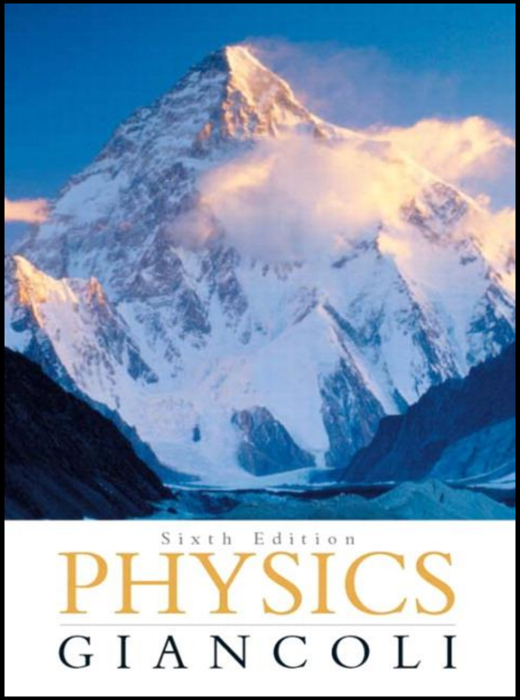


Lecture PowerPoints

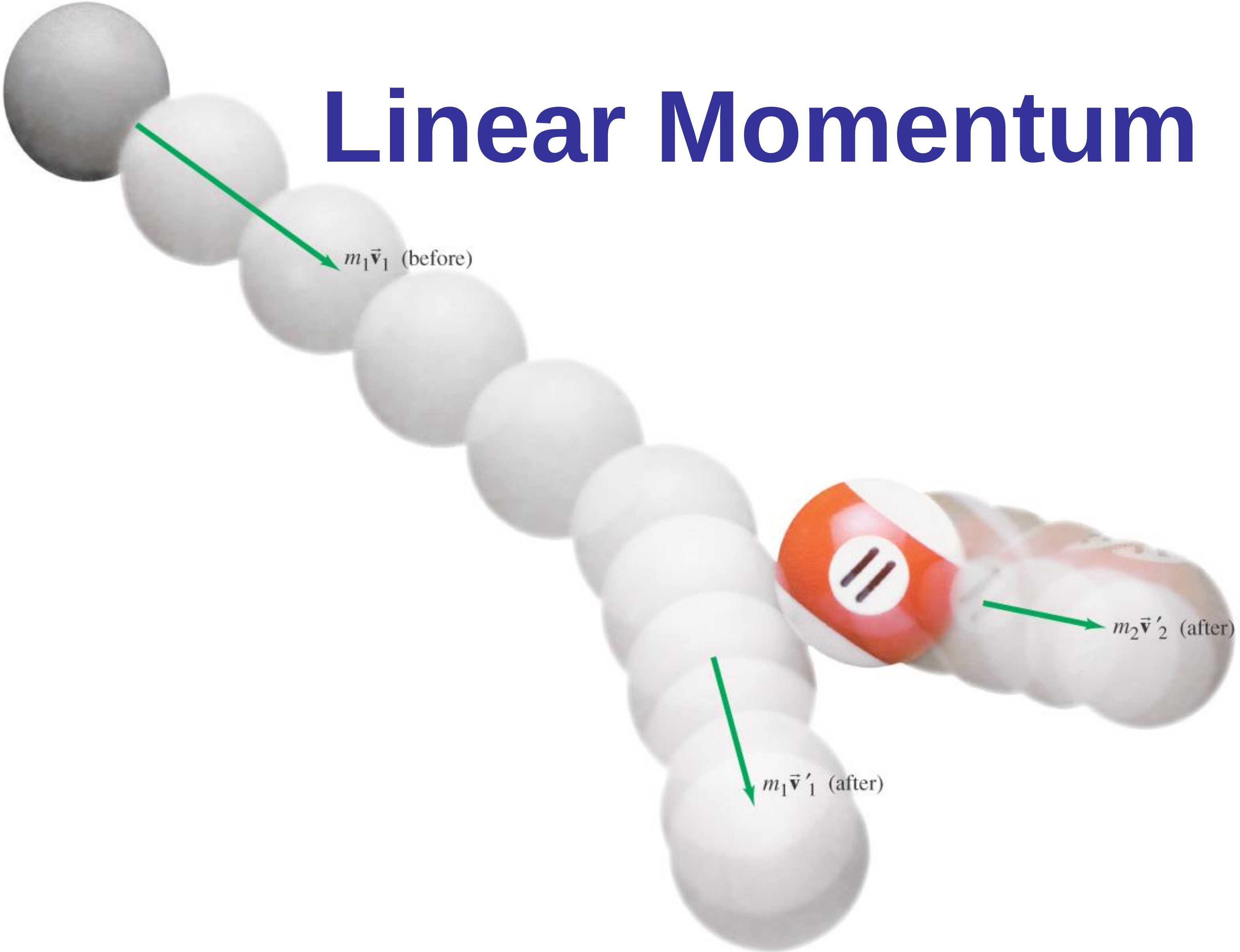
Chapter 7

Physics: Principles with Applications, 6th edition

Giancoli

Chapter 7

Linear Momentum



Units of Chapter 7

- Momentum and Its Relation to Force
- Conservation of Momentum
- Collisions and Impulse
- Conservation of Energy and Momentum in Collisions
- Elastic Collisions in One Dimension

Units of Chapter 7

- Inelastic Collisions
- Collisions in Two or Three Dimensions
- Center of Mass (CM)
- CM for the Human Body
- Center of Mass and Translational Motion

7-1 Momentum and Its Relation to Force

Momentum is a vector symbolized by the symbol **p**, and is defined as

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}} \qquad \text{(7-1)}$$

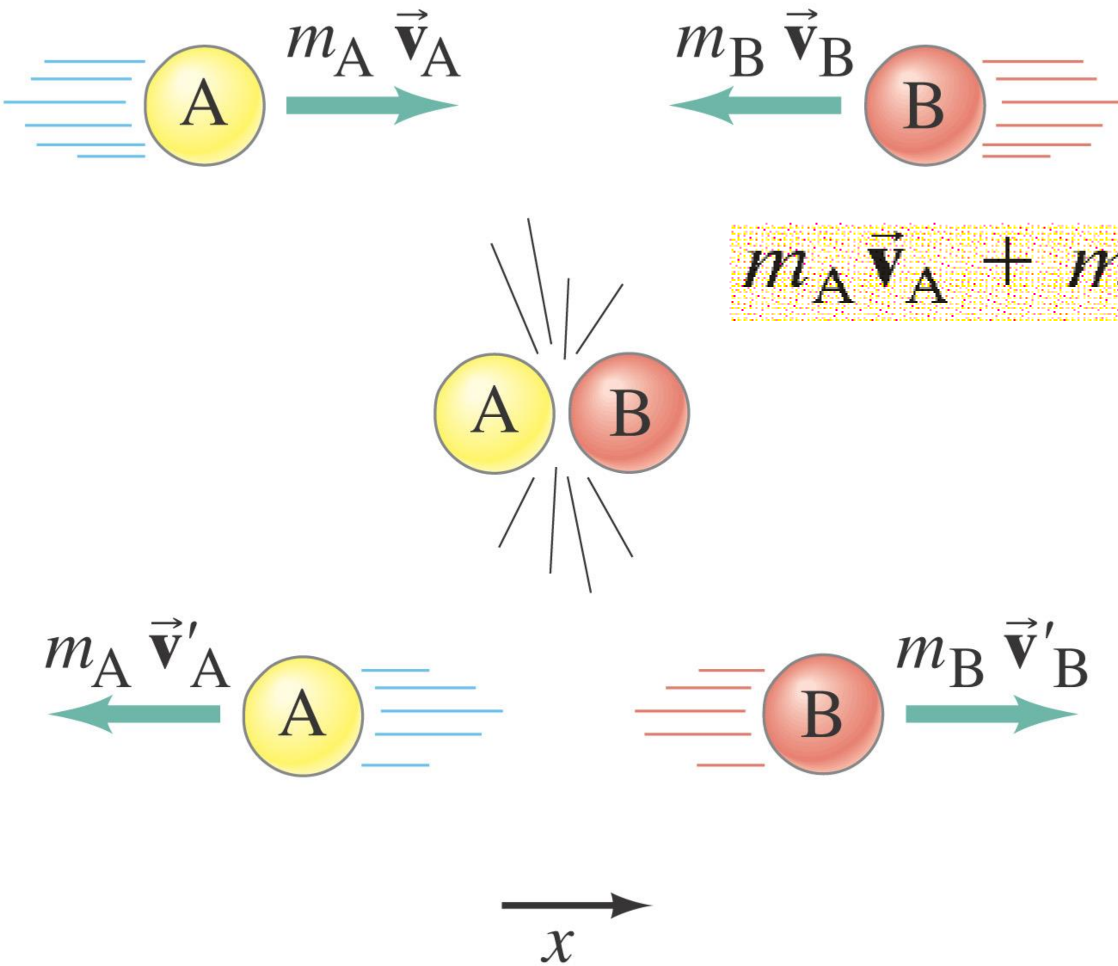
The **rate** of change of momentum is equal to the net **force**:

$$\Sigma\vec{\mathbf{F}} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t} \qquad \text{(7-2)}$$

This can be shown using Newton's **second** law.

7-2 Conservation of Momentum

During a collision, measurements show that the total momentum does not change:

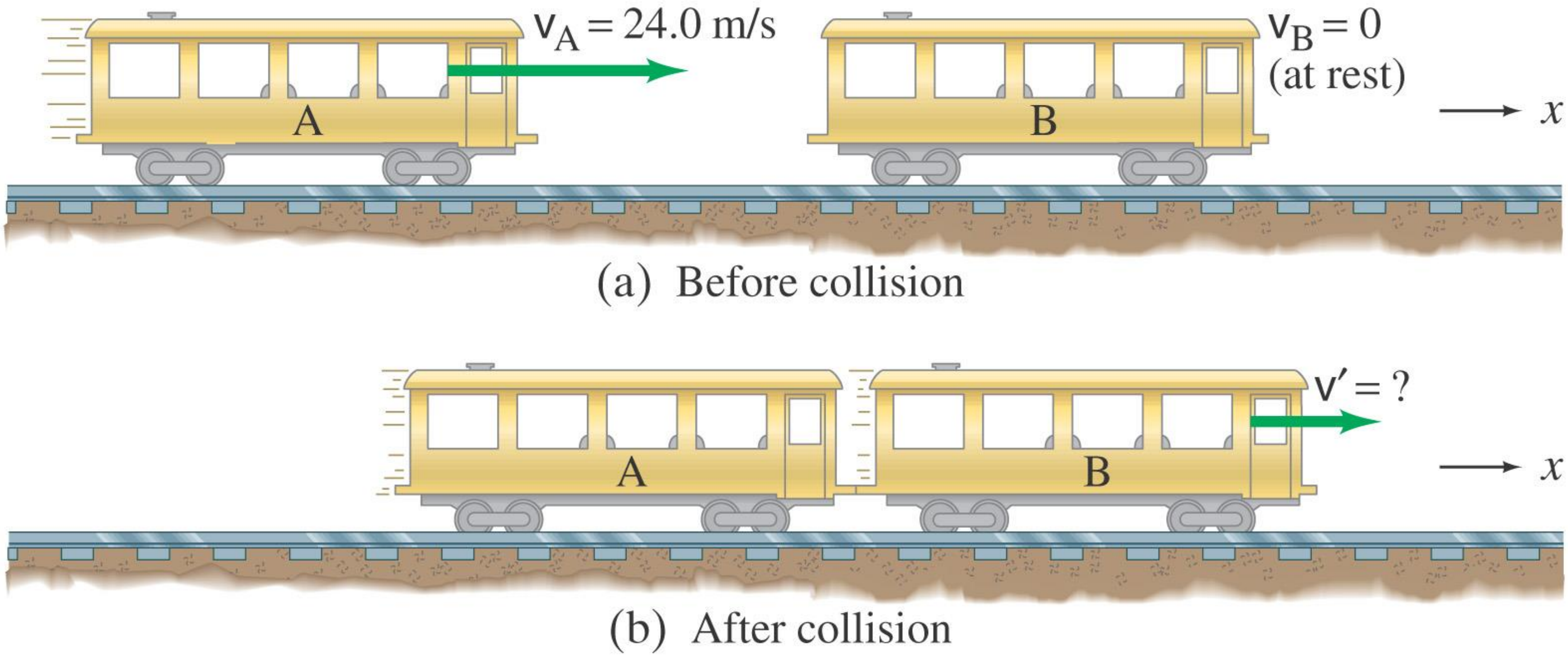


$$m_A \vec{v}_A + m_B \vec{v}_B = m_A \vec{v}'_A + m_B \vec{v}'_B \qquad (7\text{-}3)$$

7-2 Conservation of Momentum

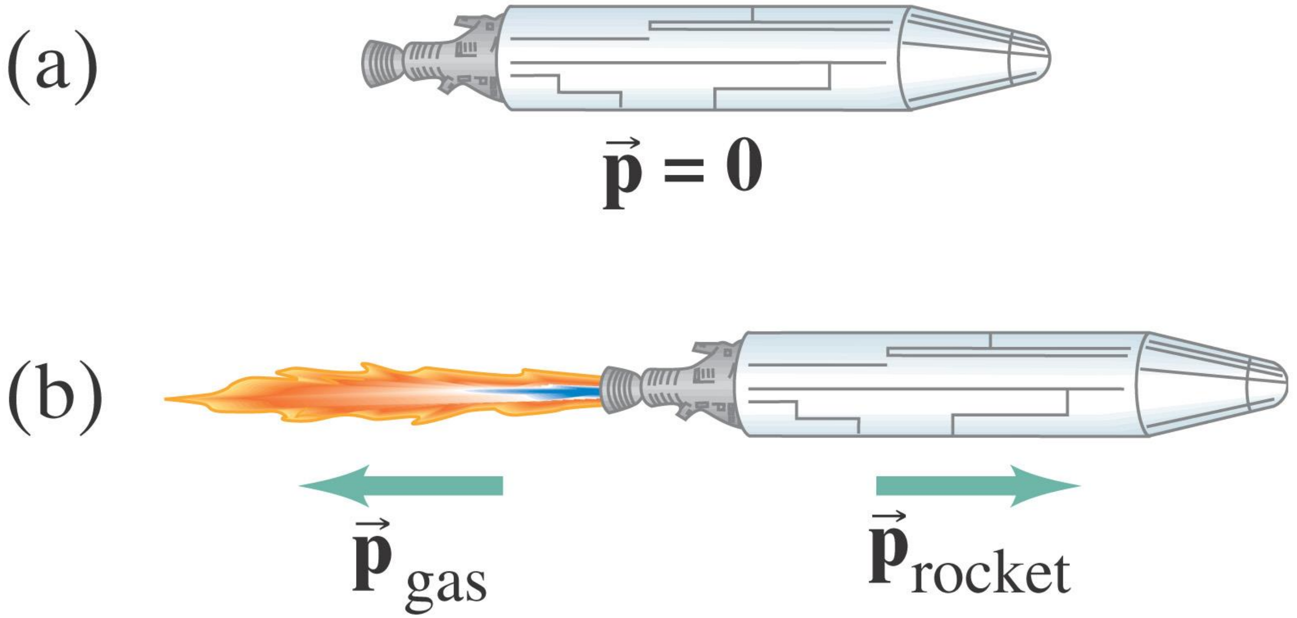
More formally, the law of **conservation** of momentum states:

The total momentum of an isolated system of objects remains constant.



7-2 Conservation of Momentum

Momentum conservation works for a rocket as long as we consider the rocket and its fuel to be one system, and account for the mass loss of the rocket.



7-3 Collisions and Impulse

During a collision, objects are **deformed** due to the large forces involved.

Since $\vec{\mathbf{F}} = \frac{\Delta \vec{\mathbf{p}}}{\Delta t}$, we can

write $\vec{\mathbf{F}}\,\Delta t = \Delta \vec{\mathbf{p}}$ **(7-5)**

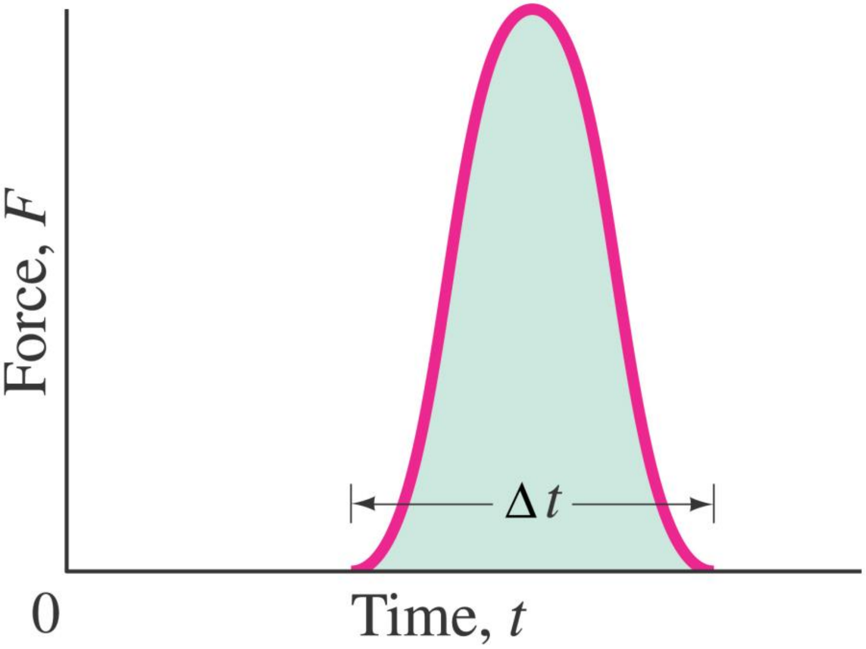
The definition of impulse:

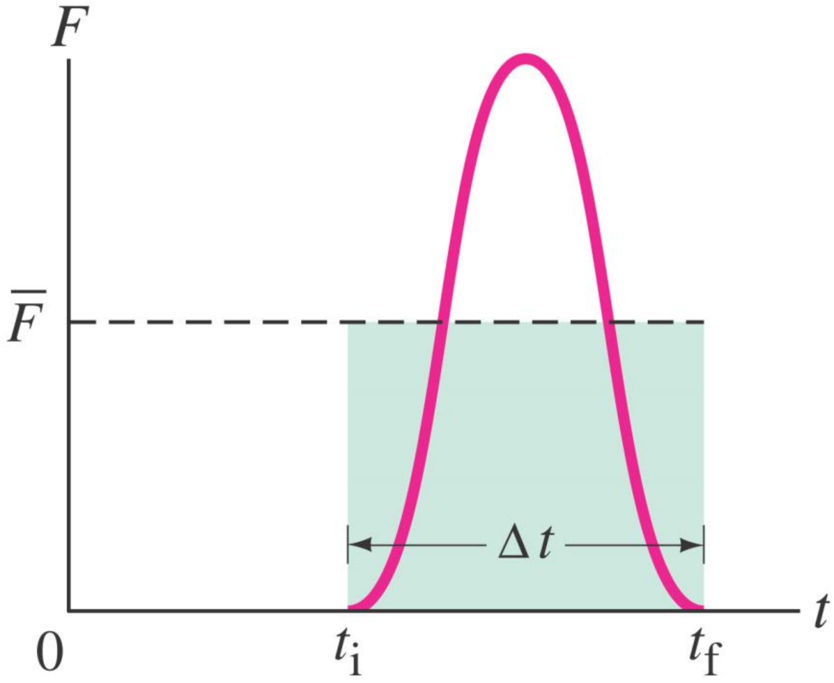
$$\text{Impulse} = \vec{\mathbf{F}}\,\Delta t$$

7-3 Collisions and Impulse

Since the time of the collision is very short, we need not worry about the exact time dependence of the force, and can use the average force.

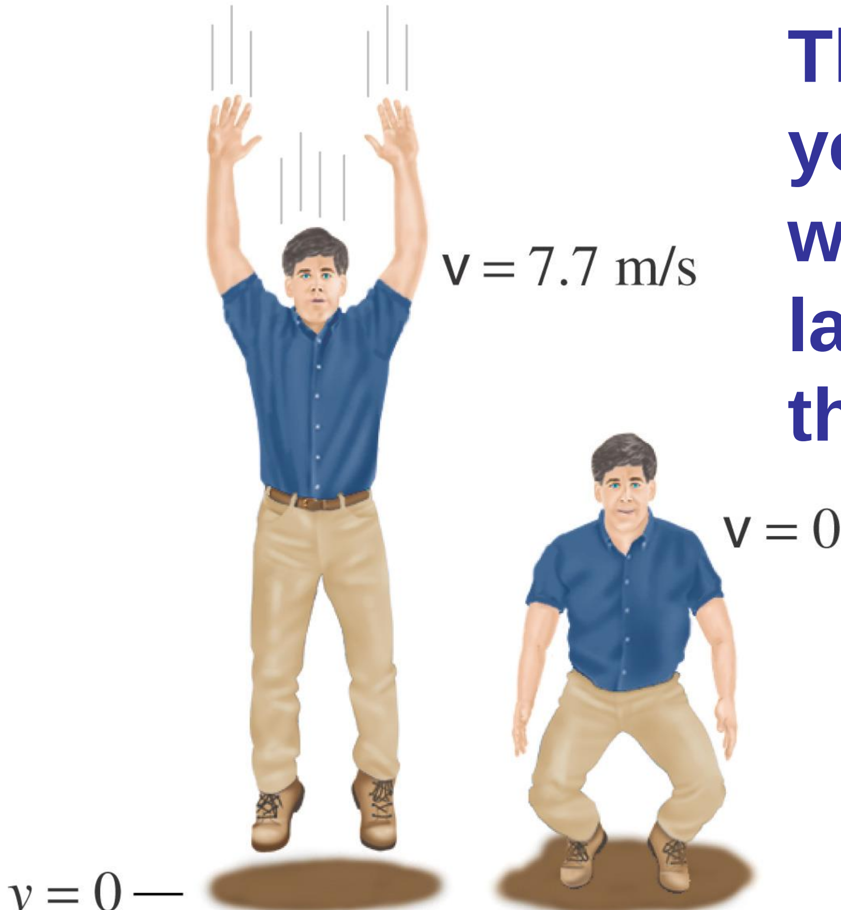
$$\text{Impulse} = \vec{\mathbf{F}}\,\Delta t$$





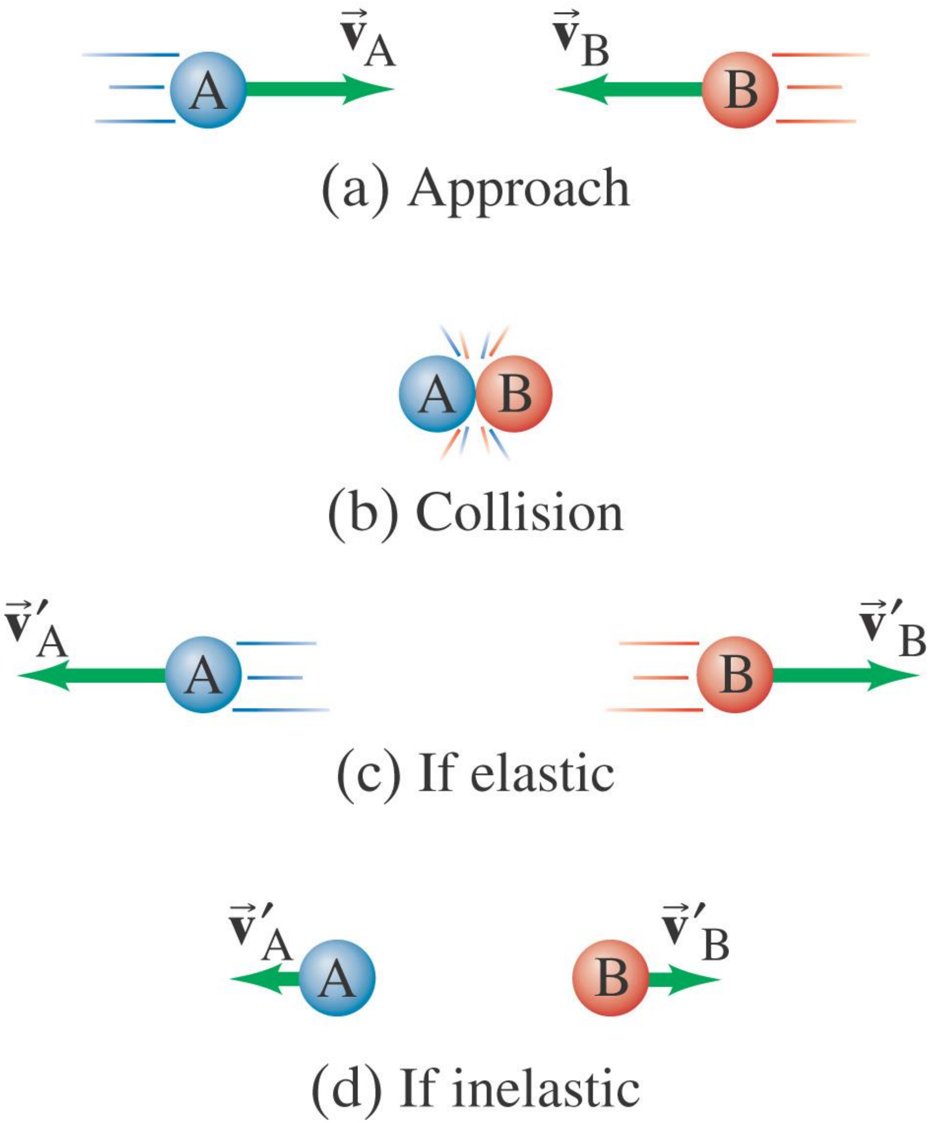
7-3 Collisions and Impulse

The **impulse** tells us that we can get the same **change** in momentum with a **large** force acting for a **short** time, or a **small** force acting for a **longer** time.



This is why you should **bend** your knees when you land; why **airbags** work; and why landing on a **pillow** hurts less than landing on **concrete**.

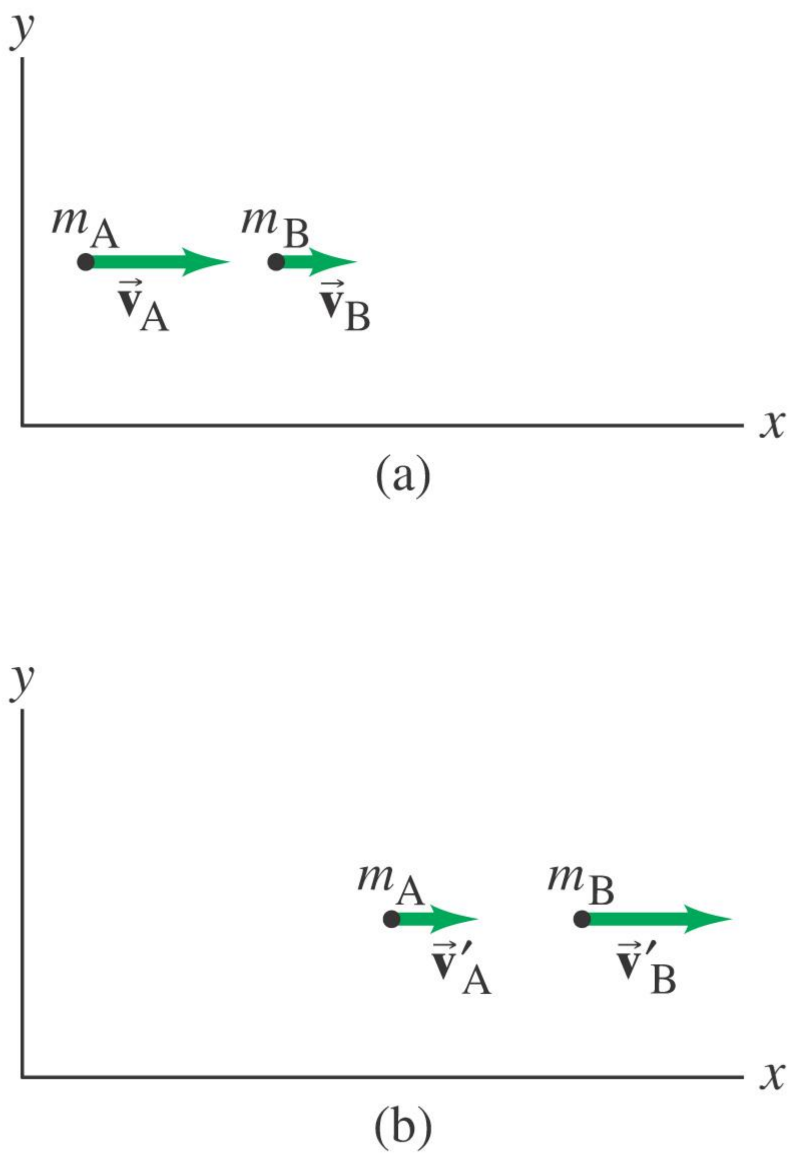
7-4 Conservation of Energy and Momentum in Collisions



Momentum is **conserved** in all **collisions**.

Collisions in which **kinetic energy** is conserved as well are called **elastic** collisions, and those in which it is not are called **inelastic**.

7-5 Elastic Collisions in One Dimension



Here we have two objects colliding **elastically**. We know the masses and the initial speeds.

Since both **momentum** and **kinetic energy** are conserved, we can write **two** equations. This allows us to solve for the **two** unknown final speeds.

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

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

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

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

$$m_1({v_{1i}}^2 - {v_{1f}}^2) = m_2({v_{2f}}^2 - {v_{2i}}^2)$$

and then factor both sides:

$$m_1(v_{1i} - v_{1f})(v_{1i} + v_{1f}) = m_2(v_{2f} - v_{2i})(v_{2f} + v_{2i}) \qquad (9.17)$$

Next, let us separate the terms containing m_1 and m_2 in Equation 9.15 to obtain

$$m_1(v_{1i} - v_{1f}) = m_2(v_{2f} - v_{2i}) \qquad (9.18)$$

To obtain our final result, we divide Equation 9.17 by Equation 9.18 and obtain

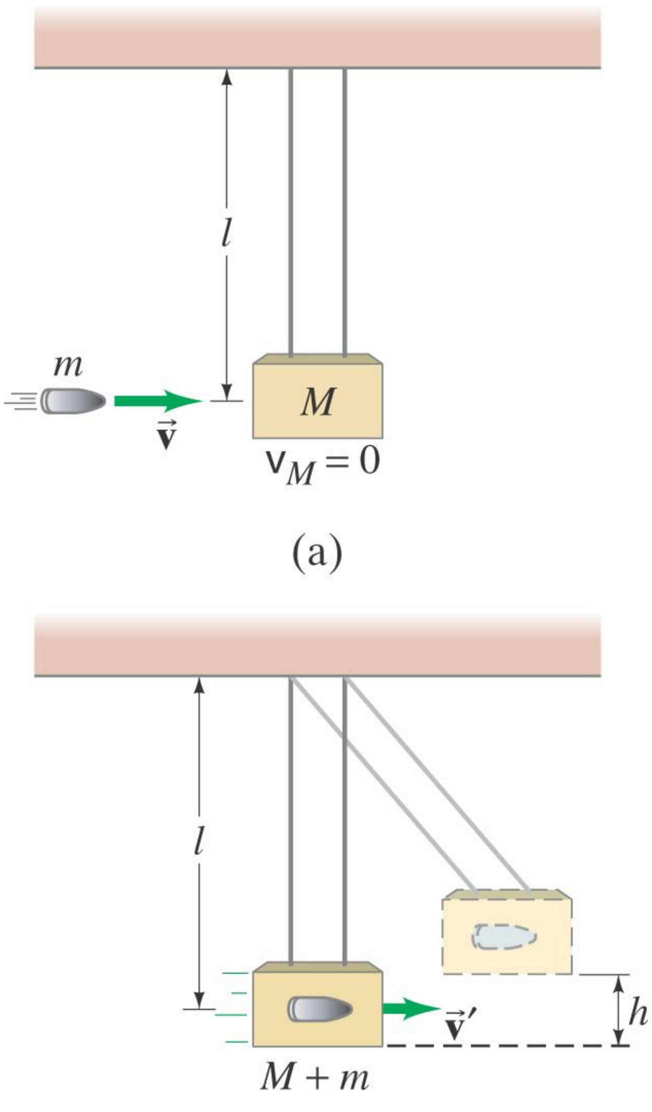
$$v_{1i} + v_{1f} = v_{2f} + v_{2i}$$

$$v_{1i} - v_{2i} = -(v_{1f} - v_{2f}) \qquad (9.19)$$

There are two important points from eq. (9.19)

- **If m1=m2 ?**
- **If v2 = 0 ?**

7-6 Inelastic Collisions



With **inelastic** collisions, some of the initial kinetic energy is lost to **thermal** or **potential** energy. It may also be gained during **explosions**, as there is the addition of **chemical** or **nuclear** energy.

A **completely inelastic** collision is one where the objects **stick together** afterwards, so there is only one final velocity.

7-6 Inelastic Collisions

An **inelastic collision** is one in which **the total kinetic energy of the system is not the same before and after the collision (even though the momentum of the system is conserved).** Inelastic collisions are of two types. When the colliding objects stick together after the collision, as happens when a meteorite collides with the Earth, the collision is called **perfectly inelastic.** When the colliding objects do not stick together, but some kinetic energy is lost, as in the case of a rubber ball colliding with a hard surface, the collision is called **inelastic** (with no modifying adverb). When the rubber ball collides with the hard surface, some of the kinetic energy of the ball is lost when the ball is deformed while it is in contact with the surface.

that the total momentum before the collision equals the total momentum of the composite system after the collision:

$$m_1\mathbf{v}_{1i} + m_2\mathbf{v}_{2i} = (m_1 + m_2)\mathbf{v}_f \tag{9.13}$$

Solving for the final velocity gives

$$\mathbf{v}_f = \frac{m_1\mathbf{v}_{1i} + m_2\mathbf{v}_{2i}}{m_1 + m_2} \tag{9.14}$$

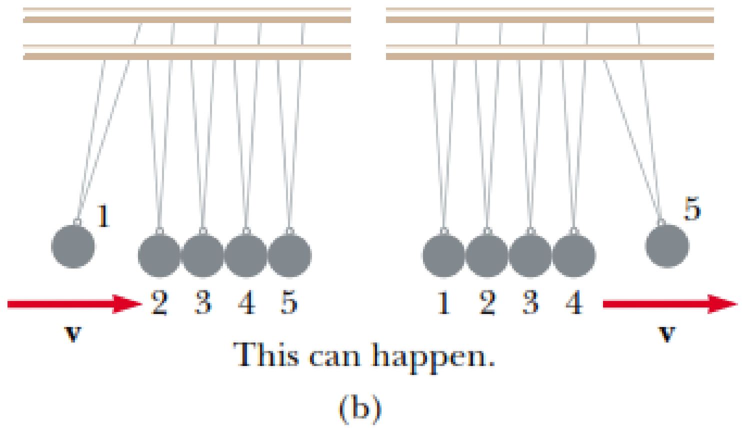
7-6 Inelastic Collisions

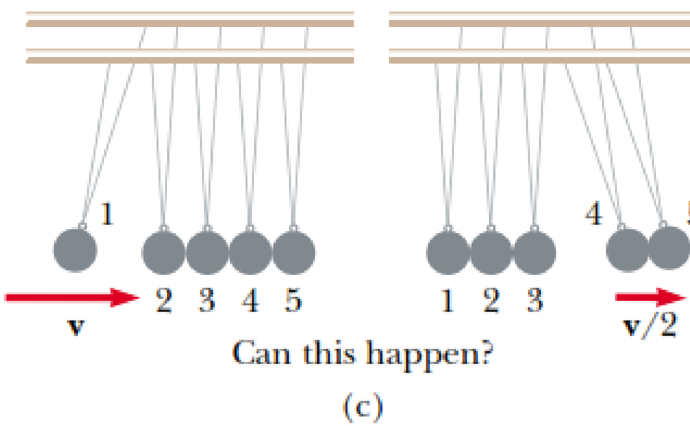
The important distinction between these two types of collisions (perfectly inelastic and elastic collisions) is that **momentum of the system is conserved** in all collisions,

but

kinetic energy of the system is **conserved only in elastic collisions**.

Example



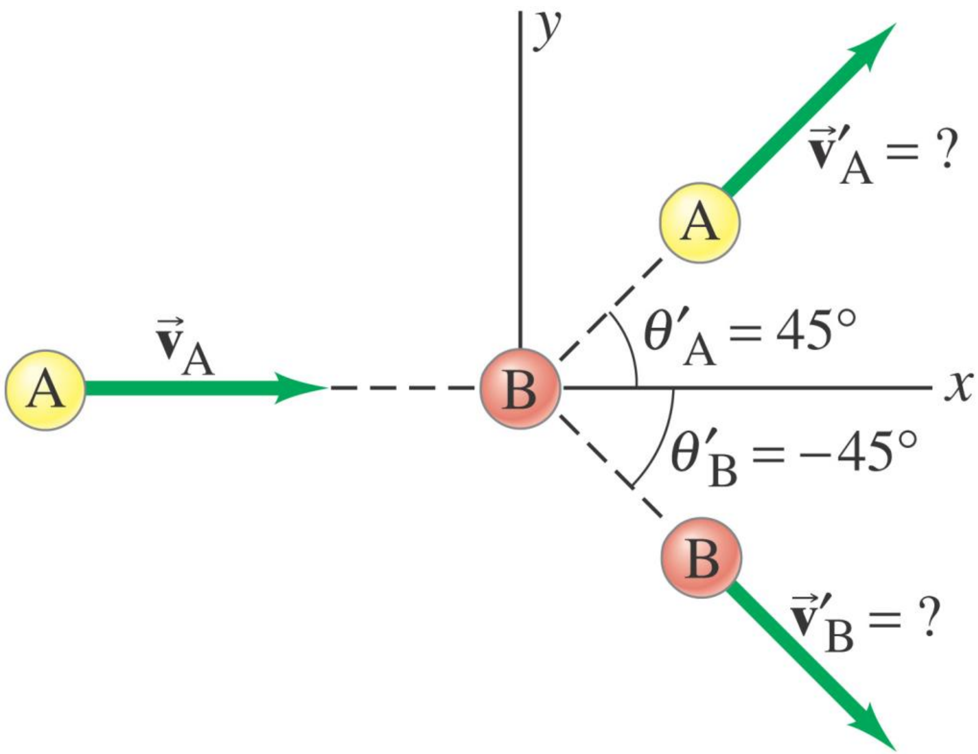


Explain how the state of the system in figure (a) and figure (b) is related to momentum and kinetic energy?

Assuming, (b) the collision is **almost-elastic**, (c) the collision is elastic

7-7 Collisions in Two or Three Dimensions

Conservation of energy and momentum can also be used to analyze collisions in **two** or **three** dimensions, but unless the situation is very simple, the math quickly becomes unwieldy.



Here, a **moving** object collides with an object initially at **rest**. Knowing the masses and initial velocities is not enough; we need to know the **angles** as well in order to find the final velocities.

7-7 Collisions in Two or Three Dimensions

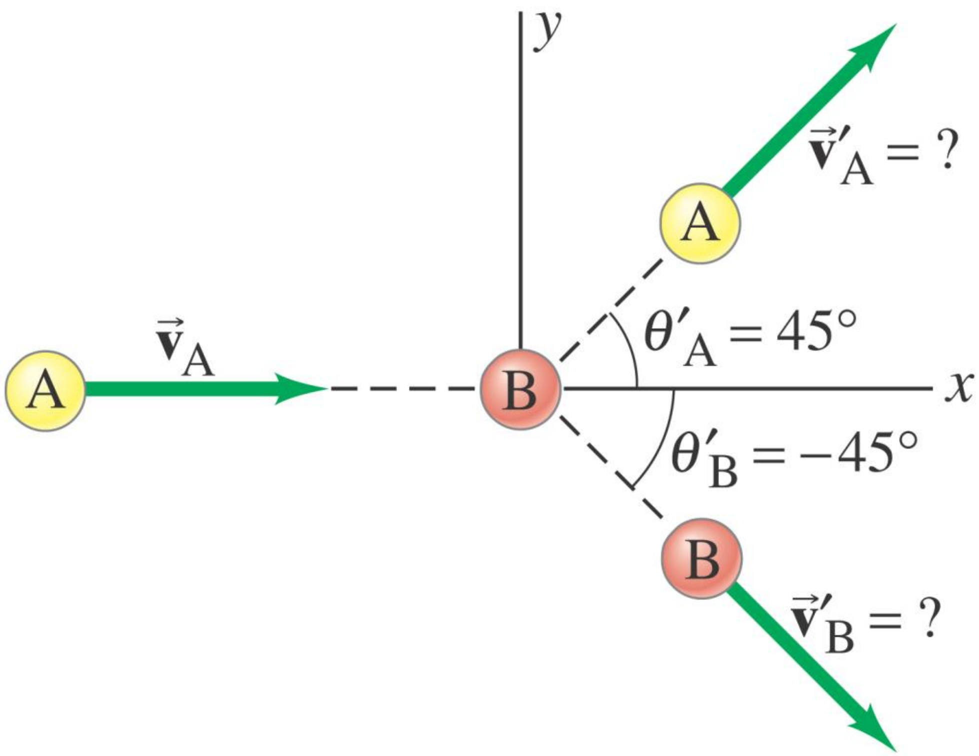
We need 2 component:

$$m_1 v_{1ix} + m_2 v_{2ix} = m_1 v_{1fx} + m_2 v_{2fx}$$

$$m_1 v_{1iy} + m_2 v_{2iy} = m_1 v_{1fy} + m_2 v_{2fy}$$

and 3 subscripts:

1. **The identification of the object**
2. **Initial and final values**
3. **Velocity component**



7-7 Collisions in Two or Three Dimensions

Problem solving:

1. Choose the **system**. If it is complex, **subsystems** may be chosen where one or more conservation laws apply.
2. Is there an **external** force? If so, is the collision time short enough that you can **ignore** it?
3. **Draw** diagrams of the initial and final situations, with **momentum** vectors labeled.
4. Choose a **coordinate** system.

7-7 Collisions in Two or Three Dimensions

5. Apply momentum conservation; there will be one equation for each dimension.

6. If the collision is elastic, apply conservation of kinetic energy as well.

7. Solve.

8. Check units and magnitudes of result.

7-7 Collisions in Two or Three Dimensions

Applying the law of conservation of momentum in component form and noting that the initial y component of the momentum of the two-particle system is zero, we obtain

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

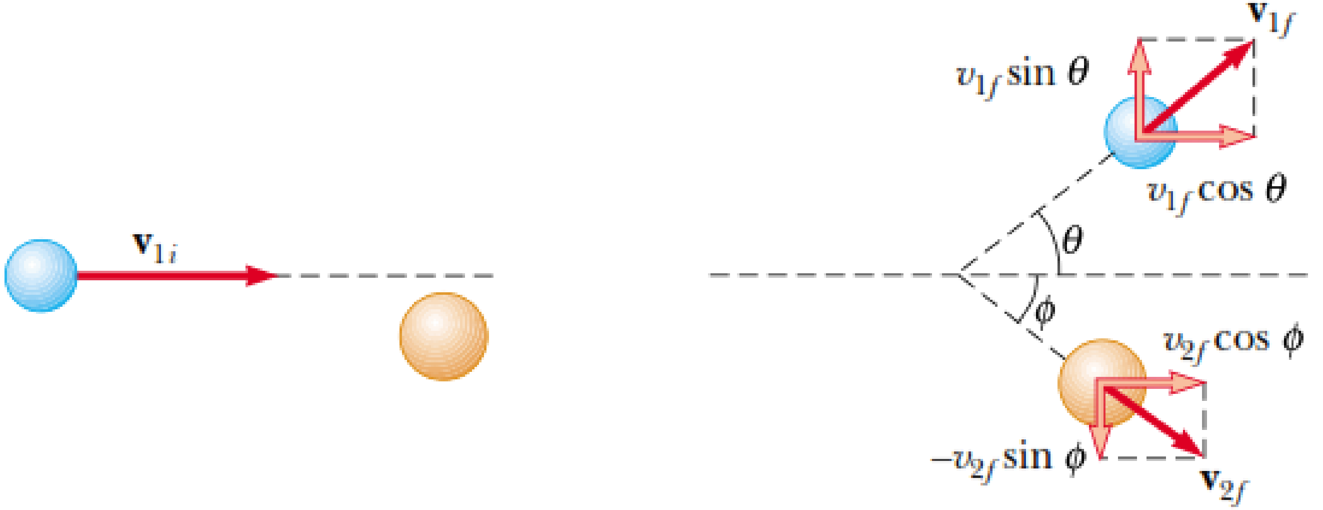
$$0 = m_1 v_{1f} \sin\theta - m_2 v_{2f} \sin\phi$$

If the collision is elastic, we can also use Equation 9.16 (conservation of kinetic energy) with $v_{2i} = 0$ to give

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

Example

Sebuah proton bertabrakan secara elastis dengan proton lain yang awalnya diam. Proton yang datang memiliki **kecepatan awal** 3,50 x 10^5 m/s dan membuat tumbukan sekilas dengan proton kedua, seperti pada gambar . (pada jarak yang dekat, proton mengerahkan gaya elektrostatik repulsive satu sama lain). Setelah tumbukan, satu proton bergerak dengan sudut 37,0^0 (theta) terhadap arah gerak awalnya, dan proton kedua membelok pada sudut theta terhadap sumbu yang sama. Tentukan kecepatan akhir kedua proton dan sudut phi?

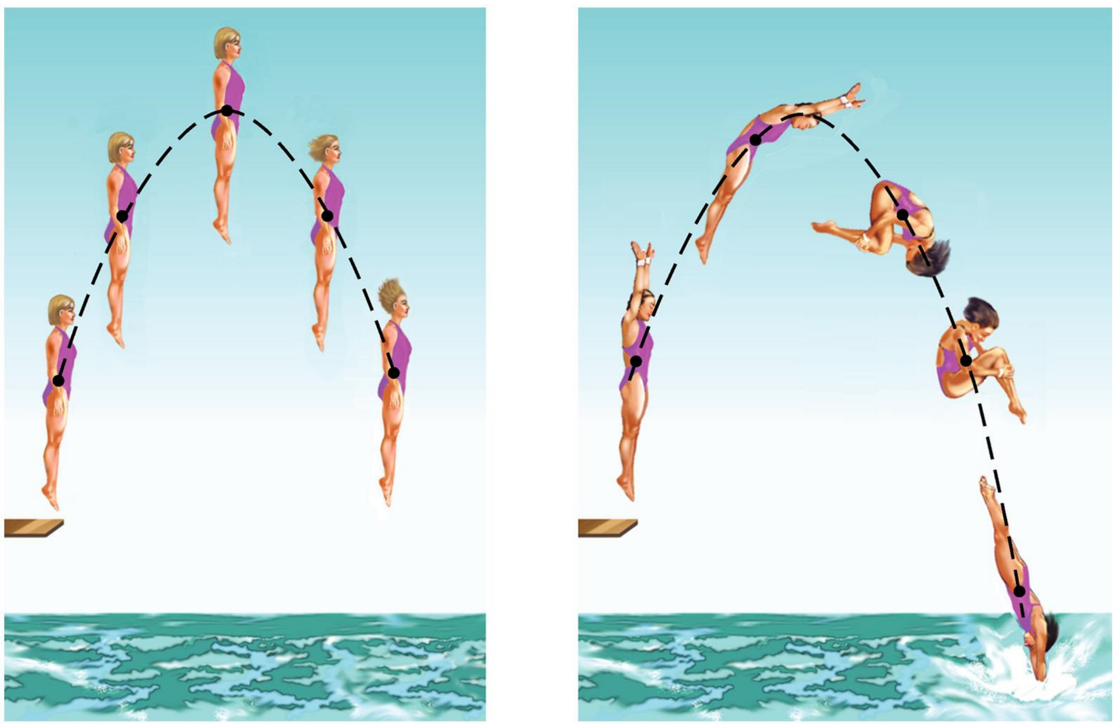


(a) Before the collision (b) After the collision

7-8 Center of Mass

In (a), the diver's motion is pure **translation**; in (b) it is **translation** plus **rotation**.

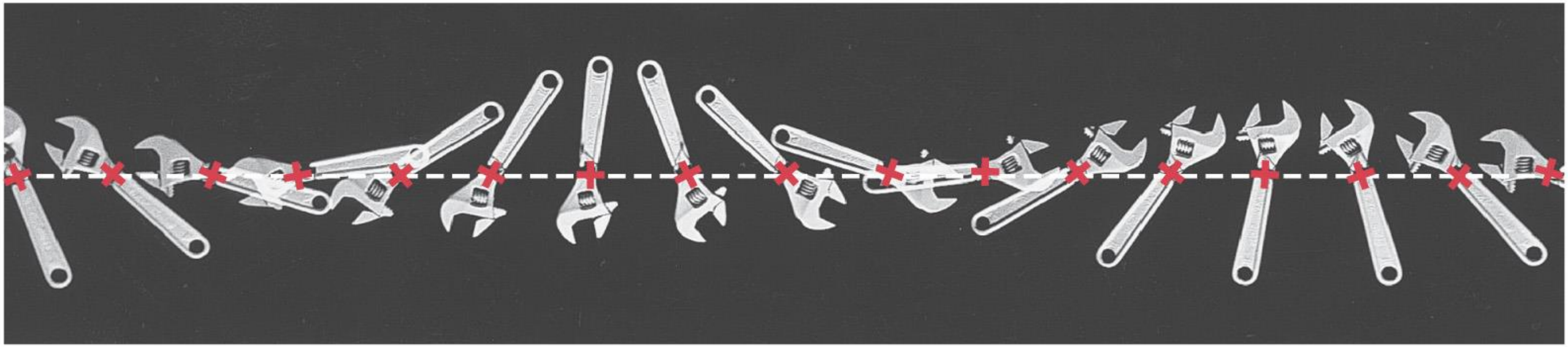
There is one point that moves in the **same** path a particle would take if subjected to the same force as the diver. This point is called the **center of mass** (**CM**).



(a) (b)

7-8 Center of Mass

The **general** motion of an object can be considered as the **sum** of the **translational** motion of the **CM**, plus **rotational**, **vibrational**, or other forms of motion about the CM.

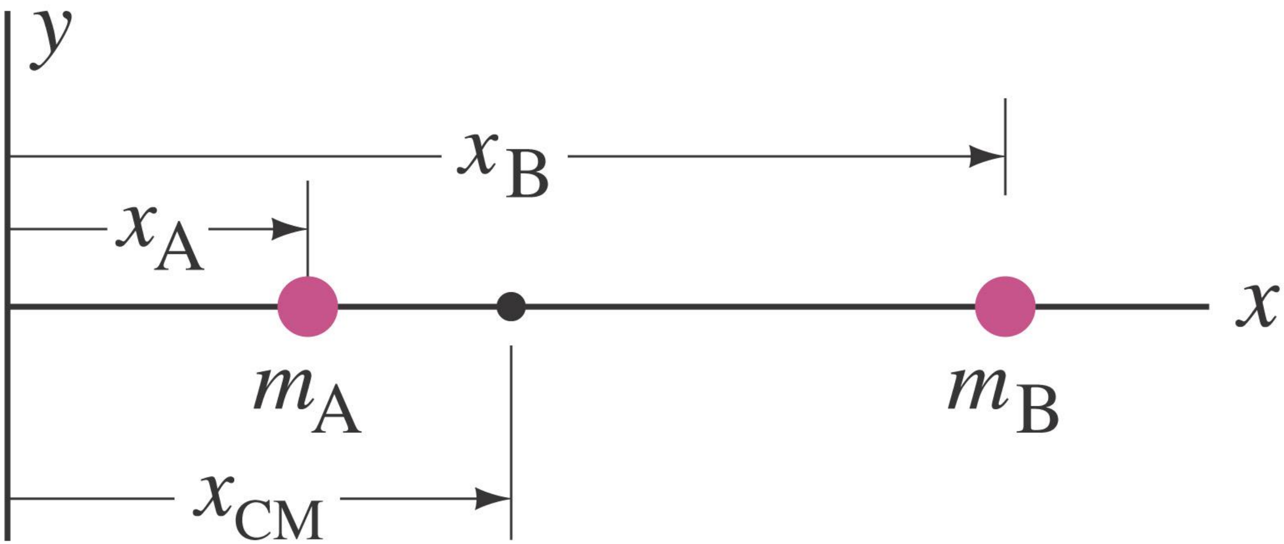


7-8 Center of Mass

For two particles, the **center of mass** lies closer to the one with the most mass:

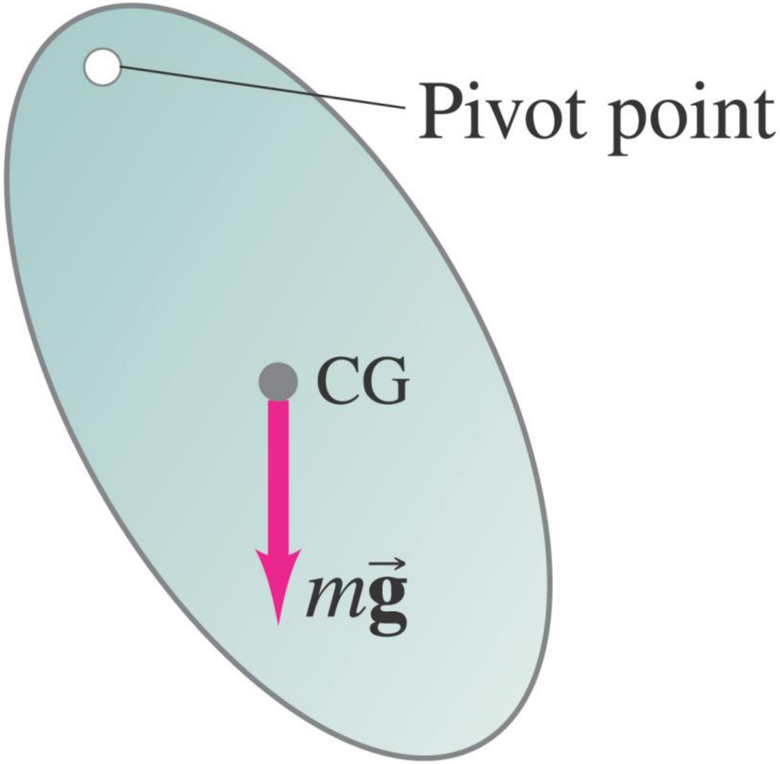
$$x_{CM} = \frac{m_A x_A + m_B x_B}{m_A + m_B} = \frac{m_A x_A + m_B x_B}{M}$$

where *M* is the **total** mass.



7-8 Center of Mass

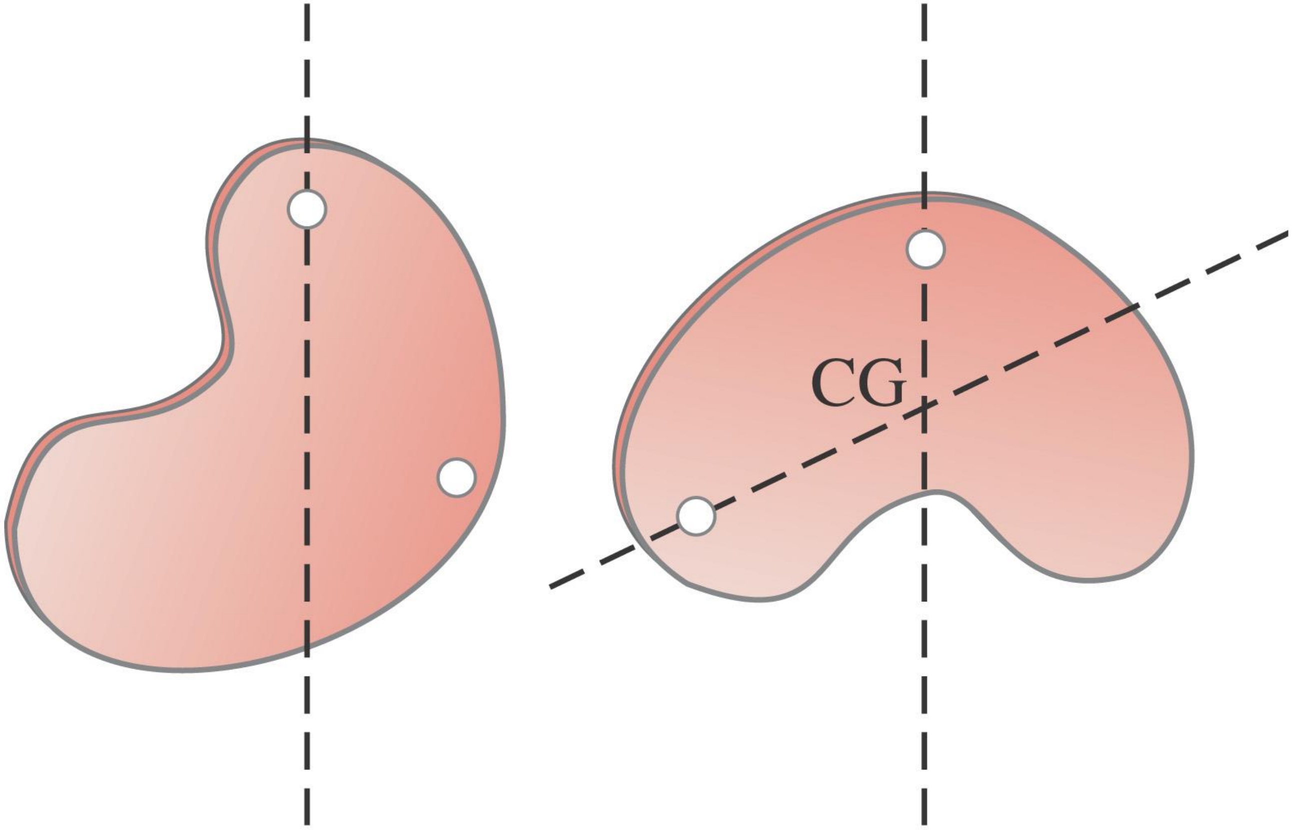
The center of gravity is the point where the gravitational force can be considered to act. It is the same as the center of mass as long as the gravitational force does not vary among different parts of the object.



7-8 Center of Mass

The center of gravity can be found **experimentally** by **suspending** an object from different points.

The CM need not be **within** the actual object – a doughnut's CM is in the center of the hole.

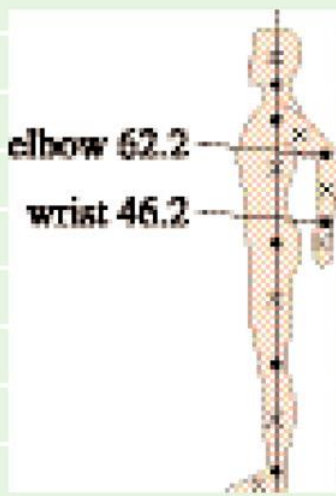


7-9 CM for the Human Body

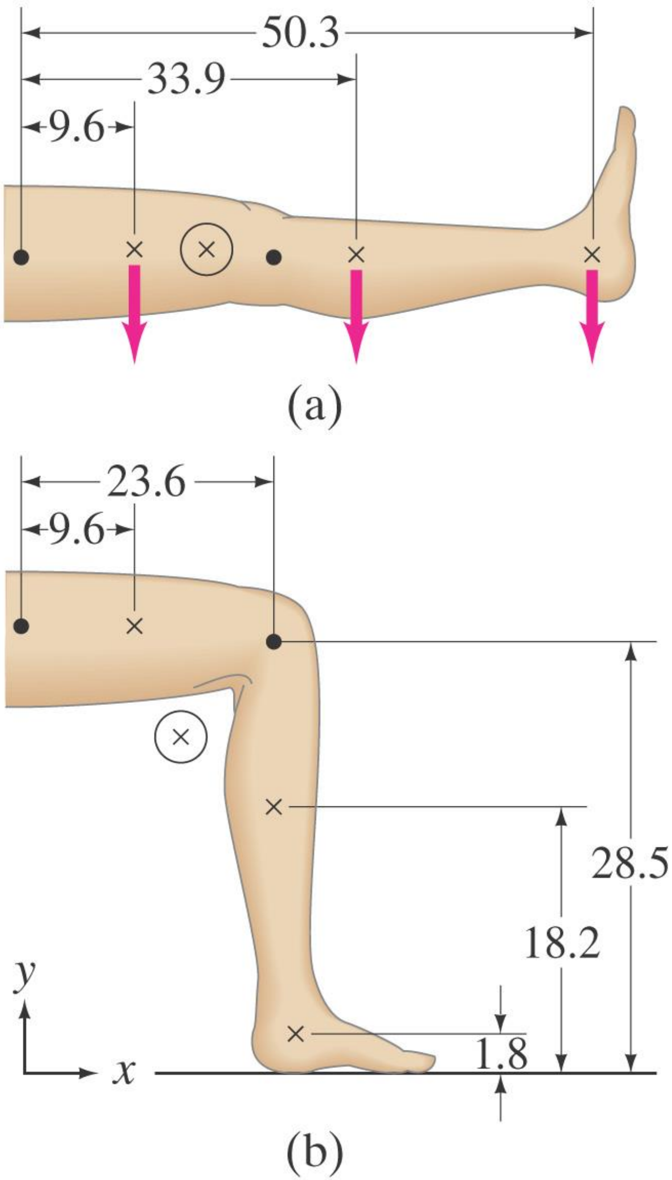
The x's in the small diagram mark the CM of the listed body segments.

TABLE 7–1 Center of Mass of Parts of Typical Human Body
(full height and mass = 100 units)

Distance Above Floor of Hinge Points (%)	Hinge Points (•) (Joints)	Center of Mass (×) (% Height Above Floor)		Percent Mass
91.2	Base of skull	Head	93.5	6.9
81.2	Shoulder joint	Trunk and neck	71.1	46.1
		Upper arms	71.7	6.6
		Lower arms	55.3	4.2
52.1	Hip joint	ands	43.1	1.7
		Upper legs (thighs)	42.5	21.5
28.5	Knee joint			
		Lower legs	18.2	9.6
4.0	Ankle joint	eet	1.8	3.4
		Body CM =	58.0	100.0



7-9 CM for the Human Body



The location of the center of mass of the leg (circled) will depend on the position of the leg.

7-9 CM for the Human Body

High jumpers have developed a technique where their CM actually passes under the bar as they go over it. This allows them to clear higher bars.

7-10 Center of Mass and Translational Motion

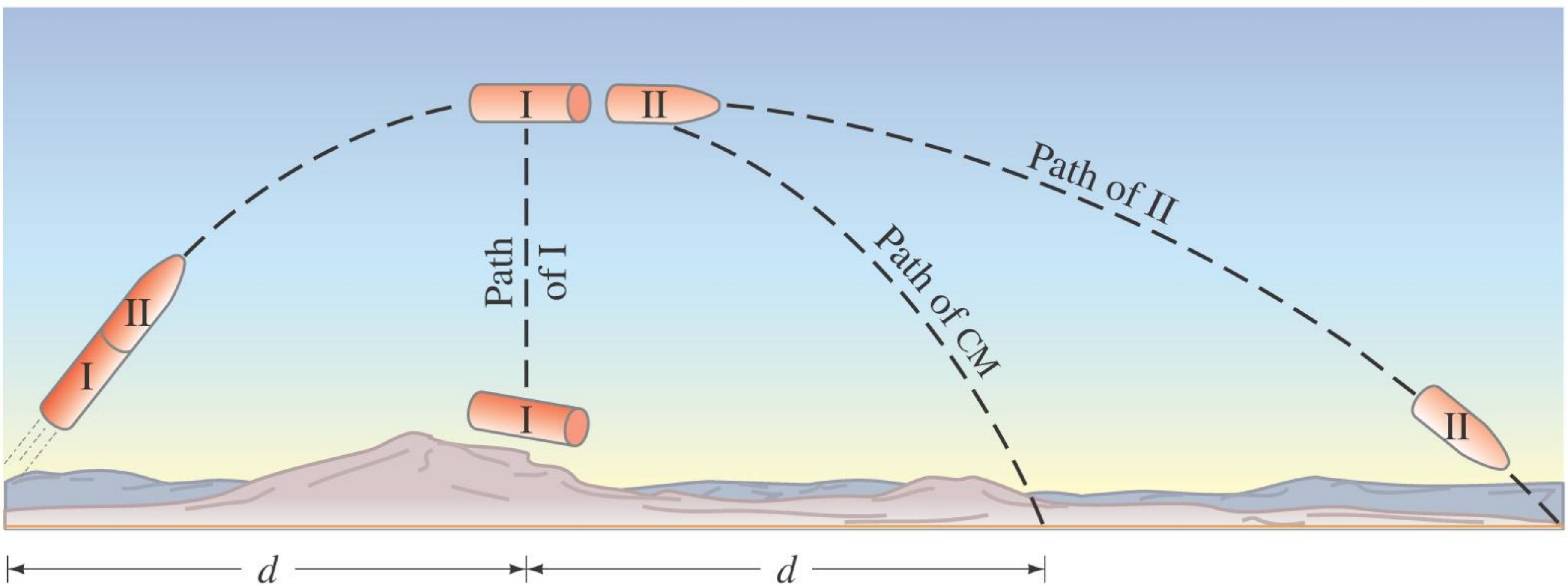
The **total momentum** of a system of particles is equal to the product of the **total mass** and the **velocity** of the **center of mass**.

The **sum** of all the **forces** acting on a system is equal to the **total mass** of the system multiplied by the **acceleration** of the **center of mass**:

$$M a_{\mathrm{CM}} = F_{\mathrm{net}} \qquad \textbf{(7-11)}$$

7-10 Center of Mass and Translational Motion

This is particularly useful in the analysis of **separations** and **explosions**; the center of mass (which may not correspond to the position of any particle) continues to move according to the net force.



Summary of Chapter 7

- Momentum of an object: $\vec{\mathbf{p}} = m\vec{\mathbf{v}}.$

- Newton's second law:

$$\Sigma\vec{\mathbf{F}} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t}$$

- Total momentum of an isolated system of objects is conserved.

- During a collision, the colliding objects can be considered to be an isolated system even if external forces exist, as long as they are not too large.

- Momentum will therefore be conserved during collisions.

Summary of Chapter 7, cont.

- $\text{Impulse} = \vec{\mathbf{F}}\,\Delta t = \Delta\vec{\mathbf{p}}$

- In an elastic collision, total kinetic energy is also conserved.

- In an inelastic collision, some kinetic energy is lost.

- In a completely inelastic collision, the two objects stick together after the collision.

- The center of mass of a system is the point at which external forces can be considered to act.