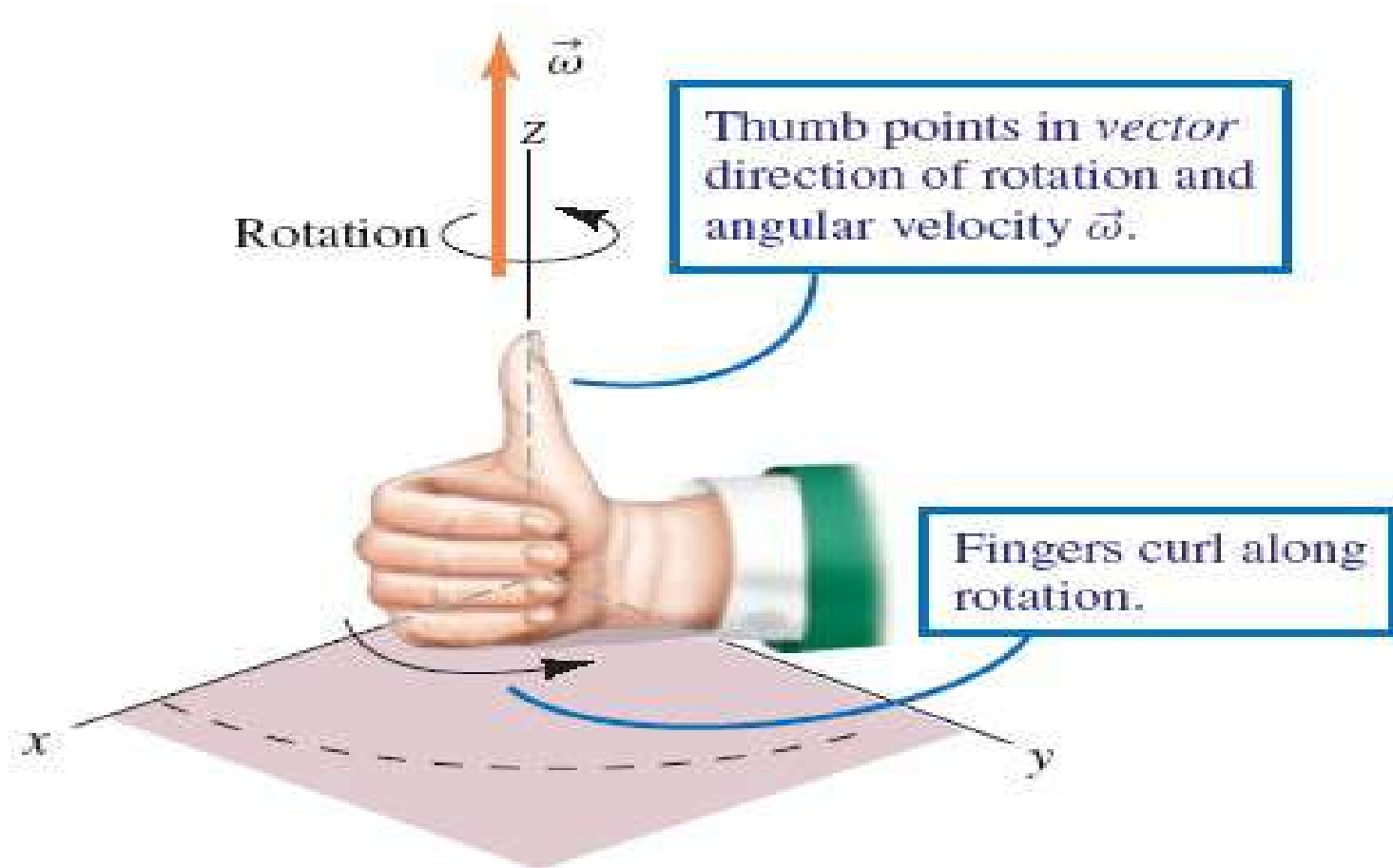
$$\alpha \equiv \lim_{\Delta t \rightarrow 0} \frac{\Delta\omega}{\Delta t} = \frac{d\omega}{dt}$$

Angular Acceleration

- Units of angular acceleration are rad/s^2 or s^{-2} since radians have no dimensions.
- Angular acceleration will be positive if an object rotating counterclockwise is speeding up.
- Angular acceleration will also be negative if an object rotating clockwise is slowing down.

Angular Acceleration

Right-hand rule for finding direction of angular velocity:



Angular Acceleration

- Strictly speaking, the speed and acceleration (ω , α) are the magnitudes of the velocity and acceleration vectors.
- The directions are actually given by the right-hand rule.



Angular Quantities

Here is the correspondence between linear and rotational quantities:

Linear	Type	Rotational	Relation
x	displacement	θ	$x = r\theta$
v	velocity	ω	$v = r\omega$
a_{tan}	acceleration	α	$a_{\text{tan}} = r\alpha$

Rigid Object under Constant Angular Acceleration

Section 10.2

Constant Angular Acceleration

The equations of motion for constant angular acceleration are the same as those for linear motion, with the substitution of the angular quantities for the linear ones.

TABLE 10.1 Kinematic Equations for Rotational and Translational Motion

Rigid Object Under Constant Angular Acceleration		Particle Under Constant Acceleration	
$\omega_f = \omega_i + \alpha t$	(10.6)	$v_f = v_i + at$	(2.13)
$\theta_f = \theta_i + \omega_i t + \frac{1}{2}\alpha t^2$	(10.7)	$x_f = x_i + v_i t + \frac{1}{2}at^2$	(2.16)
$\omega_f^2 = \omega_i^2 + 2\alpha(\theta_f - \theta_i)$	(10.8)	$v_f^2 = v_i^2 + 2a(x_f - x_i)$	(2.17)
$\theta_f = \theta_i + \frac{1}{2}(\omega_i + \omega_f)t$	(10.9)	$x_f = x_i + \frac{1}{2}(v_i + v_f)t$	(2.15)

Constant Angular Acceleration

Example : A wheel rotates with a constant angular acceleration of 3.50 rad/s^2 . If the angular speed of the wheel is 2.00 rad/s at $t_i = 0$, through what angular displacement does the wheel rotate in 2.00 s ?

Angular displacement of the wheel

$$\Delta\theta = \theta_f - \theta_i = \omega_i t + \frac{1}{2}\alpha t^2$$

Substitute the known values to find the angular displacement at $t = 2 \text{ s}$

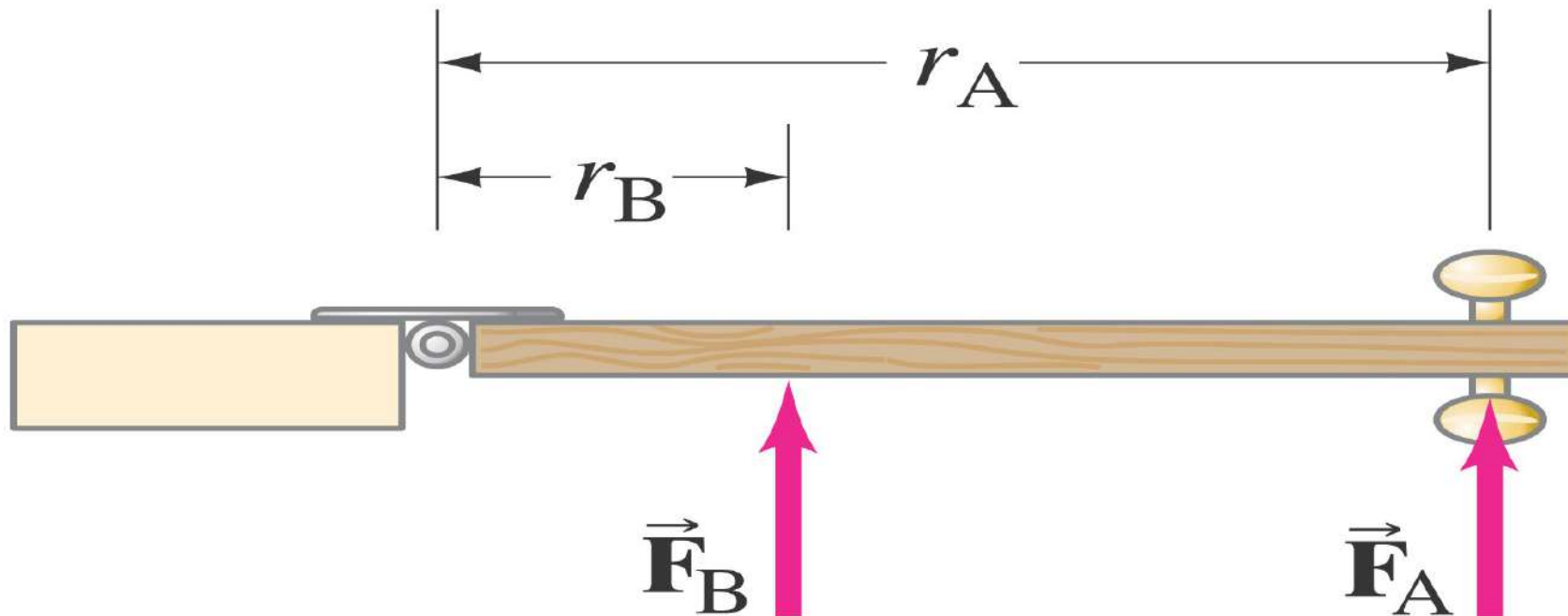
$$\begin{aligned}\Delta\theta &= (2.00 \text{ rad/s})(2.00 \text{ s}) + \frac{1}{2}(3.50 \text{ rad/s}^2)(2.00 \text{ s})^2 \\ &= 11.0 \text{ rad} = (11.0 \text{ rad})(180^\circ/\pi \text{ rad}) = 630^\circ\end{aligned}$$

Torque, Rigid Object Under a Net Torque

Section 10.4

Torque

- To make an object start **rotating**, a force **is needed**; the position and direction of the **force** matter as well.
- The perpendicular distance from the axis of rotation to the line along which the force acts is called the lever arm.



Torque

- The torque depends on the force, the lever arm, and the angle:

$$\tau = rF \sin \theta$$

- The torque causes angular acceleration which depends on the rotational inertia:

$$\tau = I\alpha$$

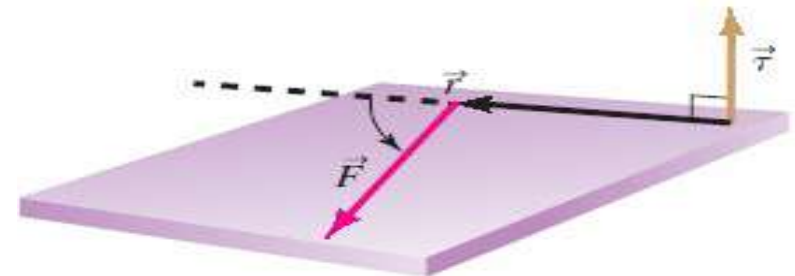
Torque



A longer lever arm is very helpful in rotating objects.

Direction of Torque

A right-hand rule gives the direction of the torque.



Torque and Rotational Inertia

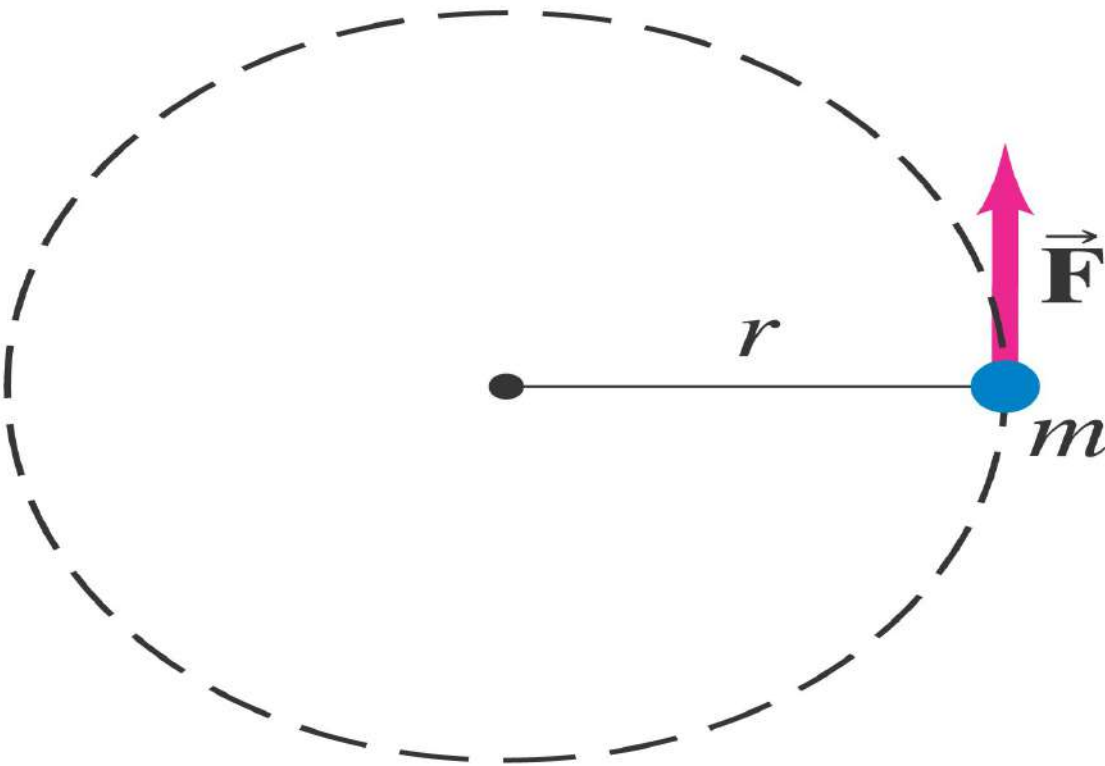
Knowing that $F = ma$ see that

$$\tau = mr^2\alpha$$

This is for a single point mass; what about an extended object?

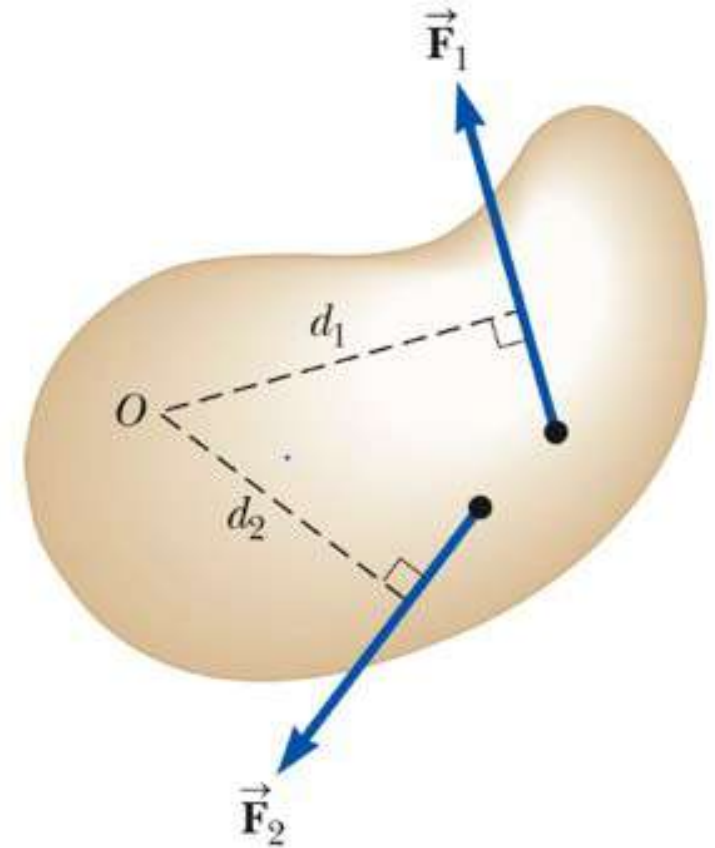
As the angular acceleration is the same for the whole object, we can write:

$$\Sigma\tau = (\Sigma mr^2)\alpha$$



Net Torque

- The force $\vec{F}_1$ will tend to cause a counterclockwise rotation about O .
- The force $\vec{F}_2$ will tend to cause a clockwise rotation about O .



Torque Units

- The SI units of torque are N.m.
- Although torque is a force multiplied by a distance, it is very different from work and energy.
- The units for torque are reported in N.m and not changed to Joules.

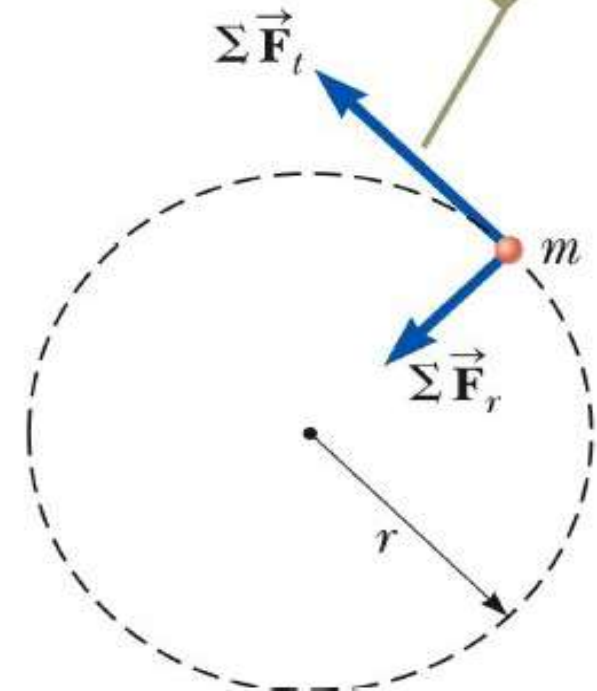
Torque and Angular Acceleration

- Consider a particle of mass m rotating in a circle of radius r under the influence of tangential force .
- The tangential force provides a tangential acceleration:

$$F_t = ma_t$$

- The radial force causes the particle to move in a circular path.

The tangential force on the particle results in a torque on the particle about an axis through the center of the circle.



Torque and Angular Acceleration

- The magnitude of the torque produced by $\vec{\tau}$ on a particle about an axis through the center of the circle is
- The tangential acceleration is related to the angular acceleration.
- Since mr^2 is the moment of inertia of the particle,
- The torque is directly proportional to the angular acceleration and the constant of proportionality is the moment of inertia.

Torque and Angular Acceleration

Example : A uniform rod of length L and mass M is attached at one end to a frictionless pivot and is free to rotate about the pivot in the vertical plane as in Figure 10.12. The rod is released from rest in the horizontal position. What are the initial angular acceleration of the rod and the initial translational acceleration of its right end?

Write an expression for the magnitude of the net external torque due to the gravitational force about an axis through the pivot:

$$\sum \tau_{\text{ext}} = Mg \left(\frac{L}{2} \right)$$

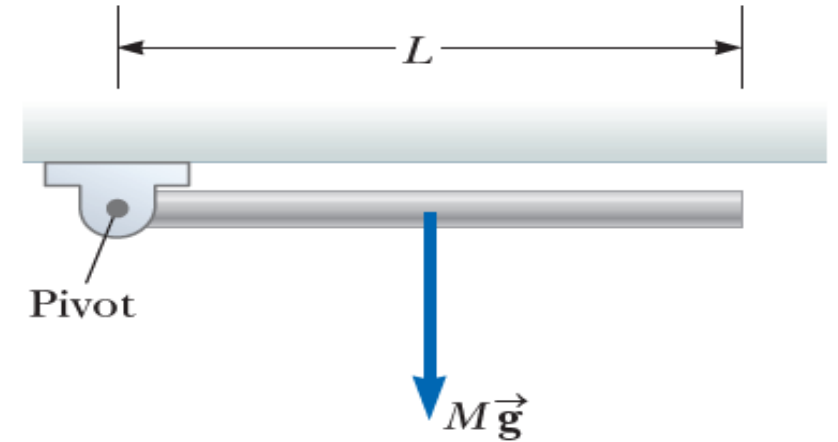


Figure 10.12 (Example 10.4) A rod is free to rotate around a pivot at the left end. The gravitational force on the rod acts at its center of mass.

Torque and Angular Acceleration

Use Equation 10.18 to obtain the angular acceleration of the rod, using the moment of inertia for the rod from Table 10.2:

$$(1) \quad \alpha = \frac{\sum \tau_{\text{ext}}}{I} = \frac{Mg(L/2)}{\frac{1}{3}ML^2} = \frac{3g}{2L}$$

Use Equation 10.11 with $r = L$ to find the initial translational acceleration of the right end of the rod:

$$a_t = L\alpha = \frac{3}{2}g$$

Thank
You





الجامعة السعودية الإلكترونية
SAUDI ELECTRONIC UNIVERSITY
2011-1432

College of Computing and
Informatics
Data Science Pre-Master Program
SCI 101
General Physics I



SCI 101 General Physics

Week 10

Electrostatics, Coulomb's law

Lecture Outlines

22.0 Electric Fields

22.1 Properties of Electric Charges

22.2 Charging Objects by Induction

22.3 Coulomb's Law

22.4 Analysis Model: Particle in a Field (Electric)

22.5 Electric Field Lines

22.6 Motion of a charged particle in a Uniform Electric Field

Weekly Learning Outcomes

- Recall electric charges, types and properties of electric charges
- Understand production of electric charge by Induction
- Apply coulomb's law to calculate electrostatic force
- Recall electric field and its properties
- Understand electric field lines and its properties
- Apply coulombs law to calculate electric field strength
- Analyze electric field and calculate force experienced by a charge

Required Reading

Chapter 22 : Electric field in Physics for scientists and engineers with modern physics

Recommended Reading

Chapter 16: Physics Principles with Applications, 7th edition, by Douglas C. Giancoli

Chapter 22: Electric field in Principles of Physics, 10th Edition. John Wiley & Sons

Recommended Video

Charge :

<https://www.youtube.com/watch?v=kCp5yYjo9zE&t=30s>

Electric field :

<https://www.youtube.com/watch?v=s2LN0upplZY&list=PLkuVD5NmHtHfEUA4hNycY-YqPF EK5dugn&index=13>

Electric field lines :

https://www.youtube.com/watch?v=laGSICm_agM

Electric field due to Dipole :

<https://www.youtube.com/watch?v=puTZvhOFpRA>

Motion of electric charge : https://www.youtube.com/watch?v=f8_l_ec1l_Q

Electric Fields

Section 22.0

Static Electricity and Electric Charge

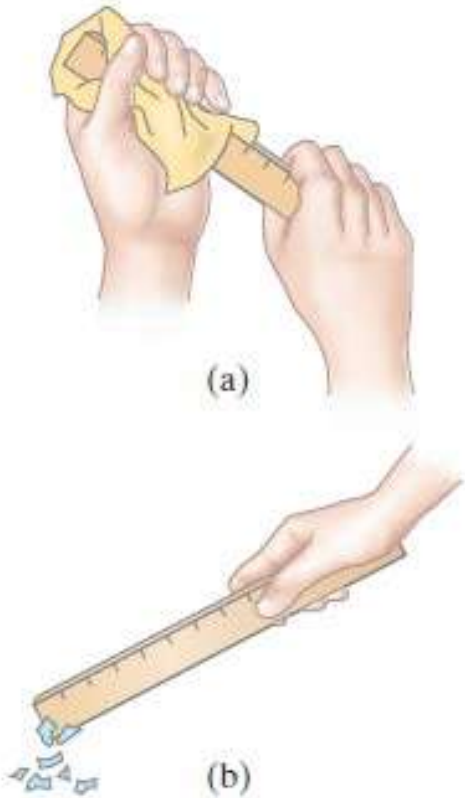


FIGURE 16-1 (a) Rub a plastic ruler with a cloth or paper towel, and (b) bring it close to some tiny pieces of paper.

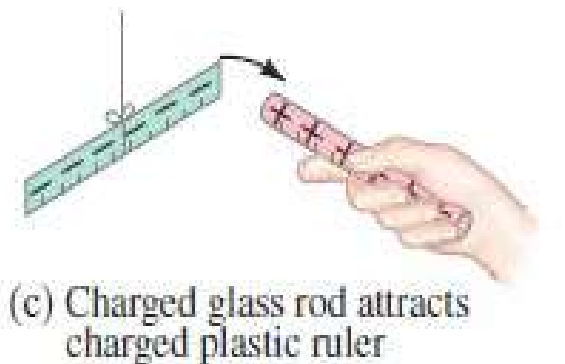
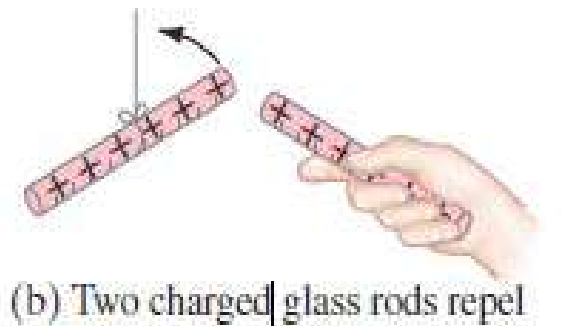
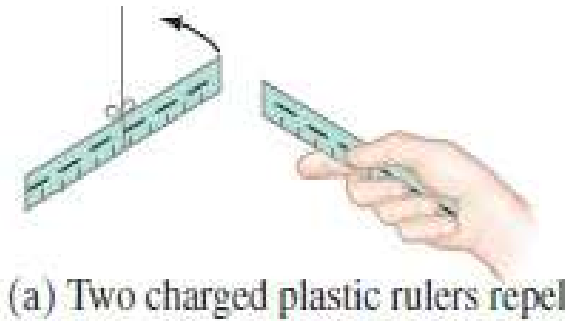
- A piece of hard rubber, a glass rod or a plastic ruler rubbed with a cloth will display static electricity. You can readily pick up small pieces of paper with a plastic comb or ruler that you have just rubbed with a paper towel.
- You have probably experienced static electricity when combing your hair or when taking a synthetic blouse or shirt from a clothes dryer.
- In each case, an object becomes “charged” as a result of rubbing, and is said to possess a net electric charge.
- There are two types of electric charge positive charge and negative charge.

Properties of Electric Charges

Section 22.1

The properties of electric charges and its Conservation

- A plastic ruler suspended by a thread is rubbed with a cloth to charge it, when a second plastic ruler, which has been charged in the same way, is brought close to the first, it is found that one ruler *repels* the other as in Fig. a.
- If a rubbed glass rod is brought close to a second charged glass rod, again a repulsive force is seen to act, Fig. b.
- If the charged glass rod is brought close to the charged plastic ruler, it is found that they *attract* each other, Fig. c.
- Notice: Each type of charge repels the same type but attracts the opposite type, that is: unlike charges attract; like charges repel



Conservation of Electric Charge

- Electric charge is always conserved in an isolated system, that is, when one object is rubbed against another, charge is not created in the process.
- The electrified state is due to a transfer of charge from one object to the other.
- One object gains some amount of negative charge while the other gains an equal amount of positive charge.

Materials classified based on their ability to move charge

Electrical conductors

They are materials in which some of the electrons are free electrons that are not bound to atoms and can move relatively freely through the material.

Electrical insulators

They are materials in which all electrons are bound to atoms and cannot move freely through the material.

Semiconductors

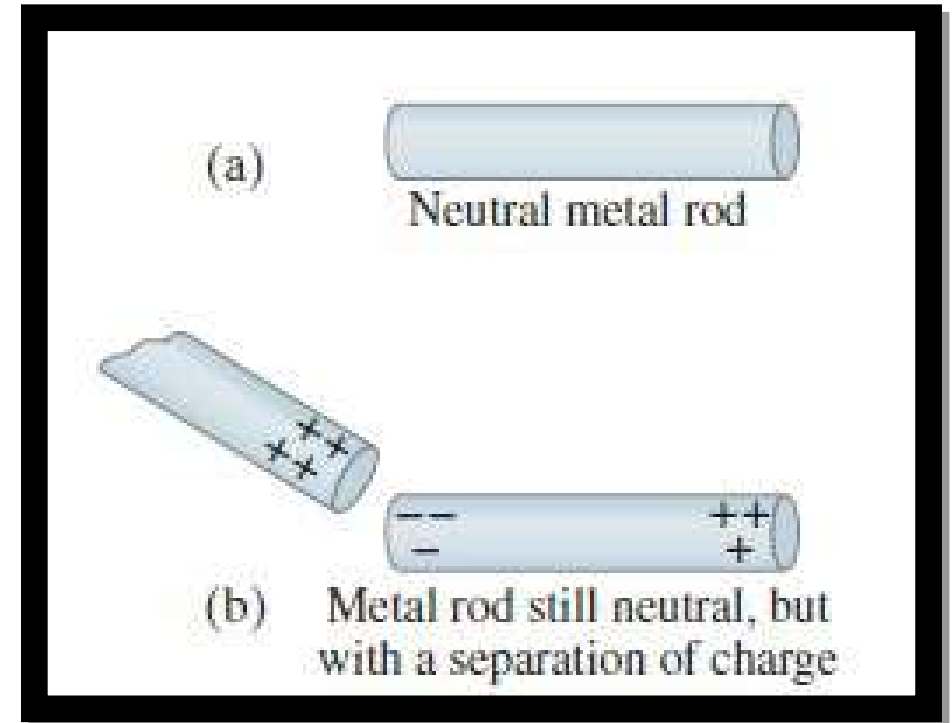
They are materials that are intermediate between conductors and insulators; examples include silicon and germanium in computer chips.

Charging Objects By Induction

Section 22.2

Charging objects by induction

- The neutral metal rod is shown in figure (a). Suppose a positively charged object is brought close to a neutral metal rod, but does not touch it as shown in figure (b). Then, the free electrons move within the metal toward the external positive charge, leaving a positive charge at the opposite end of the rod.
- A charge is said to have been **induced** at the two ends of the metal rod.
- No net charge has been created in the rod: charges have merely been *separated*, one charged positively and one charged negatively. This is **charging by induction**



Coulomb's law

Section 22.3

Coulomb's law

- In general, the electrical behavior of electrons and protons is very well described by modeling them as point charges.
- The magnitude of the electrical force between two point charges and placed at a distance is given by Coulomb's law (is called Coulomb force):

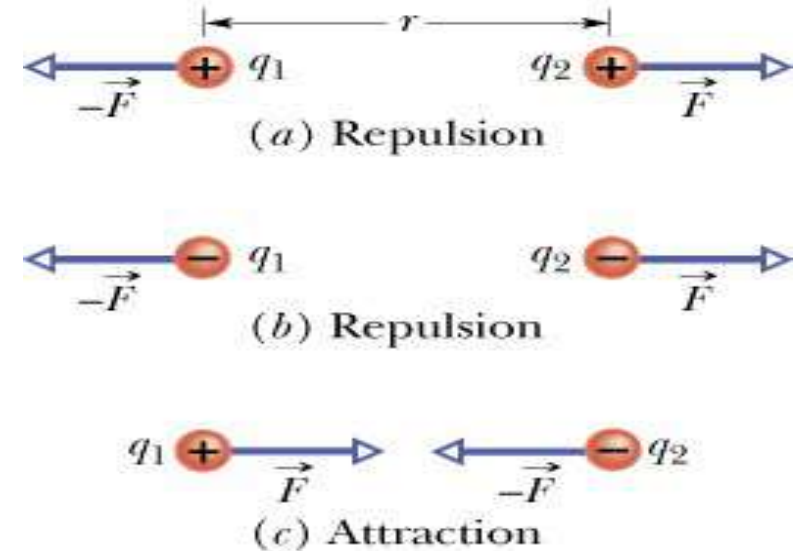


Figure: (a) and (b) Repulsive force between similar charges. (C) Attraction force between positive and negative charge

where is a constant called the Coulomb constant and it is given by .

Coulomb's law

- Coulomb constant can also be written as
where : is the permittivity of free space and it has the value
- The smallest unit of free charge known in nature, the charge on an electron or proton .
- The charges and masses of the electron, proton and neutron are given below

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	$1.674\,93 \times 10^{-27}$

Electrostatic force, Vector forms of Coulomb's law

- Coulomb's law expressed vector form for the electric force exerted by a charge on a second written as

where $\hat{r}_{12}$ is a unit vector directed from q_1 toward q_2 as shown in Figure 22.7 (a).

- Electric force obeys Newton's third law, the electric force exerted by q_1 on q_2 is equal in magnitude to the force exerted by q_2 on q_1 and in the opposite direction that is

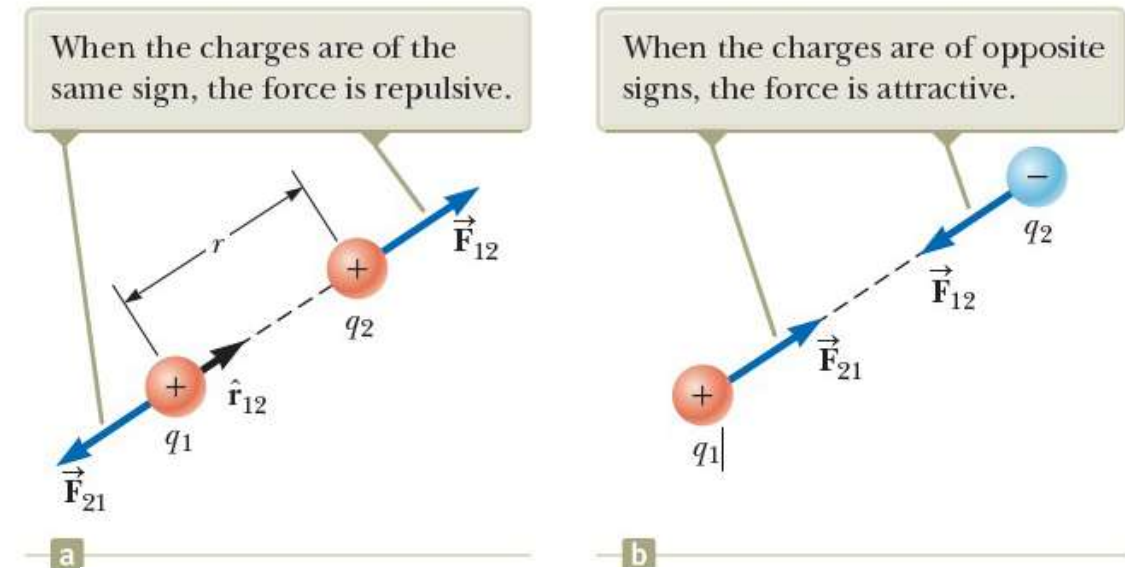


Figure 22.7 Two point charges separated by a distance r exert a force on each other that is given by Coulomb's law. The force $\vec{F}_{21}$ exerted by q_2 on q_1 is equal in magnitude and opposite in direction to the force $\vec{F}_{12}$, exerted by q_1 on q_2 .

Electrostatic force

If multiple electrostatic forces act on a particle, The resultant force (the net force)on any one of them is given by a superposition principle and equals to the vector sum (not scalar sum) of the forces exerted by the other individual charges.

For example, if four charges are present, the resultant force exerted by particles 2, 3, and 4 on particle 1 is:

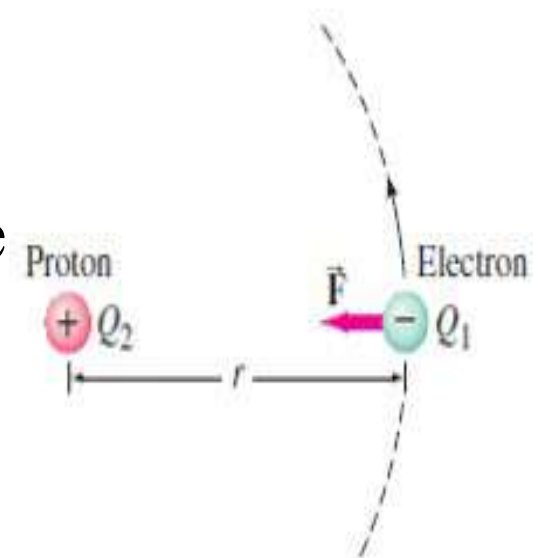
Electrostatic force

Example : Determine the magnitude and direction of the electric force on the electron of a hydrogen atom exerted by the single proton that is the atom's nucleus. Assume the average distance between the revolving electron and the proton is as in Figure

The electron and proton have the same magnitude of charge

The magnitude of the force is

The direction of the force on the electron is toward the proton, because the charges have opposite signs so the force is attractive



Electrostatic force

Example 22.2 : Consider three point charges located at the corners of a right triangle as shown in Figure 22.8, where $q_1 = q_3 = 5.00 \mu\text{C}$, $q_2 = -2.00 \mu\text{C}$, and $a = 0.100 \text{ m}$. Find the resultant force exerted on q_3 .

The force exerted by q_1 on q_3 is repulsive because both charges are positive. The repulsive force makes an angle of 45.0° with the x axis. The magnitudes of the forces and are determined using the absolute magnitudes of the charges in Coulomb's law.

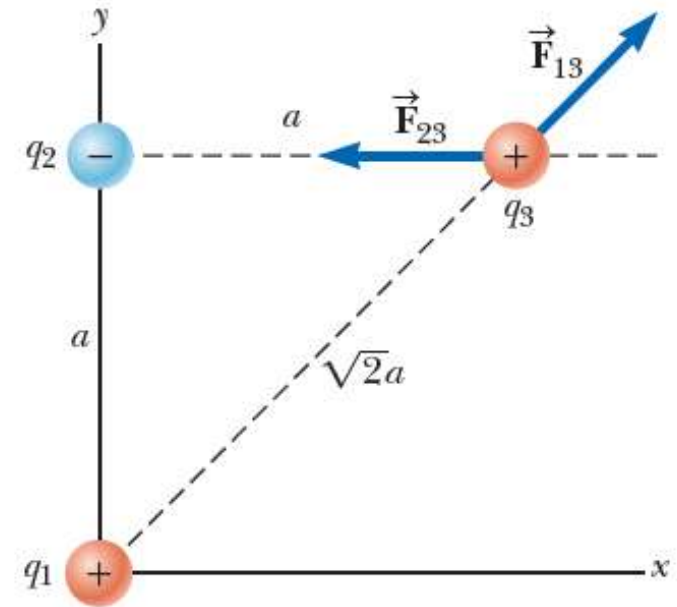


Figure 22.8 (Example 22.2) The force exerted by q_1 on q_3 is $\vec{F}_{13}$. The force exerted by q_2 on q_3 is $\vec{F}_{23}$. The resultant force $\vec{F}_3$ exerted on q_3 is the vector sum $\vec{F}_{13} + \vec{F}_{23}$.

Electrostatic force

Use Coulomb's law to find the magnitude of

$$F_{23} = k_e \frac{|q_2||q_3|}{a^2} \\ = (8.988 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(2.00 \times 10^{-6} \text{ C})(5.00 \times 10^{-6} \text{ C})}{(0.100 \text{ m})^2} = 8.99 \text{ N}$$

Find the magnitude of the force

$$F_{13} = k_e \frac{|q_1||q_3|}{(\sqrt{2} a)^2} \\ = (8.988 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(5.00 \times 10^{-6} \text{ C})(5.00 \times 10^{-6} \text{ C})}{2(0.100 \text{ m})^2} = 11.2 \text{ N}$$

Find the x and y components of the force :

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

Find the components of the resultant force acting on q_3 :

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

Express the resultant force acting on q_3 in unit-vector form: $\vec{F}_3 = (-1.04\hat{i} + 7.94\hat{j}) \text{ N}$

Electrostatic force

Example 22.4 : Two identical small charged spheres, each having a mass of 3.00×10^{-22} kg, hang in equilibrium as shown in Figure 22.10a. The length L of each string is 0.150 m, and the angle θ is 5.00° . Find the magnitude of the charge on each sphere.

The sphere is in equilibrium under the application of the force from the string, the electric force from the other sphere, and the gravitational force

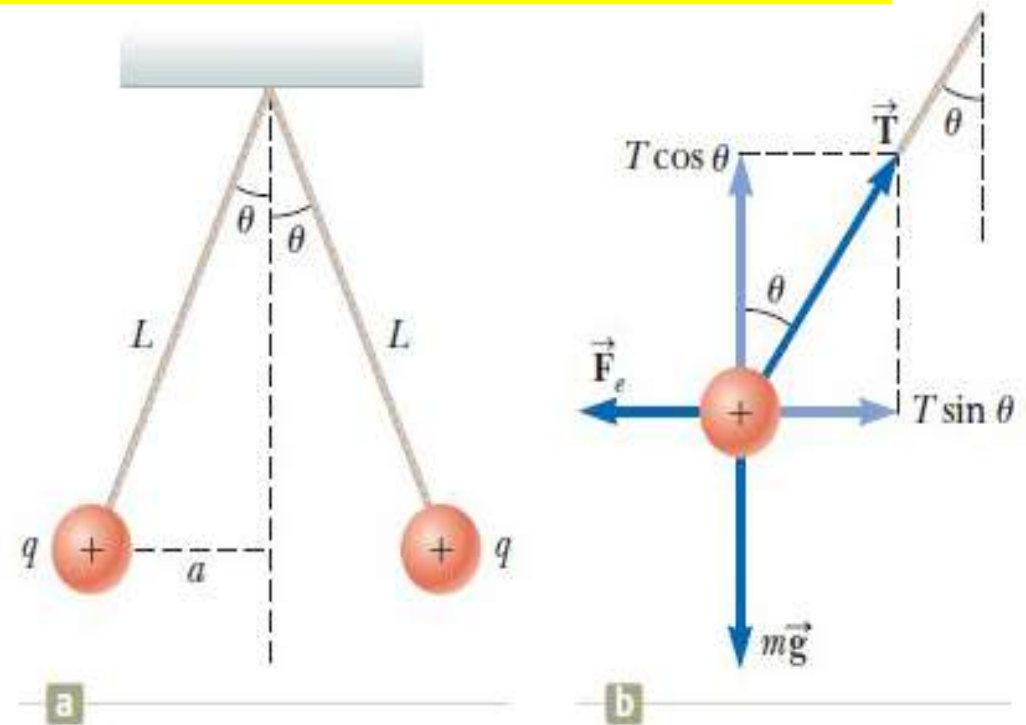


Figure 22.10 (Example 22.4) (a) Two identical spheres, each carrying the same charge q , suspended in equilibrium. (b) Diagram of the forces acting on the sphere on the left part of (a).

Electrostatic force

From the particle in equilibrium model, set the net force on the left-hand sphere equal to zero for each component:

$$(1) \quad \sum F_x = T \sin \theta - F_e = 0 \rightarrow T \sin \theta = F_e$$

$$(2) \quad \sum F_y = T \cos \theta - mg = 0 \rightarrow T \cos \theta = mg$$

Divide Equation (1) by Equation (2) to find F_e :

$$(3) \quad \tan \theta = \frac{F_e}{mg} \rightarrow F_e = mg \tan \theta$$

Electrostatic force

Use the geometry of the right triangle in Figure 22.10a to find a relationship between a , L , and θ :

$$(4) \quad \sin \theta = \frac{a}{L} \rightarrow a = L \sin \theta$$

Solve Coulomb's law for the charge on each sphere and substitute from Equations (3) and (4):

$$|q| = \sqrt{\frac{F_e r^2}{k_e}} = \sqrt{\frac{F_e (2a)^2}{k_e}} = \sqrt{\frac{mg \tan \theta (2L \sin \theta)^2}{k_e}}$$

Substitute numerical values:

$$\begin{aligned} |q| &= \sqrt{\frac{(3.00 \times 10^{-2} \text{ kg})(9.80 \text{ m/s}^2) \tan (5.00^\circ) [2(0.150 \text{ m}) \sin (5.00^\circ)]^2}{8.988 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}} \\ &= 4.42 \times 10^{-8} \text{ C} \end{aligned}$$

Analysis Model: Particle in a Field

Section 22.4

Electric Field

- An electric field exists in the region of space around a charged object, the source charge.
- Figure 2.11a shows the source charge and the resulting electric field at point P in the space external to the source charge.
- To detect the electric field place a test charge in the field and noting an electric force acts on it Figure 2.11b.
- The electric field vector at a point P in space is:
Electric force acting on a positive test charge placed at that point divided by the test charge.
- The unit of in SI units (N/C) and the direction of is parallel to .

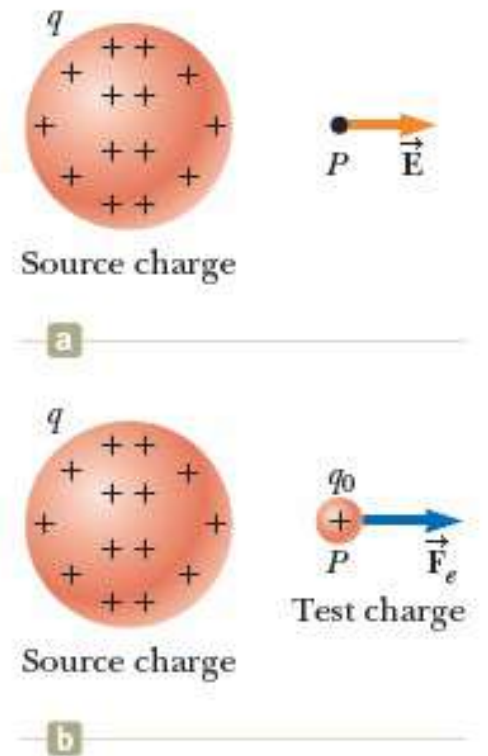


Figure 22.11 An electric force between two particles is a two-step process: (a) A source charge q creates an electric field at a point P in space. (b) When another charge q_0 is placed at P , it feels the effect of that electric field as an electric force.

Electric Force on a charge in an electric field

- If a charge is placed in the electric field it experience an electric force as:
- To determine the direction of the and , the test charge is used (Figure 22.12 a)
- The exerted by on the test charge is:

where $\hat{r}$ is a unit vector directed from q to P .

- This force in (Figure 22.12 a) is directed away from the source charge .

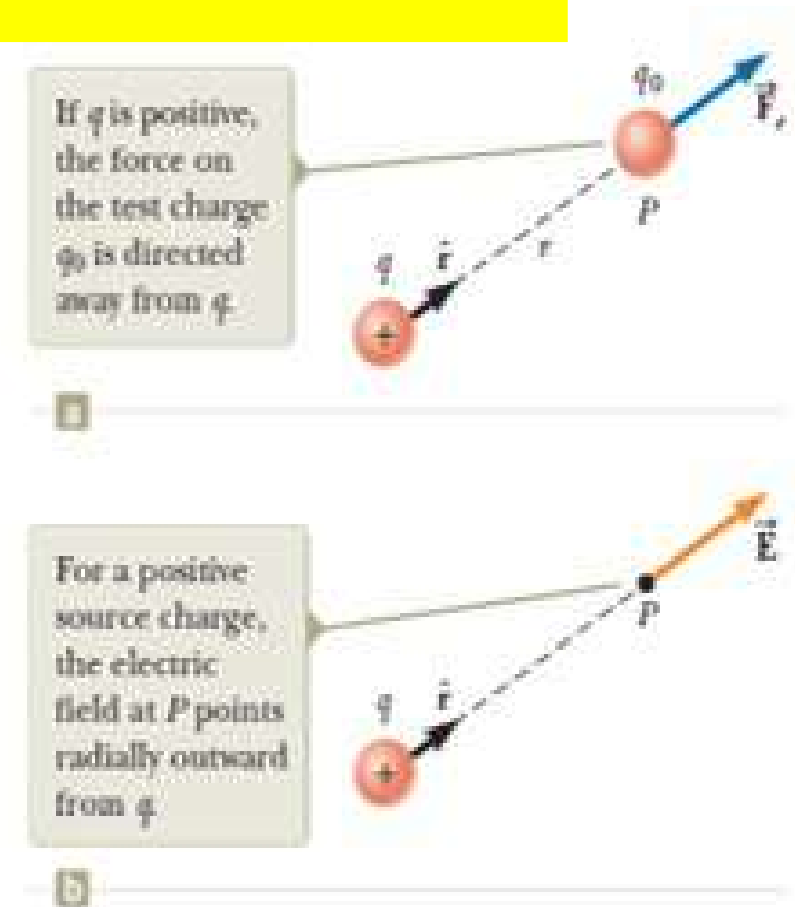


Figure 22.12: (a) electric force on the Test charge exerted by +
(b) Electric field at point P when the test charge is removed, the electric field is directed away from q .

Electric Force on a charge in an electric field

- The $\vec{F}$ at P created by q when q_0 is removed is given as :

The direction of $\vec{F}$ is the same direction as $\vec{E}$ (Figure 22.12 b).

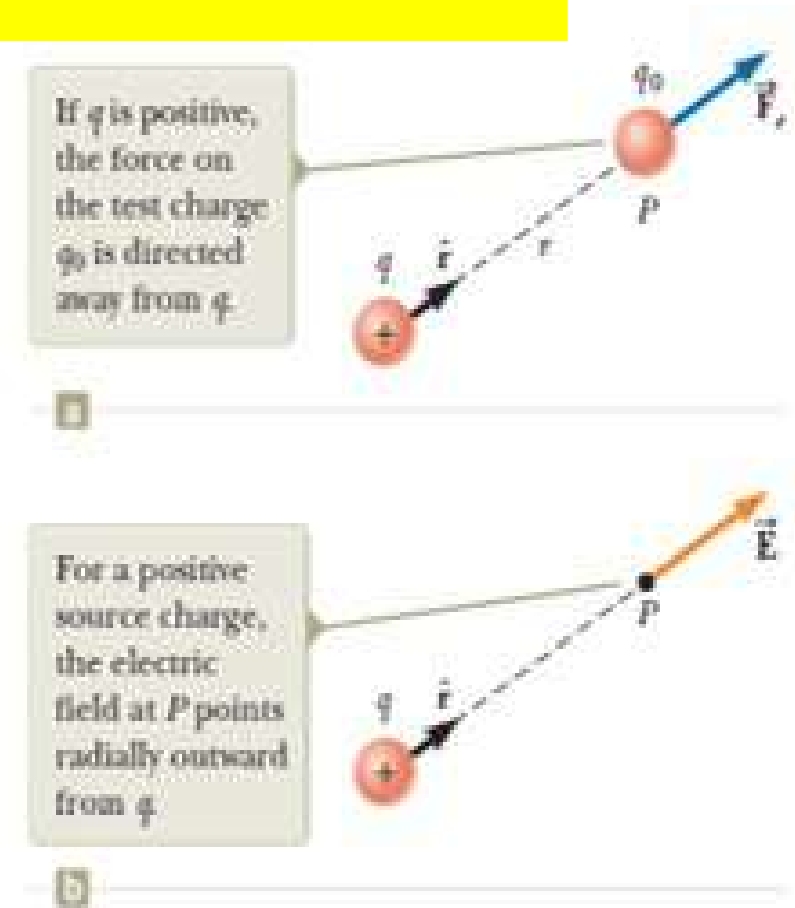


Figure 22.12: (a) electric force on the Test charge exerted by +
(b) Electric field at point P when the test charge is removed, the electric field is directed away from q .

Electric Force on a charge in an electric field

If q is negative as in Figure 22.12c, the force on the test charge is toward the source charge, so the electric field at P is directed toward the source charge as in Figure 22.12d.

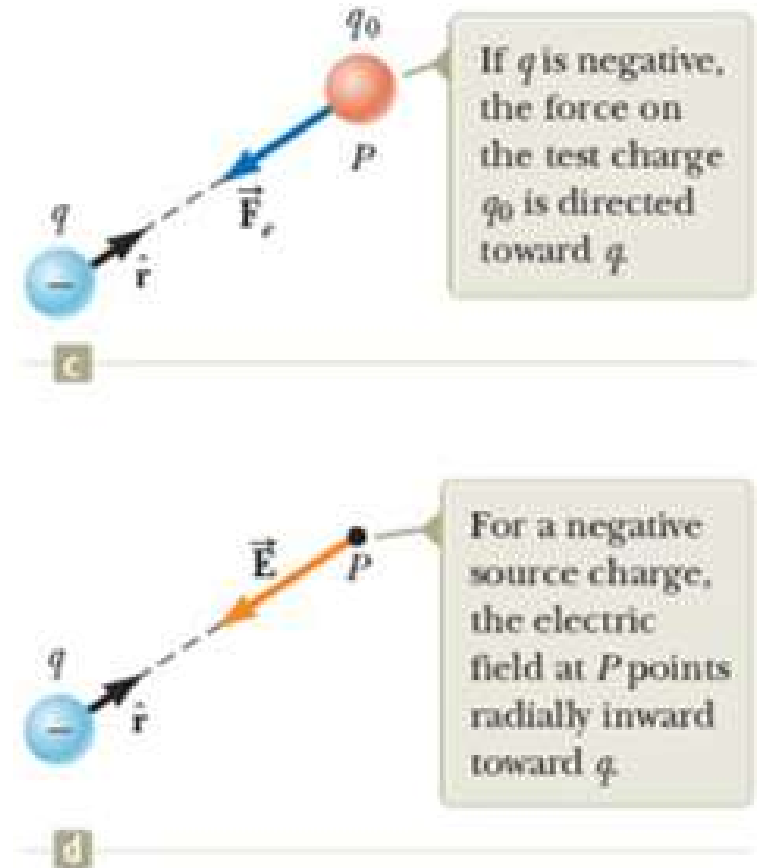


Figure 22.12: (c) electric force on the test charge exerted by -
(d) Electric field at point P when the test charge is removed, the electric field is directed toward $-q$.

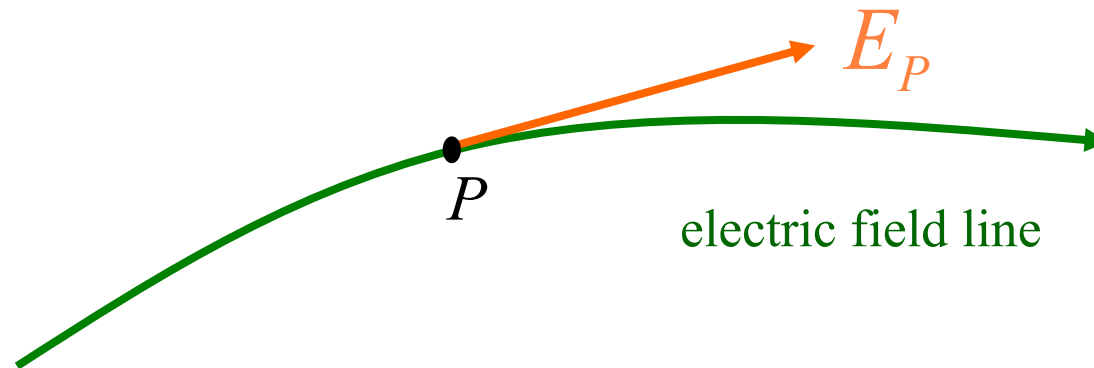
Electric Field Lines

Section 22.5

Electric field Lines

To visualize electric field patterns the **electric field lines** are drawn following the rules:

1- The electric field vector $\mathbf{E}$ is tangent to the electric field line at each point. The line has a direction, indicated by an arrowhead, that is the same as that of the electric field vector.



Electric field Lines

2- The field lines are close together where the electric field is strong and far apart where the field is weak. These properties are illustrated in Figure 22.15.

- The density of field lines through surface A is greater than the density of lines through surface B. Therefore, the magnitude of the electric field is larger on surface A than on surface B.
- The density of electric field lines indicates the strength of the field. In the following figure

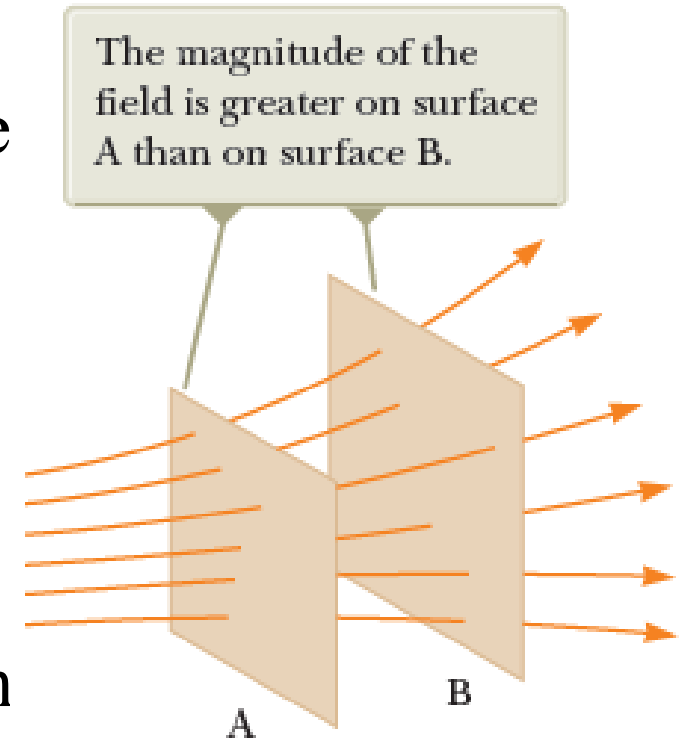
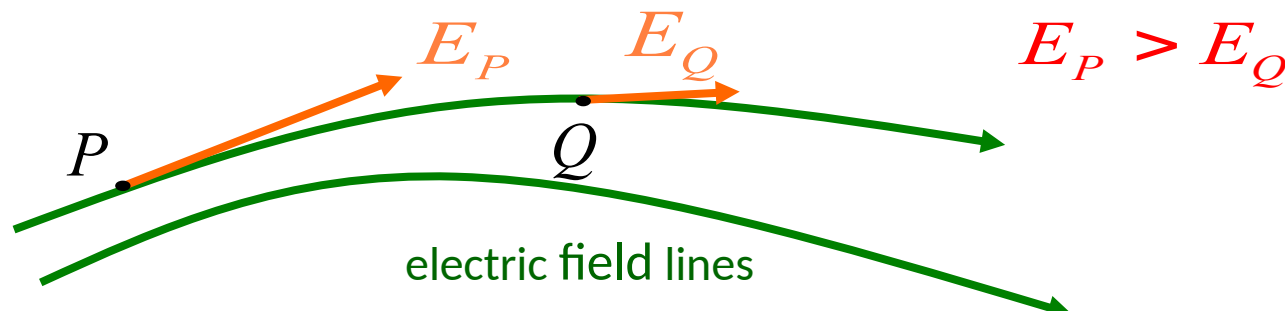
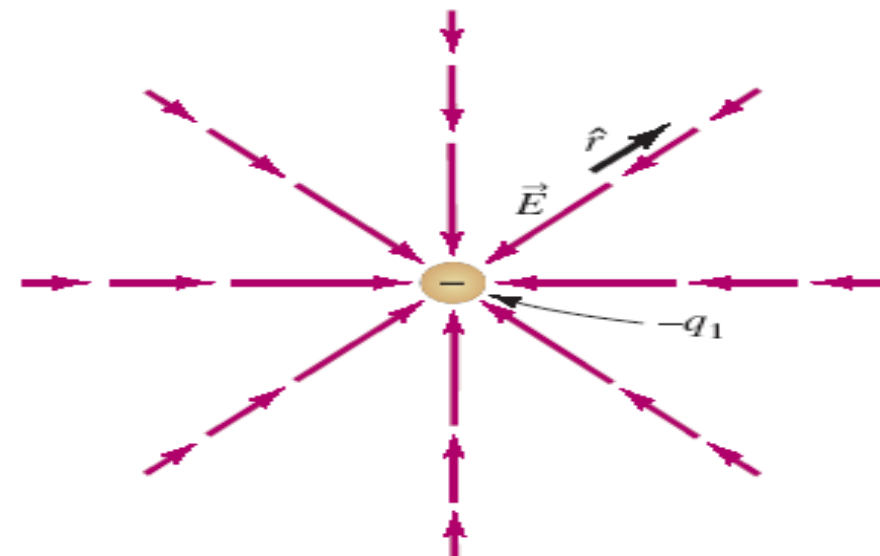
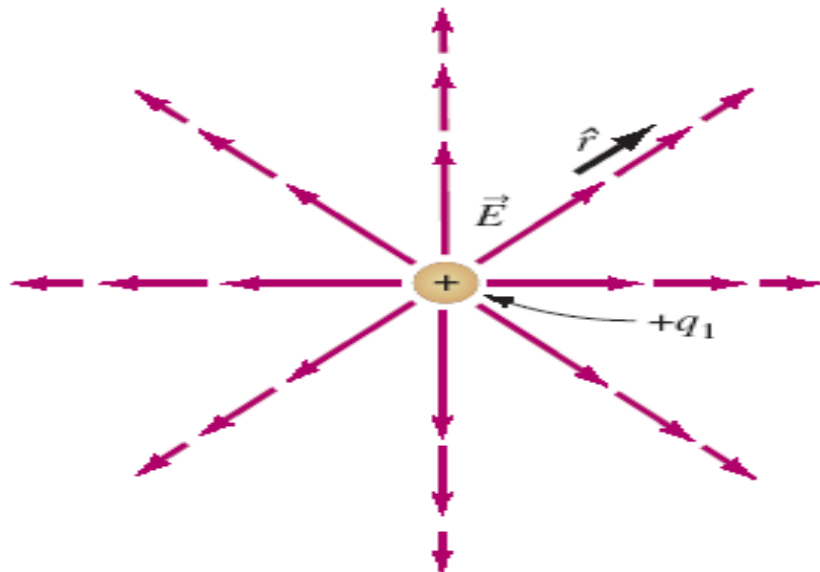


Figure 22.15 Electric field lines penetrating two surfaces.

Electric field Lines

The field points outwards from a positive charge and it points inwards to a negative one.

Notice: The lines become closer together as they approach the charge, indicating that the strength of the field increases as we move toward the source charge.



Electric field Lines

The rules for drawing electric field lines are as follows:

- The lines must begin on a positive charge and terminate on a negative charge. The electric field lines of a point charge go infinitely far away.
- The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge.
- No two field lines can cross, even when multiple charges are present.

Electric field Lines

- Figure 22.17 shows the electric field lines in the vicinity of two equal positive point charge and negative point charge.
- Because the charges are of equal magnitude, the number of lines that begin at the positive charge must equal the number that terminate at the negative charge.
- At points very near the charges, the lines are nearly radial, as for a single isolated charge.
- The high density of lines between the charges indicates a region of strong electric field.

The number of field lines leaving the positive charge equals the number terminating at the negative charge.

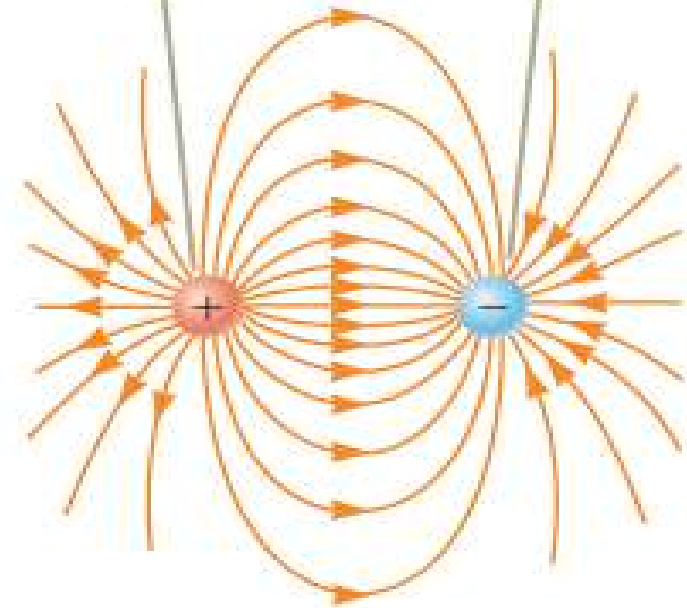
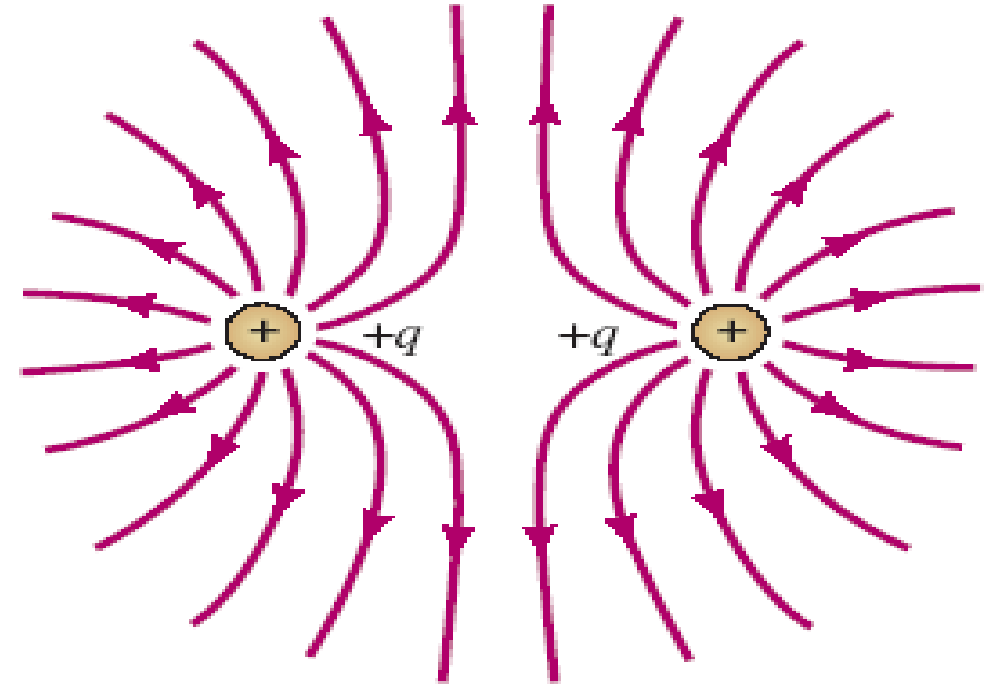


Figure 22.17 The electric field lines for two point charges of equal magnitude and opposite sign (an electric dipole).

Electric field Lines

- Figure shows the electric field lines in the vicinity of two equal positive point charges.
- The lines are nearly radial at points close to either charge, and the same number of lines emerges from each charge (they are equal in magnitude).
- The electric field lines end infinitely far away.



Electric field generated by two positive charges of equal magnitude

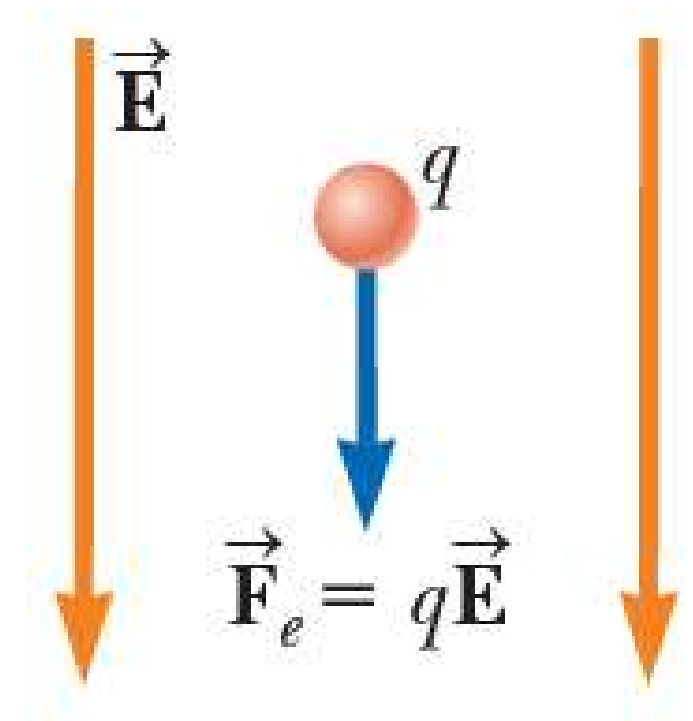
Motion of a charged particle in a Uniform Electric Field

Section 22.6

Particle in a Field (Electric)

- The source charge establishes an electric field throughout space.
- If a particle of charge q is placed in the electric field, the particle interacts with the electric field and experiences an electric force

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



Particle in a Field (Electric)

Example 22.5 : A water droplet of mass 3.00×10^{-12} kg is located in the air near the ground during a stormy day. An atmospheric electric field of magnitude 6.00×10^3 N/C points vertically downward in the vicinity of the water droplet. The droplet remains suspended at rest in the air. What is the electric charge on the droplet?

Write Newton's second law from the particle in equilibrium model in the vertical direction:

$$(1) \quad \sum F_y = 0 \rightarrow F_e - F_g = 0$$

Using the two particle in a field models mentioned in the Categorize step, substitute for the forces in Equation (1), recognizing that the vertical component of the electric field is negative:

$$q(-E) - mg = 0$$

Particle in a Field (Electric)

Solve for the charge on the water droplet:

$$q = -\frac{mg}{E}$$

Substitute numerical values:

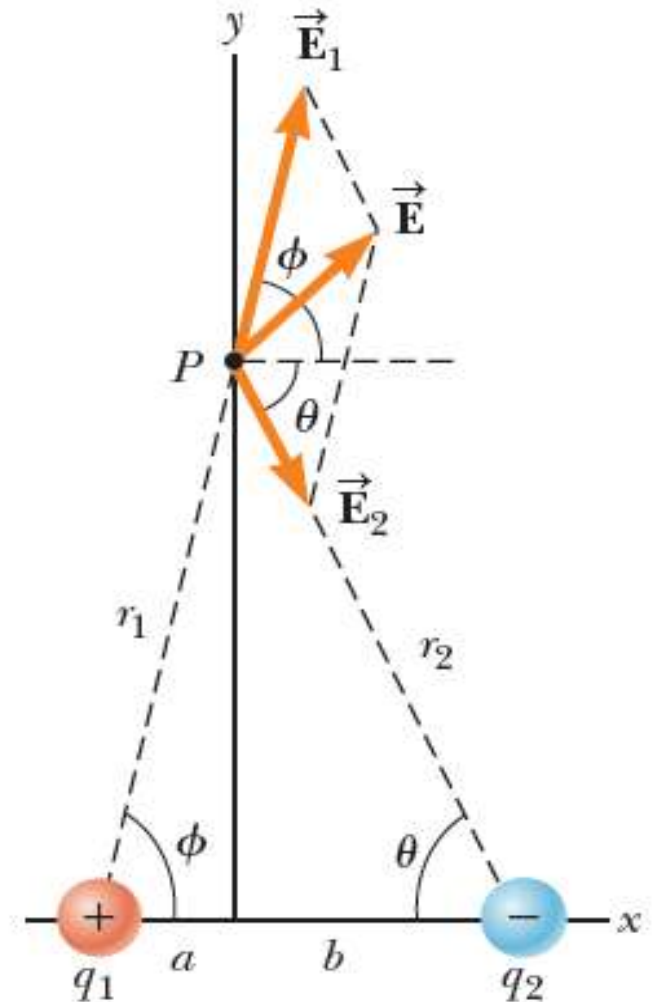
$$q = -\frac{(3.00 \times 10^{-12} \text{ kg})(9.80 \text{ m/s}^2)}{6.00 \times 10^3 \text{ N/C}} = -4.90 \times 10^{-15} \text{ C}$$

Electric Field Due to Two Charges

Example 22.6 : 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 ?

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



Electric Field Due to Two Charges

Find the magnitude of the electric field at P due to charge q_1

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

Find the magnitude of the electric field at P due to charge q_2

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

Write the electric field vectors for each charge in unit-vector form:

$$\vec{E}_1 = k_e \frac{|q_1|}{a^2 + y^2} \cos \phi \hat{\mathbf{i}} + k_e \frac{|q_1|}{a^2 + y^2} \sin \phi \hat{\mathbf{j}}$$

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

Electric Field Due to Two Charges

Write the components of the net electric field vector:

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

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

Thank
You





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Week 11

The electric field due to charge distributions