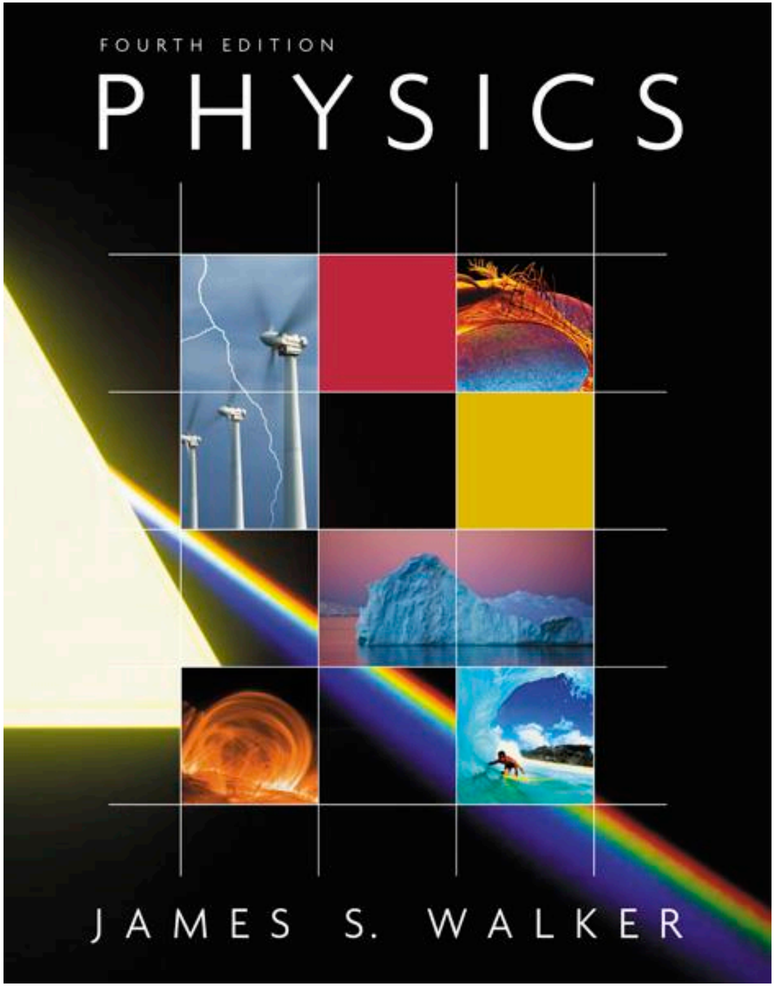


Lecture Outline

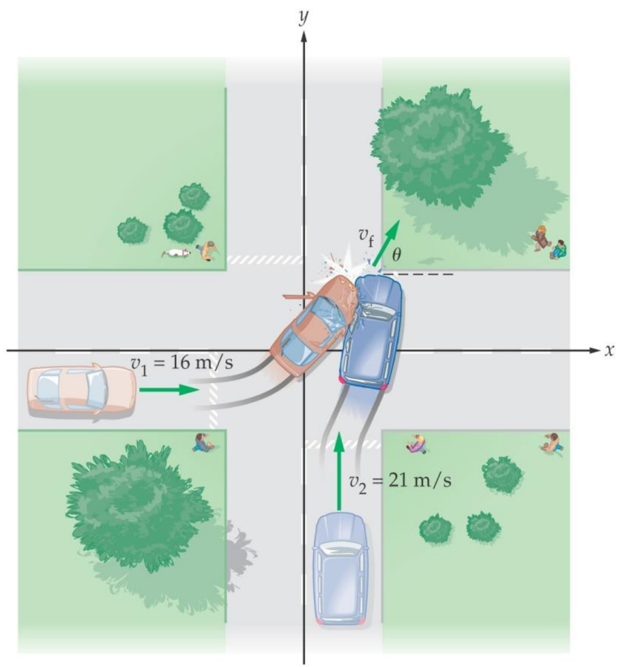
Chapter 9

Physics, 4th Edition

James S. Walker

Chapter 9

Linear Momentum and Collisions



Units of Chapter 9

- Linear Momentum
- Momentum and Newton’s Second Law
- Impulse
- Conservation of Linear Momentum
- Inelastic Collisions
- Elastic Collisions

9-1--- Linear Momentum

Definition of Linear Momentum, $\vec{p}$

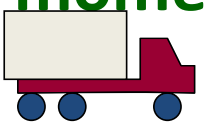
$$\vec{p} = m\vec{v}$$

SI unit: $\mathrm{kg \cdot m/s}$

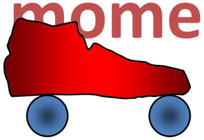
Momentum is a vector; its direction is the same as the direction of the velocity.

So What's Momentum ?

- **Momentum = mass x velocity**
- Momentum is a measure of inertia in motion
- This can be abbreviated to : .
  momentum = mv



- Or, if direction is not an important factor : . .
  momentum = mass x speed



- So, A really slow moving truck and an extremely fast roller skate can have the same momentum.

Linear Momentum

– Huge ship moving at a small velocity

$$\mathrm{P} = \mathrm{M}v$$

– High velocity bullet

$$\mathrm{P} = {}_{m}\mathrm{V}$$

Exercise 9-1

- A)A 1180- Kg car drives along a city street at 30 miles/hr.(13.4m/s)What is the magnitude of cars momentum
- Sol:--15,800Kgm/s

$P = mv$, $(1180)(13.4) = 15812$

- B)A major league pitcher can give a 0.142-Kg baseball a speed of 101mi/hr.(45.1m/s)Find the magnitude of baseballs momentum
- Sol:-6.40Kgm/s

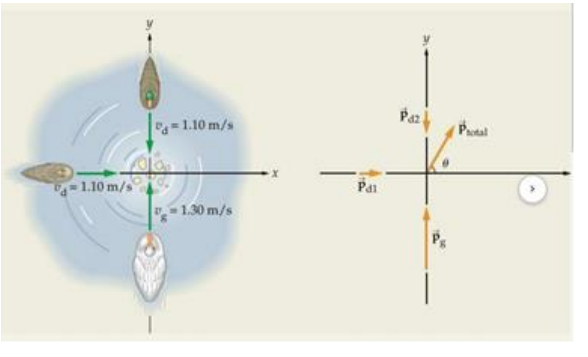
$P = mv$, $(0.142)\ 45.1)$

$= 6.40$ Kg m/s

Example 9-1

- At a city park a person throws some bread into a duck pond. Two 4Kg ducks and 9Kg goose paddle rapidly towards the bread. If the ducks swim at 1.10m/s and goose swim with a speed of 1.30m/s, find the
- magnitude and direction of total momentum of the three birds.
- P_{total} = (4.40Kgm/s)i+ (7.30Kgm/s)j
- Magnitude of P = 8.52Kgm/s
- $\theta = 58.9^0$

?



Ducks : 4 x 1.10 = 4.40

Goose : 9 x 1.30 = 7.30

+ 8.52

Prob-3

A 26.2 kg dog is running northward at 2.70 m/s, while a 5.30 kg cat is running eastward at 3.04 m/s. Their 74.0 kg owner has the same momentum as the two pets taken together. Find the direction and magnitude of the owners velocity?

Answer: 77.1 north of east

Prob – 5

A 0.15 kg baseball is dropped from rest. If the magnitude of the baseball's momentum is 0.780 kg.m/s just before it lands on the ground, from what height it was dropped?

Answer: 1.38 m

9-2 ---Momentum and Newton's Second Law

Newton's second law, as we wrote it before:

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

is only valid for objects that have constant mass. Here is a more general form, also useful when the mass is changing:

Newton's Second Law

$$\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

in general form

A 0.2 kg baseball traveling at 40 m/s is hit and returned at 50 m/s in the opposite direction. If the ball and bat are in contact for 0.002s determine the **average force on the ball**

p +

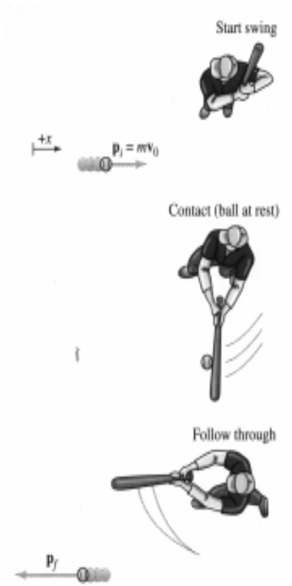
p -

m_{ball} = 0.2 kg $\mathbf{v}_{bi}$ = 40 m/s $\mathbf{v}_{Bf}$ = -50 m/s

Δt =0.002s $\mathbf{F}_{av}$ = ?

$\mathbf{F}_{av}\,\Delta t = m\,\Delta\mathbf{v} = m\,(\mathbf{v}_{Bf} - \mathbf{v}_{Bi})$ therefore $\mathbf{F}_{av} = m\,(\mathbf{v}_{Bf} - \mathbf{v}_{Bi}) / \Delta t$

$\mathbf{F}_{av}$ = (0.2 kg) (-50 m/s - 40 m/s) / (0.002s) = **- 9000N**



9-3-- Impulse

Definition of Impulse, $\vec{I}$

$I = \Delta p$

$$\vec{I} = \vec{F}_{av}\Delta t$$

$I = \Delta p$

SI unit: $N \cdot s = kg \cdot m/s$

Impulse is a vector, in the same direction as the average force.

$I = \Delta P$

or $I = \Sigma F \; \Delta T$

9-3--- Impulse

We can rewrite

$$\vec{\mathbf{F}}_{\mathrm{av}} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t}$$

as

$$\vec{\mathbf{F}}_{\mathrm{av}}\Delta t = \Delta\vec{\mathbf{p}}$$

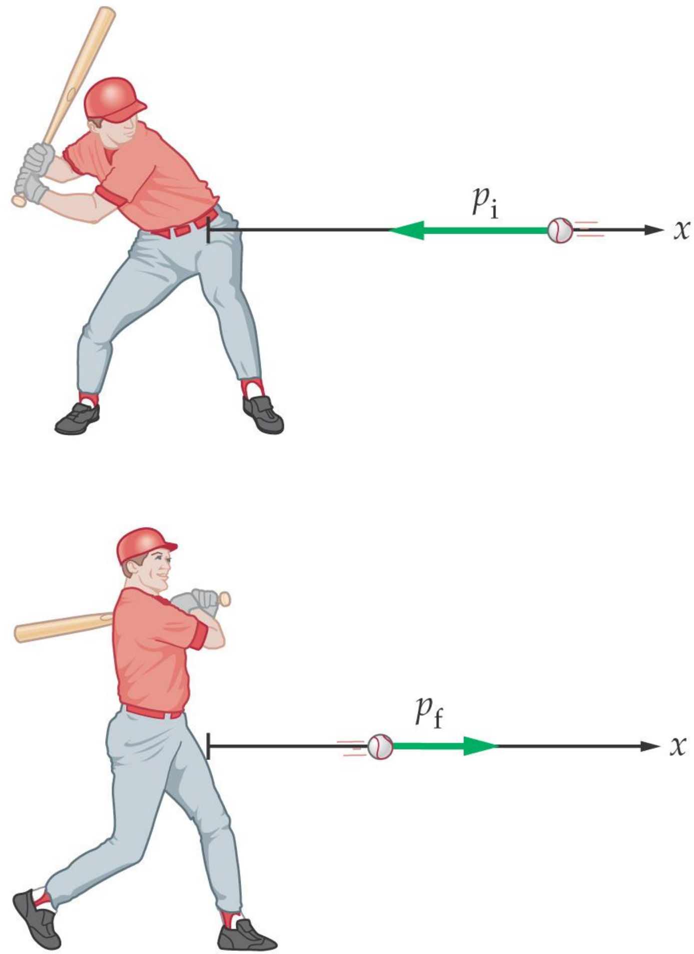
So we see that

The impulse is equal to the change in momentum.

$$\vec{\mathbf{I}} = \vec{\mathbf{F}}_{\mathrm{av}}\Delta \mathrm{t} = \Delta\vec{\mathbf{p}}$$

9-3-- Impulse

Therefore, the same change in momentum may be produced by a large force acting for a short time, or by a smaller force acting for a longer time.



absent

Example-2

- After winning a prize on a game show,
- a 72 Kg contestant jumps for joy
- A) If the jump results in an upward speed of 2.1m/s,What is the impulse experienced by the contestant.
- Sol:- I = 150kgm/s j
- B) Before the jump, the floor exerts an upward force of mg on the contestant .What additional average upward force does the floor exert if the contestant pushes down on it for 0.36s during the jump?
- Sol:- F = 420Nj

$m = 72\,kg$

$v_i = 0$

a) $v_f = 2.1\,m/s$

$I = ?$

$I = P_f - P_i$

$I = mv_f - \cancel{mv_i}$

$(72)(2.1) = (151.2\ kg \cdot m/s)\ \hat{y}$

b) ① Upward force $= N = w = mg$ $\quad 72\,(9.81) = 706.3\ N$

Normal force is not enough to make him jump

② $= f_{avg} = \dfrac{\Delta p}{\Delta t} = \dfrac{I}{\Delta t} = \dfrac{151.2}{0.36} = (420N)\ \hat{y}$

Prob-13

Find the magnitude of the impulse delivered to a soccer ball when a player kicks it with a force of 1250 N. Assume that the player's foot is in contact with the ball for 5.95x 10^{-3} s.

$$I = F_{avg} \cdot \Delta t$$

Answer: 7.44 kg.m /s

$$1250 \times 5.95 \times 10^{-3} = 7.4 \text{ Kg.m/s}$$

Prob-14

In a typical golf swing, the club is in contact with the ball for about 0.0010 s. If the 45g ball acquires a speed of 67 m/s, estimate the magnitude of the force exerted by the club on the ball.

Answer:

$$F_{avg} = \frac{\Delta P}{\Delta t} \quad \frac{m v_f}{\Delta t} = \frac{(0.045)(67)}{0.0010}$$

$$= 3015 \text{ N}$$

15. • A 0.50-kg croquet ball is initially at rest on the grass. When the ball is struck by a mallet, the average force exerted on it is 230 N. If the ball's speed after being struck is 3.2 m/s, how long was the mallet in contact with the ball?

$t = ?$

$m = 0.5\ kg$

$f = 230N$

$v = 3.2$

$$\Delta t = \frac{\Delta p}{F} \rightarrow \frac{(0.5)(3.2)}{230}$$

$$\rightarrow 6.96 \times 10^{-3}$$

9-4 --Conservation of Linear Momentum

The net force acting on an object is the rate of change of its momentum:

$$\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

If the net force is zero, the momentum does not change:

Forces are balanced.

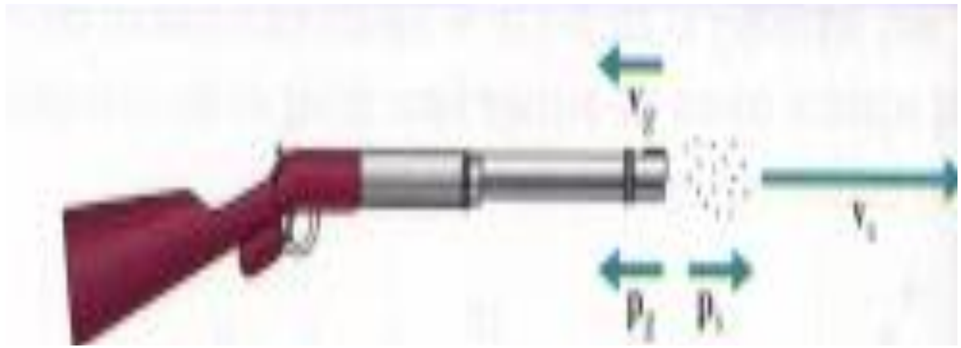
Conservation of Momentum

If the net force acting on an object is zero, its momentum is conserved; that is, $\vec{p}_f = \vec{p}_i$

any f = i

$P_{f(1)} + P_{f(2)} = P_{i(1)} + P_{f(2)}$

Example:-If a shotgun of mass 3.0 kg fires shot having a total mass of 0.05kg with a muzzle velocity of 525 m/s, what is its recoil velocity?



m_g = 3.0 kg m_s = 0.05 kg $p_{total\ I}$ = 0 kgm/s v_{sf} = 525 m/s v_{gf} = ?

$p_{total\ I} = p_{total\ f} = m_g\ \mathbf{v_{gf}} + m_s\ \mathbf{v_{sf}} =$ 0 kgm/s

(3.0 kg) $\mathbf{v_{gf}}$ + (0.05 kg) (+525 m/s) = 0 kgm/s

$\mathbf{v_{gf}}$ = - (0.05 kg) (+525 m/s) / (3.0 kg)

$\mathbf{v_{gf}}$ = - 8.75 m/s = **- 9 m/s**

By using Conservation law of Momentum.

$m = 3\,Kg$

$v_{i\,gun+muzzle} = 0$

$m_{shot} : 0.05$

$v_{f\,gun} = ?$

$v_{muzzle} = 525\ m/s$

recoil velocity

$$mv_{f(gun)} + mv_{f(muzzle)} = mv_{i(gun)} + mv_{i(muzzle)}$$

$$(3)\,v_f + (0.05)(525) = 0 + 0$$

$$v_f = \frac{-26.25}{3}$$

$$v_{f\,gun} = -8.75\ m/s$$

Example 9-3

- Two groups of canoeists meet in the middle of the lake. After a brief visit, a person in canoe 1 pushes on canoe 2 with a force of 46 N to separate the canoes. If the mass of the canoe 1 and its occupants is m_1 = 130 kg, and the mass of the canoe 2 and its occupants is m_2 = 250 kg
- (a) find the momentum of each canoes after 1.2 s of pushing?
- Answer: (a) $a_{1,x}$ = - 0.35 m/s^2 , $a_{2,x}$ + 0.18 m/s^2
- v1 = -0.42m/s, v2 = 0.22m/s
- P1 = -55kgkgm/s
- P2= 55kgm/s

Caneo 1 (push) = −46 N

Caneo 2 (push) 46 N

m (1) = 130

m (2) = 250

t = 1.2 s

① Find v. :

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

$$\Delta p = F \Delta t$$

$$p_f - \cancel{p_i} = F \Delta t$$

$$p_{f(1)} = -46 (1.2)$$

$$= -55 \, (kg \cdot m/s) \, \hat{x}$$

$$p_{f(2)} = 46 (1.2)$$

$$= 55 \, (kg \cdot m/s) \, \hat{x}$$

Conservation law

Prob:-22---Two ice skaters stand at rest in the center of an icerink. When they push off against one another the 45 Kg skater acquires a speed of 0.62m/s. If the speed of the other skater is 0.89m/s, what is this skaters mass.

Answer: 31Kg

$$P_f = P_i$$

$v_i = 0$

$S_{(1)}\ M = 45\,Kg$

$S_1\ v = 0.62$

$S_2\ v = 0.89$

$S_2\ M = ?$

$$M v_{f(1)} + m v_{f(2)} = m v_{i(1)} + m v_{i(2)}$$

$$45(0.62) + m(0.89) = 0 + 0$$

$$m = \frac{45(0.62)}{(0.89)} = 31\,Kg$$

Problem:-22---Two ice skaters stand at rest in the center of an ice rink. When they push off against one another the 45 Kg skater acquires a speed of 0.62m/s. If the speed of the other skater is 0.89m/s, what is this skaters mass.

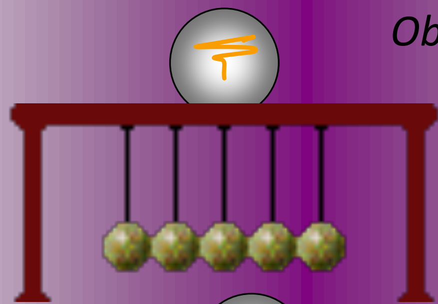
- Answer:- 31Kg

COLLISIONS

- **ELASTIC COLLISIONS** we can calculate the vf for each ball seprately

Kinebic energy is conserved

Momentum transfer from one Object to another .

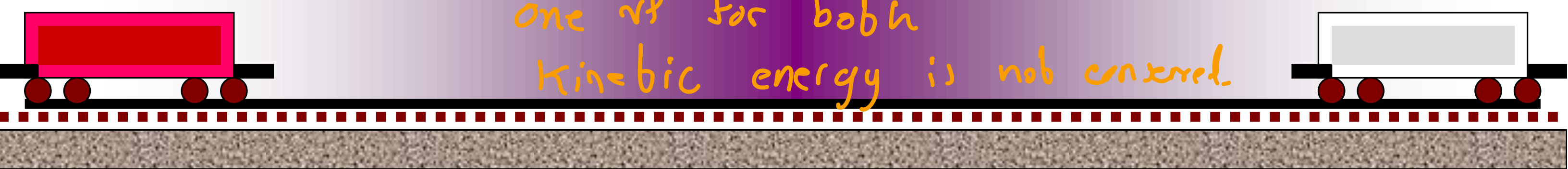


Is a Newton's cradle like the one Pictured here, an example of an elastic or inelastic collision?

- **INELASTIC COLLISIONS**

one vf for both

Kinebic energy is not conserved



9-5-- Inelastic Collisions

Collision: two objects striking one another

Time of collision is short enough that **external forces** may be ignored

ex: friction

Inelastic collision: momentum is conserved but kinetic energy is not

$P_i = P_f$

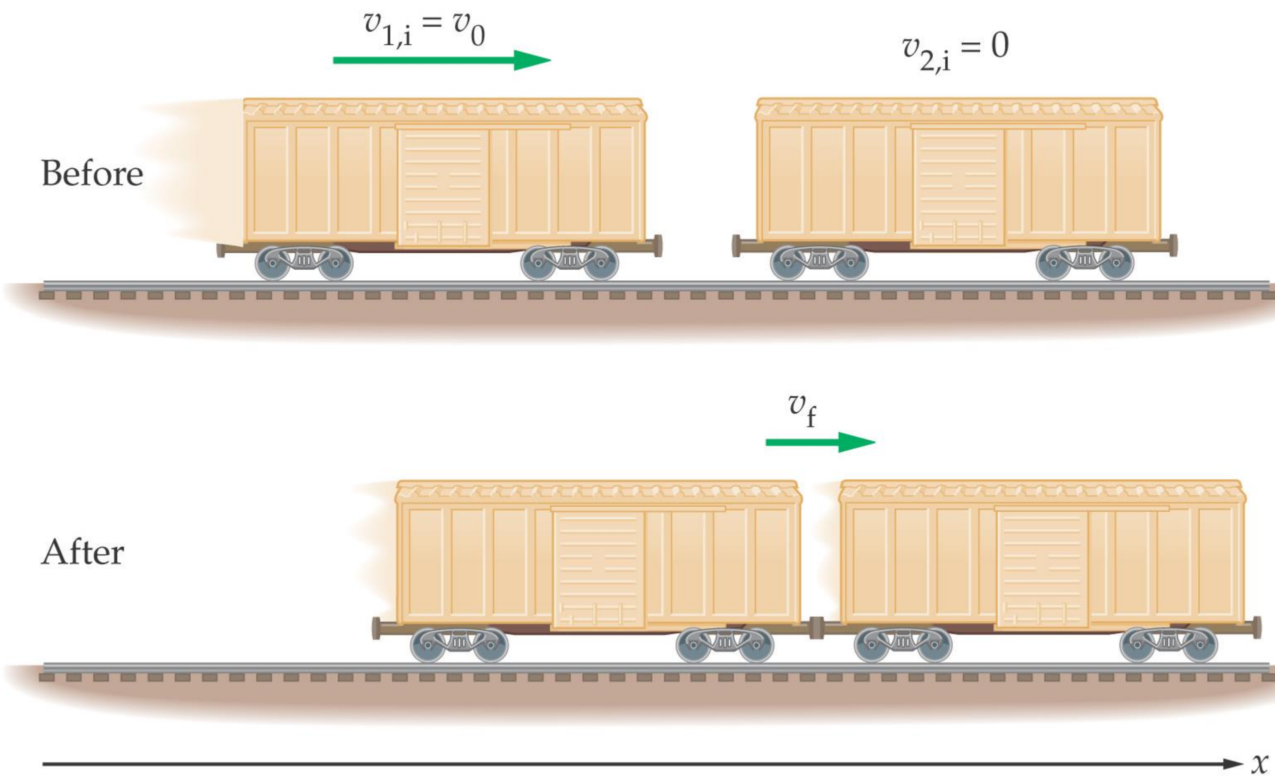
An inelastic collision is one in which part of the kinetic energy is changed to some other form of energy in the collision ex: car accident.

ex: sound, thermal, light, heat

Completely inelastic collision: objects stick together afterwards

9-5 --Inelastic Collisions

A completely inelastic collision:



momentum ← $P_i = P_f$

kinetic energy ← $KE_i \neq KE_f$

$$(mv_i)_1 + (mv_i)_2 = (mv_f)_1 + (mv_f)_2$$

$$(mv_i)_1 + (mv_i)_2 = (m_1 + m_2) v_f$$

$$v_f = \frac{(mv_i)_1 + (mv_i)_2}{(m_1 + m_2)}$$

$v_f = \frac{1}{2} v_i$

?

for inelastic

when $m_1 = m_2$

9-5 --Inelastic Collisions

Solving for the final momentum in terms of the initial momenta and masses:

$$p_{\mathrm{i}} = m_1 v_{1,\mathrm{i}} + m_2 v_{2,\mathrm{i}}$$

$$p_{\mathrm{f}} = (m_1 + m_2) v_{\mathrm{f}}$$

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

EXERCISE 9–2 Inelastic

A 1200-kg car moving at 2.5 m/s is struck in the rear by a 2600-kg truck moving at 6.2 m/s. If the vehicles stick together after the collision, what is their speed immediately after colliding? (Assume that external forces may be ignored.)

$m_1 = 1200 kg$

$m_2 = 2600 kg$

$v_{i_2} = 6.2 m/s$

$v_{i_1} = 2.5$

$v_f = ?$

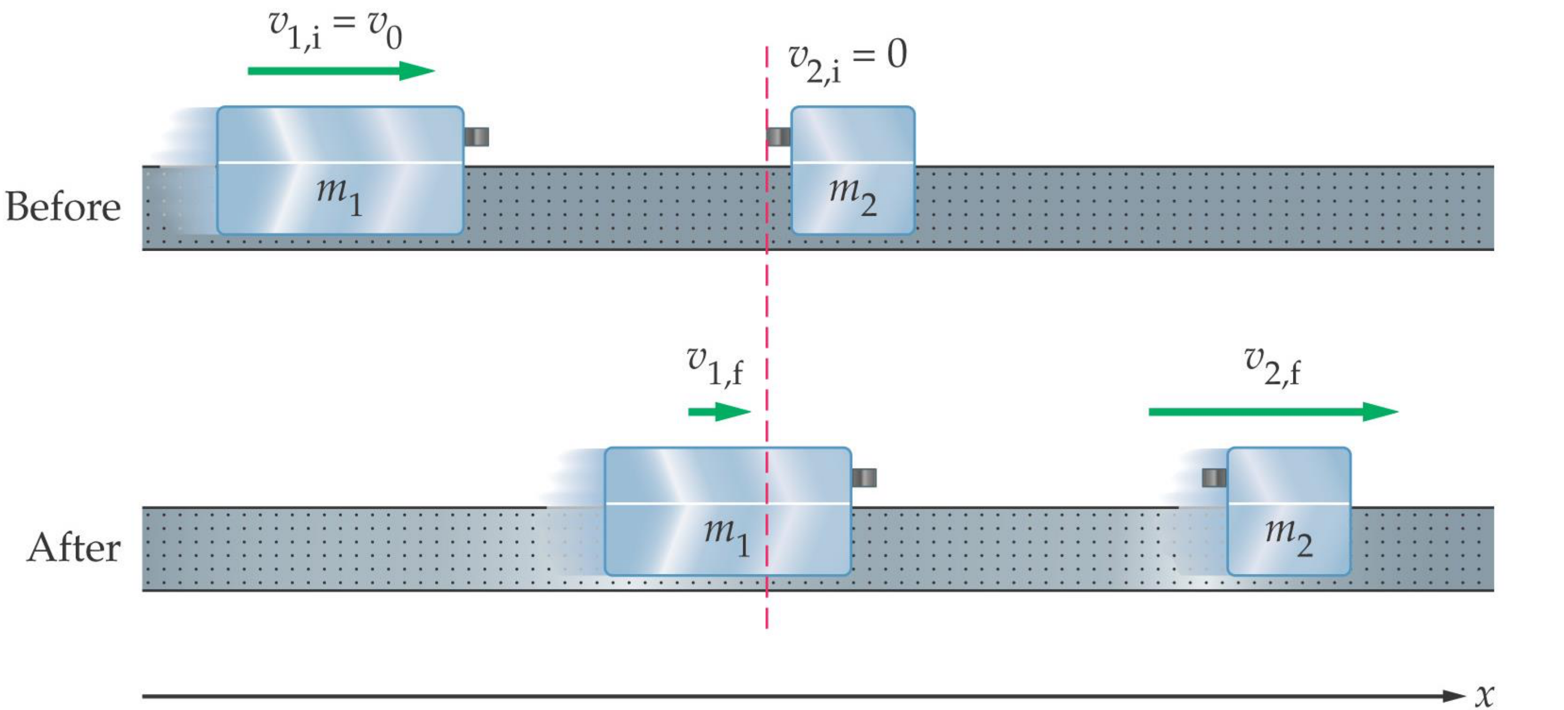
$$v_f = \frac{(mv_i)_1 + (mv_i)_2}{m_1 + m_2}$$

$$v_f = \frac{(1200)(2.5) + (2600)(6.2)}{(1200 + 2600)} = 5.03 \ m/s$$

9-6 --Elastic Collisions

•In elastic collisions, both kinetic energy and momentum are conserved.

•A perfectly elastic collision is defined as one in which there is no loss of kinetic energy in the collision.



$$P_i = P_f$$

$$(mv_i)_1 + (mv_i)_2 = (mv_f)_1 + (mv_f)_2$$

$$KE_i = KE_f$$

$$\left(\frac{1}{2}mv_i\right)_1 + \left(\frac{1}{2}mv_i\right)_2 = \left(\frac{1}{2}mv_f\right)_1 + \left(\frac{1}{2}mv_f\right)_2$$

9-6 --Elastic Collisions

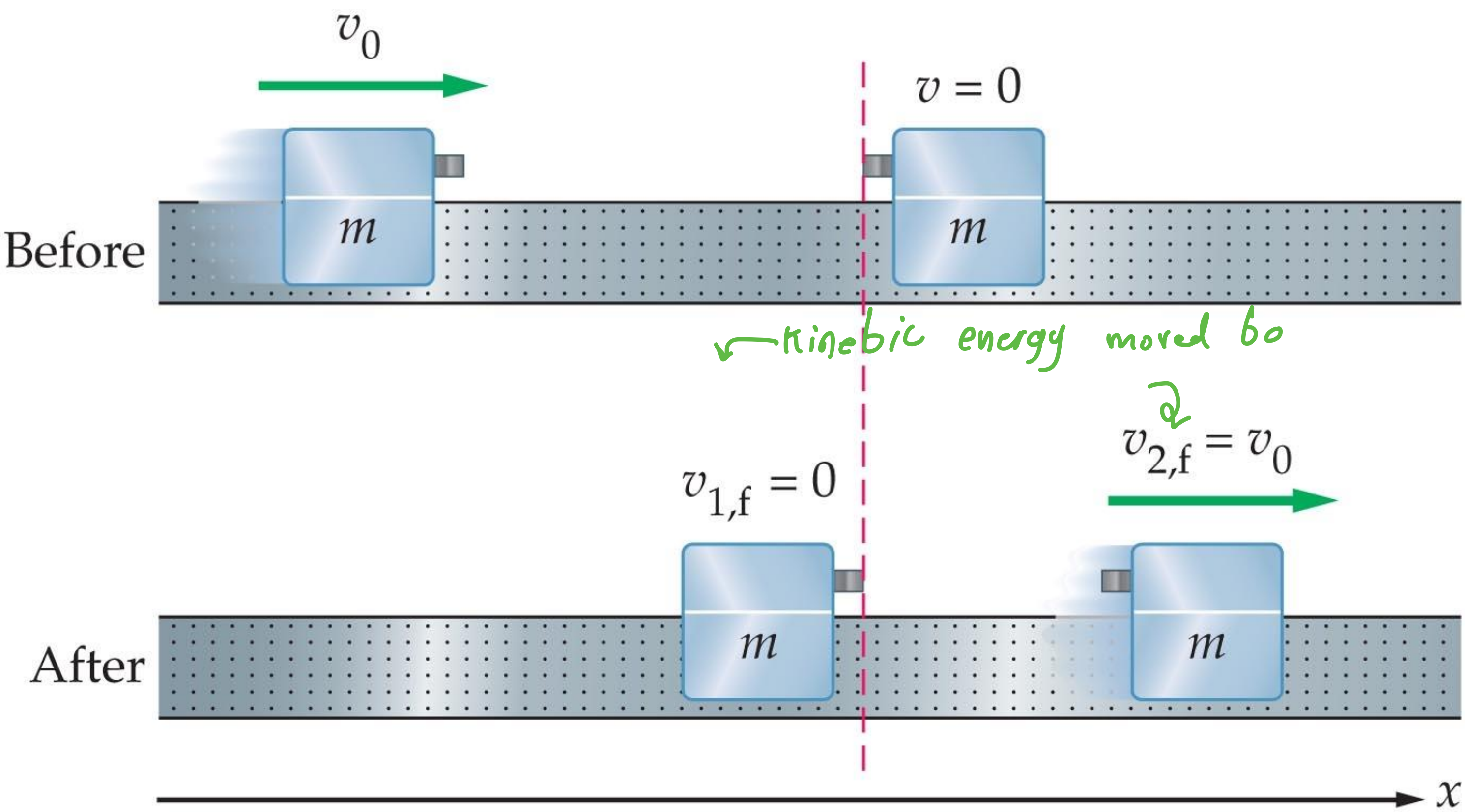
We have two equations (conservation of momentum and conservation of kinetic energy) and two unknowns (the final speeds). Solving for the final speeds:

can be (+ , - , zero)

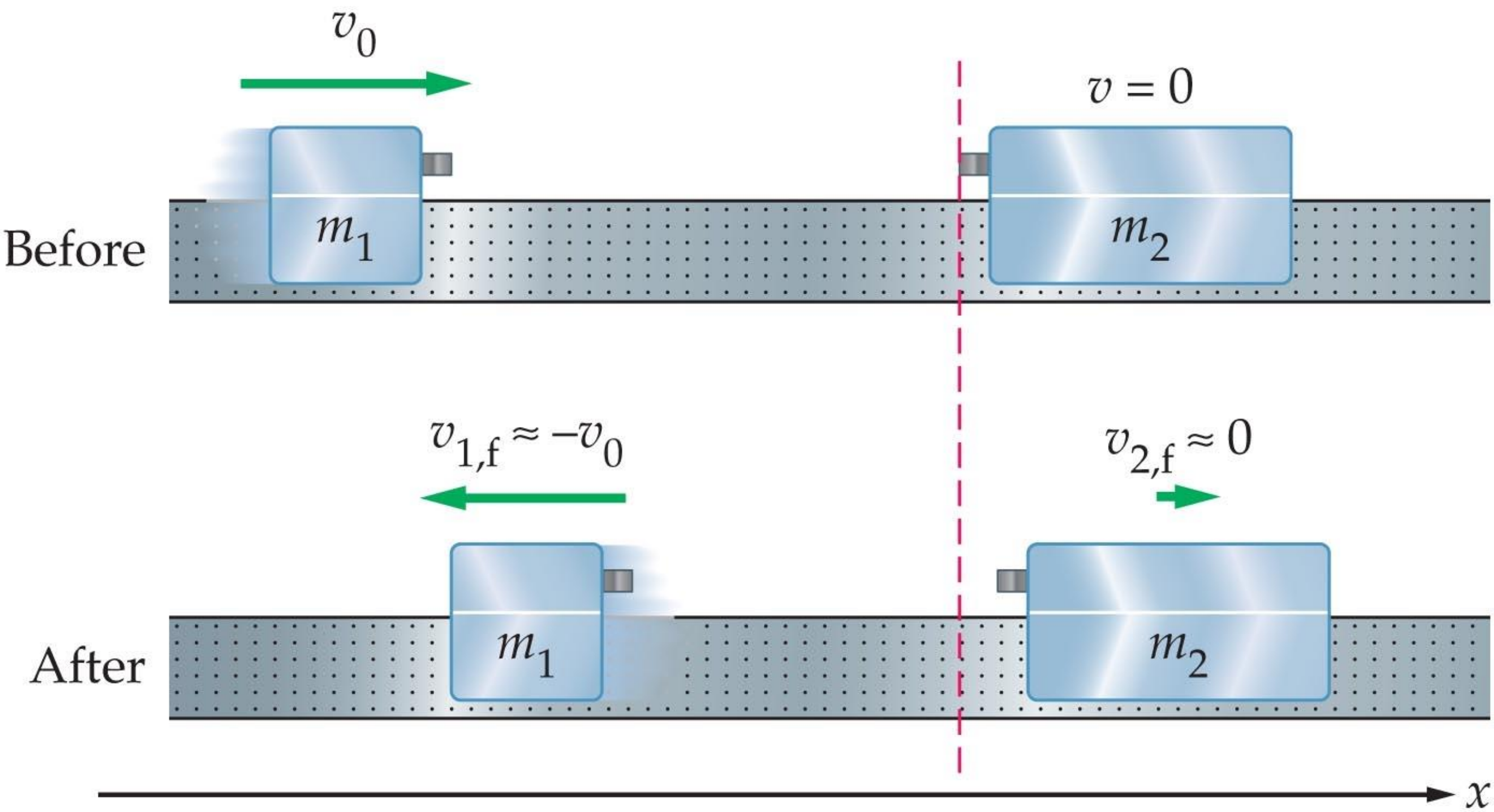
$$v_{1,f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)v_0 \rightarrow (v_{i_1} + v_{i_2})$$

only (+)

$$v_{2,f} = \left(\frac{2m_1}{m_1 + m_2}\right)v_0 \rightarrow (v_{i_1} + v_{i_2})$$

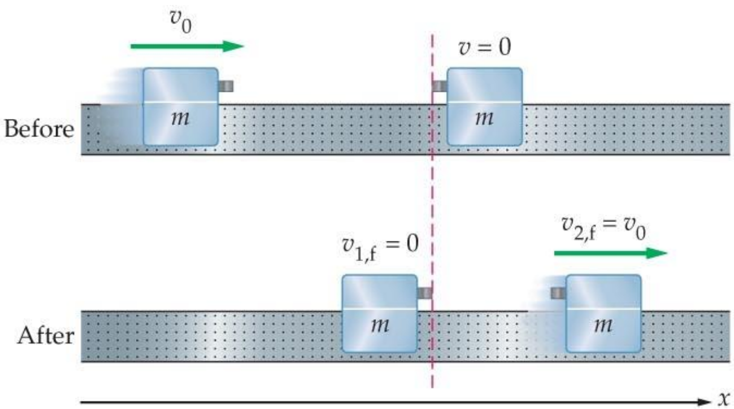

v_0
$v = 0$
Before
m
m
kinetic energy moved to
2
$v_{1,f} = 0$
$v_{2,f} = v_0$
After
m
m
x

(a) $m_1 = m_2 = m$



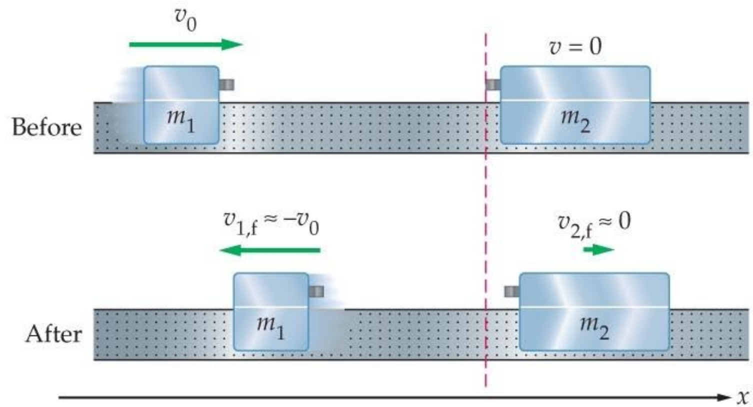
(b) $m_1 << m_2$

$m_1 = m_2 \; : \; v_{f_1} = 0$



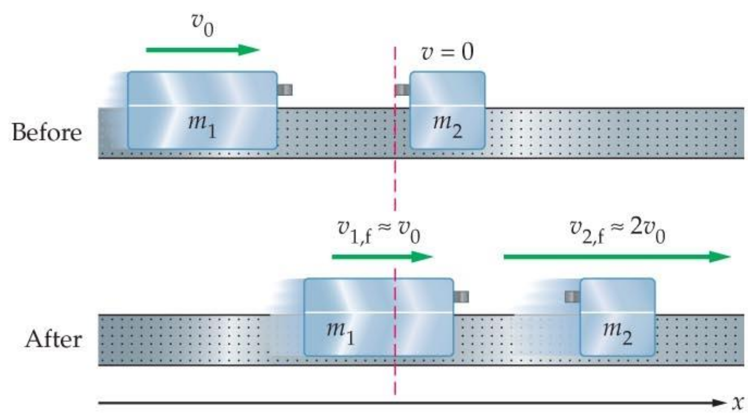
(a) $m_1 = m_2 = m$

$m_1 < m_2 \; : \; v_{f_1} = (-)$



(b) $m_1 << m_2$

$m_1 > m_2 \; : \; v_f (+)$



(c) $m_1 >> m_2$

Elastic and Inelastic Collisions

The comparison between **Elastic and inelastic collision** is given below:

S.No	ELASTIC COLLISION	INELASTIC COLLISION
1	Momentum Conserved	Momentum Conserved
2	Kinetic energy Conserved	Kinetic energy not conserved
3	Example: Bouncing ball	example: Bullet shot in wood

Exercise- 9—3

- At an amusement park, a 96-kg bumper car moving with a speed of 1.24m/s bounces elastically off a 135kg bumper car at rest.Find the final velocities of the cars.
- Sol:- V1,f= -0.209m/s,   v2,f = 1.03m/s

$m_1 = 96$

$v_{i1} = 1.24$

$m_2 = 135$

$v_{i2} = 0$

$$v_{f1} = \frac{(m_1 - m_2)}{(m_1 + m_2)}(v_i)$$

$$\frac{(96 - 135)}{(96 + 135)}(1.24 + 0)$$

$$= -0.209 \text{ m/s}$$

$$v_{f2} = \frac{2m_1}{(m_1 + m_2)}(v_i)$$

$$\frac{2(96)}{(96 + 135)}(1.24 + 0)$$

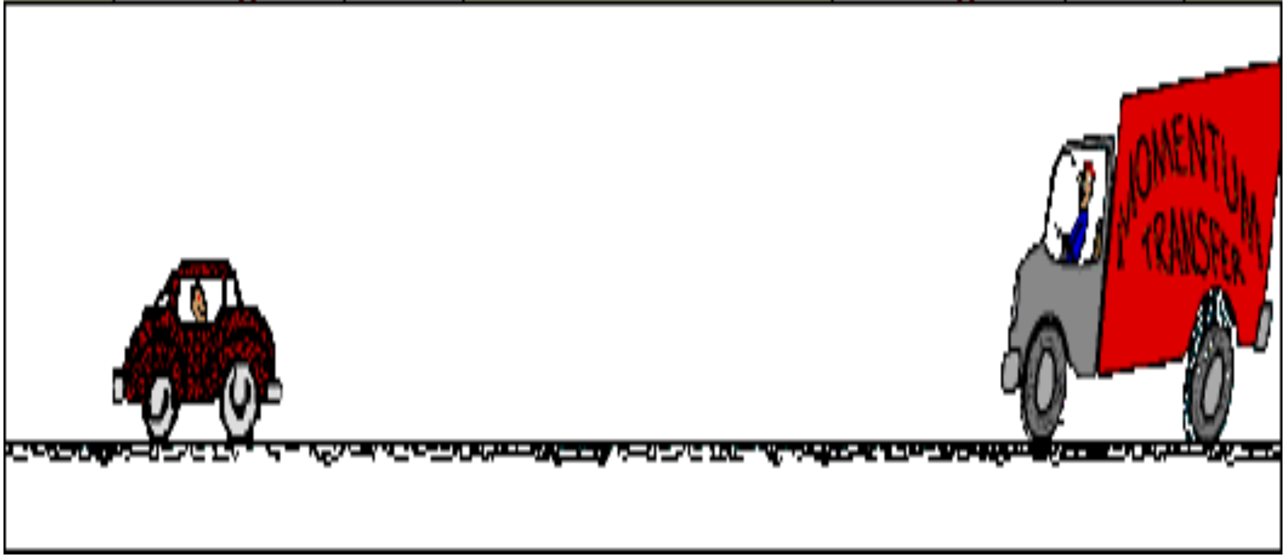
$$= 1.03 \text{ m/s}$$

Car

mass (kg)	1000
vel. (m/s)	20.0
mom. (kg m/s)	20 000

Truck

mass (kg)	3000
vel. (m/s)	- 20.0
mom. (kg m/s)	-60 000



Linear Momentum

mass + velocity

Another way to compare linear momentum is to consider a collision.

If a boy is running at you at full speed and hits you, you'll probably be knocked down but will still be okay. However, if a truck is coming at you at the same speed and hits you, you will be hurt badly. In this example, the boy has much less linear momentum than the larger truck.

High linear momentum = High Collision.

Summary of Chapter 9

- Linear momentum:

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}}$$

- Momentum is a vector
- Newton's second law:

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

- Impulse:
- Impulse is a vector

$$\vec{\mathbf{I}} = \vec{\mathbf{F}}_{\mathrm{av}}\Delta t = \Delta\vec{\mathbf{p}}$$

- The impulse is equal to the change in momentum
- If the time is short, the force can be quite large

Summary of Chapter 9

- Momentum is conserved if the net external force is zero
- Internal forces within a system always sum to zero
- In collision, assume external forces can be ignored
- Inelastic collision: kinetic energy is not conserved
- Completely inelastic collision: the objects stick together afterward

Summary of Chapter 9

- A one-dimensional collision takes place along a line
- Elastic collision: kinetic energy is conserved

don't take two dimension