Assignment # ___

Name
Date
Period

CH. 7 "Momentum"

(aka "Inertia in Motion")

* History:
  - People (scientists) have forgotten who actually came up with the idea of momentum. True.
  - However, it does have "seeds" of Newton's laws of motion within it.
  - Newton did not come up with the idea Δ Impulse = Δ momentum, however it does again have elements of his laws within it. ($\Delta Ft = \Delta mv$)

*Demo: "Newtonian Demonstrator"

7.1 Momentum

* Momentum = mass × velocity

$$p = m \times v$$

$m = \underline{?}\ kg$

$v = \underline{?}\ m/s$

$p = \boxed{kg \cdot m/s}$

(These are the units for momentum. Doesn't get changed to anything else).

* For an object to have momentum it must be moving with speed or velocity.

(look at Fig. 7.1)

Q: Does an object at rest have momentum?

A: No.

7.2 Impulse changes Momentum

☆ For an object to have momentum, it must be moving w/ speed or velocity.

Q: What gives an object momentum?

A: Not just a Force, but an <u>Impulse</u> (ΔFt).

In other words,

Demos: w/ track and motion car

$$\Delta Ft = \Delta mv$$

$$\Delta \text{Impulse} = \Delta \text{ momentum}$$

Prove it w/ unit analysis:

$$\Delta Ft = \Delta mv$$

$$\Delta N \cdot s = \Delta kg \cdot m/s$$

$$\left(kg \cdot \frac{m}{\cancel{s}\,s}\right)\left(\frac{\cancel{s}}{1}\right) = \left(kg \cdot m/s\right)$$

✓ $(kg \cdot m/s) = (kg \cdot m/s)$

* (look at Figure 7.1,
The Truck vs. The Skate)

Physics

Name
Date
Period

CH. 7: Momentum

~ Why does it hurt less when you fall on a wooden floor than a concrete floor?

~ How can a martial art expert break a stack of cement bricks with a blow of a bare hand?

~ Why is follow-through so important in golf, baseball, and boxing?

~ Why is the cartoon "Road Runner" so funny?

(Because many laws of physics especially conservation of momentum laws, are broken.)

The laws of momentum will explain why.

* Recall Newton's 1st Law of Motion — Inertia.

~ Now, we are going to look at inertia in motion — momentum.

7.1 Momentum

* **Momentum**: is inertia in motion. More specifically, the mass of an object multiplied by its velocity.

$$\text{momentum} = \text{mass} \times \text{velocity}$$

$$\text{or} \quad \text{momentum} = mv$$

mass = kg

(1) velocity = m/s in a given direction.
(you can use speed also)

(sometimes you see - $p = mv$)

Some examples:

~ You should see from the definition that a moving object can have a large momentum if it has a large mass, a high speed, or both.

~ A moving truck has has more momentum than a car moving at the same speed because the truck has more mass.

~ A fast car has more momentum than a slow truck.

~ A truck at rest has no momentum at all.

(See fig. 7.1 and Q pg. 87)

Ch. 7

Momentum:

Demo: w/ Newtonian Demonstrator

~ All 3 laws are within it!
~ Newton did not come-up with momentum...
~ Δ Impulse = Δ momentum came after Newton. The history has been lost.

1st Law - Inertia...

("An object at rest... An object in motion...)

momentum

$$p = m \times v$$

$$p = (kg)(m/s)$$

$$\boxed{p = kg \cdot m/s}$$

p = momentum

m = mass (kg)

v = speed or velocity (m/s)

~ We say that "momentum is inertia in motion."
~ Q: How do we measure inertia?
We measure mass (kg), mass is a surrogate (substitute) for inertia.
~ So when we say "inertia" (m = kg) "in motion" (v = m/s); it only measures inertia when an object is in motion.
~ In other words, we can only measure momentum when an object moves.
~ Q: If an object is at rest does it have momentum? NO.

Compare & contrast $\Delta Ft = \Delta mv$
w/ Newton's 2nd Law ($F = m \times a$)

Q: What are the units
for N. 2nd Law?

$$F = m \times a$$

$$F = (kg)(m/s^2)$$

$$\boxed{F = (kg)(m/s^2) = \text{Newton (N)}}$$

Q: What are the units for
p = momentum?

$$p = \Delta m v$$

$$\boxed{p = \underline{\ ?\ }(kg)(m/s)}$$

Q: Are these the same?

$$F = (kg)(m/s^2) = N$$

compared to...

$$p = (kg)(m/s) = \boxed{\underline{\ ?\ }\ kg \cdot m/s}$$

p

A: NO!

(3)

Momentum:

$\rho = m \times v$

$m = \underline{?}\ kg$

$v = \underline{?}\ m/s$

$\rho = \text{momentum} = \boxed{kg \cdot m/s}$

Don't confuse the units for momentum w/ Newton's 2nd Law: $F = m \times a$

$(N) = (kg)\ (m/s^2)$

✓ $N = kg \cdot m/s^2$

$\neq$!!! (Not the same!!)

$\rho = kg \cdot m/s$

- So the units for ρ are always $\rho = kg \cdot m/s = \underline{?}\ kg \cdot m/s$

★ We don't reduce it or substitute with anything else.

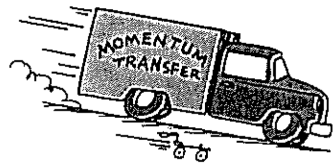


Figure 7.1 ▲
A truck rolling down a hill has more momentum than a roller skate with the same speed, because the truck has more mass. But if the truck is at rest and the roller skate moves, then the skate has more momentum because only it has speed.

■ Question

Can you think of a case where the roller skate and the truck shown in Figure 7.1 would have the same momentum?

■ Answer

The roller skate and truck can have the same momentum if the speed of the roller skate is much greater than the speed of the truck. How much greater? As many times greater as the truck's mass is greater than the roller skate's mass. Get it? For example, a 1000-kg truck backing out of a driveway at 0.01 m/s has the same momentum as a 1-kg skate going 10 m/s. Both have momentum = 10 kg m/s.

$p = m \times v$

<u>MAC Truck vs. Roller Skate</u>
(see fig. 7.1)

MAC Truck = 1000.0 kg

Roller Skate = 1.0 kg

Q: Can you think of a case where the Roller skate and the truck shown in fig. 7.1 would have the same momentum?

<u>Truck (m = 1000.0 kg)</u> vs. <u>Skate (m = 1.0 kg)</u>

$p = m \times v$

$p = (1000.0\,kg)(1.0\,m/s)$

$p = 1000.0\,kg \cdot m/s$

$p = m \times v$

$p = (1.0\,kg)(1000.0\,m/s)$

$p = 1000.0\,kg \cdot m/s$

SAME.!!

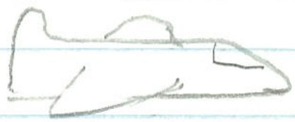
Q: What does this mean?

A: Imagine you were Superman or SuperWoman, it would take the same amount of Impulse (Force x time ; Ft) to stop both, (or to get both up to their speeds).

2nd Example...

Q: Can you get a feather to have the same momentum as the Space Shuttle in Space?

A: **YES!!!**



vs

100,000.0kg | 1.0kg

Space Shuttle

$$p = m \times v$$

$$p = (100{,}000.0\,kg)(1.0\,m/s)$$

$$p = 100{,}000.0\,kg \cdot m/s$$

Feather

$$p = m \times v$$

$$p = (1.0\,kg)(100{,}000.0\,m/s)$$

$$p = 100{,}000.0\,kg \cdot m/s$$

Same!!

Q: What does this mean?

A: Again if you were Superman or Superwoman it would take the same Impulse (Ft) to stop both, or to get both up to speed.

Q: How is the Formula for Δ Impulse = Δ Mom. derived? ($\Delta Ft = \Delta mV$)

2nd Law : $F = m \times a$

momentum

- Q: Does momentum have this idea of Newton's 2nd law within it?
- Yes (kind of)

Q: what gives an object acceleration?

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

Q: How do you measure acceleration?

$$a = \frac{\Delta V}{\Delta t} = \frac{V_f - V_i}{t_f - t_i}$$

$$a = a$$

$$\left(\frac{\cancel{m}}{1}\right)\frac{F}{\cancel{m}} = \frac{\Delta V}{\Delta t}\left(\frac{m}{1}\right)$$

$$\left(\frac{\Delta t}{1}\right) F = \left(\frac{\Delta V}{\cancel{\Delta t}}\right)\left(\frac{m}{1}\right)\left(\frac{\cancel{\Delta t}}{1}\right)$$

$$\boxed{\Delta Ft = \Delta mV}$$

Q: Does this formula here look a lot like $F = m \times a$?

A: Kind of...

Recall: kinda looks like ...

$F = m \times a$

(Remember: Momentum has the "seeds" of Newton's 3 Laws within it)

Let's prove through Unit Analysis:

$$\Delta Ft = \Delta mv$$

$$N \cdot s = kg \cdot m/s$$

$$(kg \cdot m/s^2) \times s = kg \times m/s$$

$$\left(kg \cdot \frac{m}{\cancel{s^2}\, s}\right) \times \frac{\cancel{s}}{1} = kg \times \frac{m}{s}$$

✓ $$\boxed{kg \cdot m/s = kg \cdot m/s}$$

7.2 Impulse changes momentum

$$\Delta F t = \Delta m v$$

Q: How was this formula derived mathmatically?

Start with Newton's 2nd Law:

(cause of accel.) $$F = m \times a$$

and

(what is accel.) $$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

Substitution...

$$F = (m)\left(\frac{\Delta v}{\Delta t}\right)$$

$$\left(\frac{\Delta t}{1}\right) F = (m)\left(\frac{\Delta v}{\cancel{\Delta t}}\right)\left(\frac{\cancel{\Delta t}}{1}\right)$$

$$\boxed{\Delta F t = \Delta m v}$$

* Now let's prove the units through unit analysis...

Let's prove through unit analysis:

$$\overrightarrow{\Delta F t = \Delta m v}$$

* Recall: $\Delta Ft = \Delta mv$ has "seeds" of Newton's 3 laws of motion. Kinda looks like $F = m \times a$

$$\underbrace{N \cdot S}_{} = kg \cdot m/s$$

$$\left(kg \cdot m/s^2\right)(S) = (kg)\,(m/s)$$

$$\left(kg \cdot \frac{m}{\cancel{s^2}_{s}}\right)\left(\frac{\cancel{s}}{1}\right) = (kg)(m/s)$$

$$\checkmark\ \boxed{kg \cdot m/s = kg \cdot m/s}$$

Physics

CH.7 Momentum

7.2 Impulse Changes Momentum

~ If momentum changes then either mass or velocity changes.

~ How long the force is acting on an object to give it velocity (which will also accelerate the object) is also very important.

~ Apply a brief force to a stalled automobile and you produce a change in its momentum.

~ Apply the same force over an extended period of time and you produce a greater change in the automobile's momentum.

~ A force sustained for a long time produces more change in momentum than does the same force applied briefly. So both force and time are important in changing momentum.

* Impulse: is the quantity force x time. In shorthand notation —

impulse = Ft

~ The greater the impulse exerted on something, the greater will be the change in momentum. The exact relationship is . . .

impulse = change in momentum

or

$$Ft = \Delta(mv)$$

(Impulse is impact force x time and is measured in newton-seconds)

Read

~ Consider Case 1: Increasing Momentum & Case 2: Decreasing Momentum on pg. 88-90 (See also "Bungee Jumping" then watch video!)

7.2 cont.

– See figures in text books!

Case 1: Increasing Momentum

$$\Delta F t = \Delta m v$$

Golf ball & Golf Club

$$F \quad t \quad = \quad m \quad v$$

1st AT REST

$$(10.0\,N)(1.0\,s) = 10.0\,N\cdot s = 10\,kg\cdot m/s$$

$$\checkmark\ 10.0\,Ns = 10.0\,kg\cdot m/s$$

Q: What do you have to do to give it momentum?

A: Give it an impulse (Ft)!

2nd HAS MOMENTUM

Q: What has to be done to the golf ball to bring it to a STOP?

A: An Impulse! (from the ground!)

$$m \quad v \quad = \quad F \quad t$$

$$(0.25\,kg)(40.0\,m/s) = (2.0\,N)(5.0\,s)$$

$$\checkmark\ 10.0\,kg\cdot m/s = 10.0\,N\cdot s$$

* The Idea of "Follow-Through" in Ball Sports...

= Longer Impulse time

= greater Impulse

= greater momentum

= The Golf ball goes farther!

*Q: What is the Fastest Ball game?

A: ______

Ex:

$$F \quad t \quad = \quad m \quad v$$

short time #1 $(10.0\,N)(0.25\,s) = (0.25\,kg)(10.0\,m/s)$

$$2.5\,N\cdot s \qquad 2.5\,kg\cdot m/s$$

Long time #2 $(10.0\,N)(0.75\,s) = (0.25\,kg)(30.0\,m/s)$

$$7.5\,N\cdot s \qquad 7.5\,kg\cdot m/s$$

Q: What does this mean? 3X...

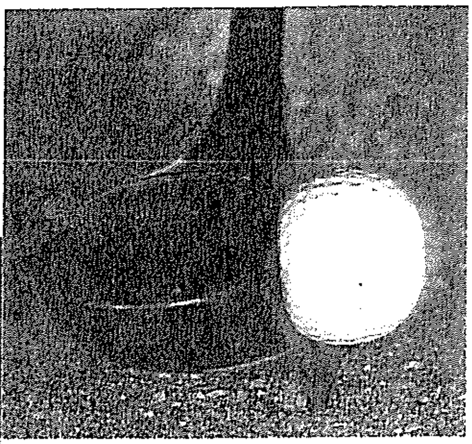


Figure 7.2 ▲
The force of impact on a golf ball varies throughout the duration of impact.

Case 1: Increasing Momentum

To increase the momentum of an object, it makes sense to apply the greatest force possible for as long as possible. A golfer teeing off and a baseball player trying for a home run do both of these things when they swing as hard as possible and follow through with their swing.

The forces involved in impulses usually vary from instant to instant. For example, a golf club that strikes a golf ball exerts zero force on the ball until it comes in contact with it; then the force increases rapidly as the ball becomes distorted (Figure 7.2). The force then diminishes as the ball comes up to speed and returns to its original shape. So when we speak of such impact forces in this chapter, we mean the *average* force of impact. (Be careful to distinguish between *impact* and *impulse.* Impact refers to a *force* and is measured in newtons; impulse is *impact force* × *time* and is measured in newton-seconds.)

Case 2: Decreasing Momentum

If you were in a car that was out of control and had to choose between hitting a concrete wall or a haystack, you wouldn't have to call on your knowledge of physics to make up your mind. Common sense tells you to choose the haystack. But knowing the physics helps you to understand *why* hitting a soft object is entirely different from hitting a hard one. In the case of hitting either the wall or the haystack and coming to a stop, your momentum is decreased by the same impulse. The same impulse does not mean the same amount of force or the same amount of time; rather it means the same *product* of force and time. By hitting the haystack instead of the wall, you extend the impact time—*the time during which your momentum is brought to zero.* A longer impact time reduces the force of the impact and decreases the resulting deceleration. For example, if the time of impact is extended 100 times, the force of impact is reduced 100 times. Whenever we wish the force of impact to be small, we extend the time of impact.

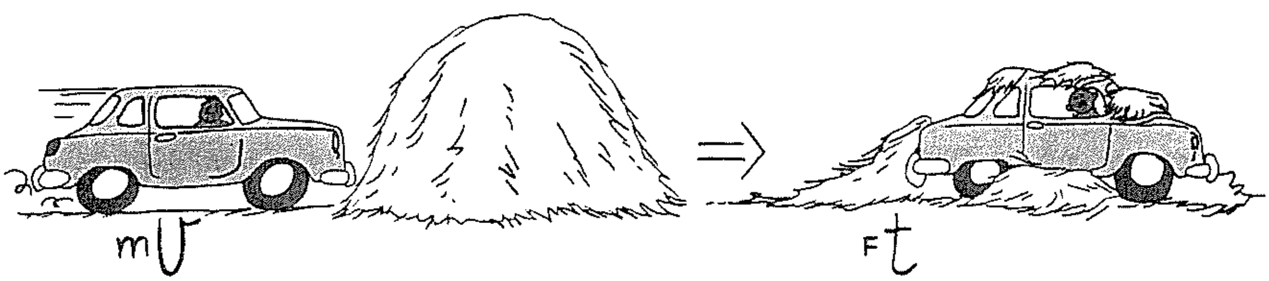


Figure 7.3 ▲
If the change in momentum occurs over a long time, the force of impact is small.

We know that a padded dashboard in a car is safer than a rigid metal one and that airbags save lives. We also know that to catch a fast-moving ball safely with your bare hand, you extend your hand forward so there's plenty of room for it to move backward after making contact with the ball. When you extend the time of impact, you reduce the force of impact.

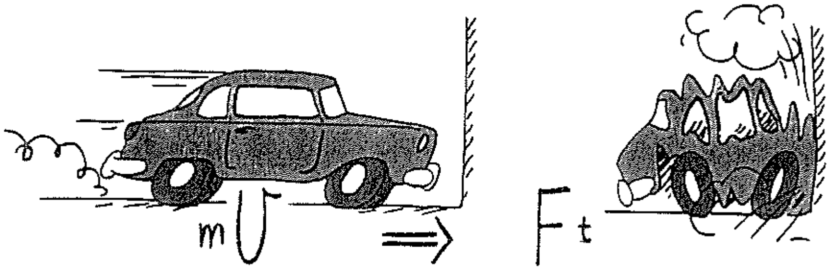


Figure 7.4
If the change in momentum occurs over a short time, the force of impact is large.

The Best From Conceptual Physics Alive!

Decreasing Momentum Over a Short Time

Side 1
Chapter 34

When jumping from an elevated position down to the ground, what would happen if you kept your legs straight and stiff? Ouch! Instead, you know to bend your knees when your feet make contact with the ground. By doing so you extend the time during which your momentum decreases by 10 to 20 times that of a stiff-legged, abrupt landing. The resulting force on your bones is reduced by 10 to 20 times. A wrestler thrown to the floor tries to extend his time of impact with the mat by relaxing his muscles and spreading the impact into a series of smaller ones as his foot, knee, hip, ribs, and shoulder successively hit the mat. Of course, falling on a mat is preferable to falling on a solid floor because the mat also increases the impact time.

We know a glass dish is more likely to survive if it is dropped on a carpet rather than a sidewalk because the carpet has more "give" than the sidewalk. Ask why a surface with more give makes for a safer fall and you will get a puzzled response from most people. They may simply say, "Because it gives more." However, your question is, "*Why* is a surface with more give safer for the dish?" In this case, a common explanation isn't really an explanation at all. A deeper explanation is needed.

To bring the dish or its fragments to rest, the carpet or the sidewalk must provide an impulse, which you know involves two variables—impact force and impact time. Since impact time is longer on the carpet than on the sidewalk, a smaller impact force results. The shorter impact time on the sidewalk results in a greater impact force.

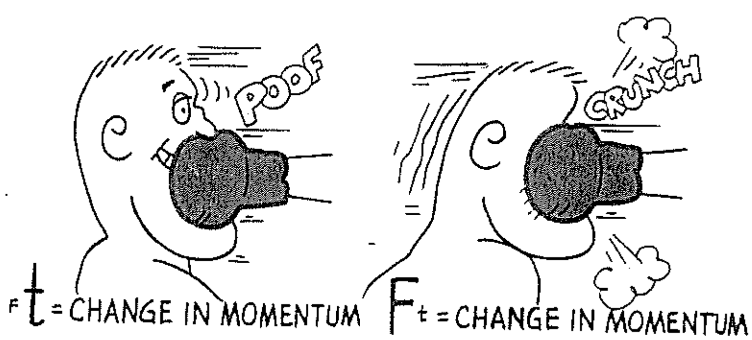


Figure 7.5
In both cases the impulse provided by the boxer's jaw must counteract the momentum of the punch. (Left) When the boxer moves away from the punch, he increases the time of impact and reduces the force of impact. (Right) When the boxer unwisely moves toward the punch, the time of impact is reduced and the force of impact is increased. Ouch!

Physics

CH. 7: Momentum

7.2 Impulse Changes Momentum (Cont.)

~ Recall: momentum

$p = mv$

~ Recall: Impulse $\longrightarrow$ The impact force x impact time can create an impulse that can increase or decrease momentum.

Ft

Now, Impulse = momentum

$Ft = mv$

Let's look at some examples:

Bungee Jumper Example:

A. Bungee on Steel Cable: $F\text{t} = mv \longrightarrow (8000N)(.01s) = (80kg)(10\,m/s)$

$800N\cdot s = 800kg\cdot m/s$

B. Bungee on a Bungee Cord: $F\text{T} = mv \longrightarrow (20N)(4s) = (80kg)(10\,m/s)$

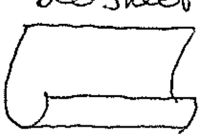
$800N\cdot s = 800\,kg\cdot m/s$

~ which would you prefer?

~ Keep in mind that the impulse for both is the same, but the force and time for both is differen

~ The longer the impact time, the less the impact force.

Bed Sheet



An Egg, A Sheet, and A Athlete:

A. Egg Thrown at a Wall: $F\text{t} = mv \longrightarrow (27N)\ (.01s) = (.01kg)(27\,m/s)$

60mph ≈ 27 m/s

$.27N\cdot s = .27kg\cdot m/s$

B. Egg thrown at a sheet: $F\text{T} = mv \longrightarrow (0.27N)\ (1\,s) = (.01kg)(27\,m/s)$

60mph ≈ 27 m/s

$.27N\cdot s = .27\,kg\cdot m/s$

Bungee Jumping Example:
- you have a choice...

A. Bungee on Steel Cable:

$$\Delta mv = \Delta Ft$$

$m = 80kg$
$v_i = 10 \, m/s$

$$(80kg)(10 m/s) = (80{,}000N)(.01s)$$
$$800 \, kg \cdot m/s = 800 \, N \cdot s$$

* This force will dismember your body!

B. Bungee on Bungee Cord:

$$\Delta mv = \Delta Ft$$

$$(80kg)(10 m/s) = (200N)(4.0s)$$
$$800 \, kg \cdot m/s = 800 \, N \cdot s$$

* This force is like falling into a bed of feathers!

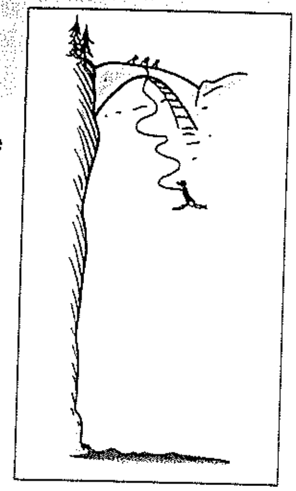
PHYSICS OF SPORTS

Bungee Jumping

The impulse-momentum relationship is put to a thrilling test during bungee jumping. Be glad the rubber cord stretches when the jumper's fall is brought to a halt, because the cord has to apply an impulse equal to the jumper's momentum in order to stop the jumper—hopefully above ground level.

Note how $Ft = \Delta(mv)$ applies here. The momentum, mv, we wish to change is the amount gained before the cord begins stretching. Ft is the impulse the cord supplies to reduce the momentum to zero.

Because the rubber cord stretches for a long time, a large time interval t ensures that a small average force F acts on the jumper. Elastic cords typically stretch to about twice their original length during the fall.



The safety net used by circus acrobats is a good example of how to achieve the impulse needed for a safe landing. The saftey net reduces the impact force on a fallen acrobat by substantially increasing the time interval of the impact.

Sometimes a difference in impact time is important even if you can't notice the give in a surface. For example, a wooden floor and a concrete floor may both seem rigid, but the wooden floor can have enough give to make quite a difference in the forces that these two surfaces exert.

Questions

1. When a dish falls, will the impulse be less if it lands on a carpet than if it lands on a hard floor?
2. If the boxer in Figure 7.5 is able to make the impact time five times longer by "riding" with the punch, how much will the force of impact be reduced?

Answers

1. No. The impulse would be the same for either surface because the same momentum change occurs for each. It is the *force* that is less for the impulse on the carpet because of the greater time of momentum change. If you answered this question incorrectly, you probably did not distinguish between impulse and impact. They sound the same, but they're not!
2. Since the time of impact increases five times, the force of impact will be reduced five times.

Q: How fast do you have to throw the egg at a bedsheet to break it?

$$\Delta m v = \Delta F t$$

Solve for v!

know:
$m = 50g = 0.05kg$
$F = 2.0N$ (to break egg)
$t = 1.5s$
v = solve for

$$\frac{\Delta \cancel{m} v}{\cancel{m}} = \frac{\Delta F t}{m}$$

$$v = \frac{\Delta F t}{m} = \frac{(2.0N)(1.5s)}{(0.05kg)}$$

$$\boxed{v = 60\, m/s}$$

How?

$$v = \frac{N \cdot s}{kg}$$

$$= \frac{(\cancel{kg} \cdot m/\cancel{s^2}) \times \left(\frac{\cancel{s}}{1}\right)}{\cancel{kg}}$$

✓ $v = m/s$

$\boxed{60 m/s = \_\_\_\_ mph?}$

$1 mph = .44704 m/s$

$$\left(\frac{60 \cancel{m/s}}{1}\right)\left(\frac{1 mph}{.44704 \cancel{m/s}}\right) =$$

$\boxed{\text{You have to throw it at!} = 134.22 mph}$

Physics

CH. 7: Momentum

7.3 Bouncing

- If a flower pot falls from a shelf onto your head (ouch!), you may be in trouble. However, if it bounces off your head it is going to hurt so much more. Why?

- Demo:

  A bouncing ball vs. a ball that doesn't bounce.
  - Which ball had the greater impulse (Ft)?

- Impulses are greater when an object bounces. The impulse required to bring an object to a stop and then to "throw it back again" is greater than the impulse required merely to bring the object to a stop.

Practical Example:
- Catch a flower pot and bring it to a stop.

  vs.

  Catch a flower pot, bring it to a stop and then throw it into the air again.

- This increased amount of impulse is supplied by your head if the pot bounces from it!

  (look at fig. 7.6 & 7.7)

- Lester A. Pelton patented his invention and made a lot more money than many of the gold miners during California's Gold Rush.

  Physics = $$

Figure 7.6
Is the karate chop delivered in a short time or a long time? If the hand bounces upon impact, is the change in momentum greater? Is the impulse greater?

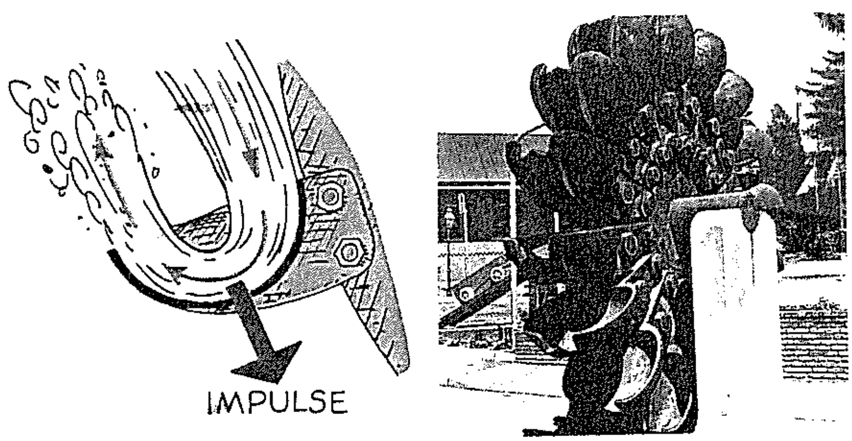


Figure 7.7
The Pelton Wheel. The curved blades cause water to bounce and make a U-turn, producing a large impulse that turns the wheel.

Physics

CH. 7: Momentum

7.4 Conservation of momentum (The Law of Conservation of Momentum)

*The Law of Conservation of momentum can be seen as an extension of Newton's 3rd Law. "Action-Reaction"

~ Recall: From Newton's 2nd Law ($a = \frac{F}{m}$) you know to accelerate an object a net force must be applied to it. ($F_{net} > 0$) $F = m \times a$ (N. 2nd Law)

~ The Law of conservation of momentum says much the same thing but in a different way. If you wish to change the momentum of an object, exert an impulse on it.

$$\Delta F t = \Delta m v$$

* In either case, the force or impulse must be exerted on the object by something outside the object. (Internal Forces vs. External Forces)

* Internal forces ~~work~~ won't do it.

Examples:

A. Molecular forces inside a ball won't have any effect on the momentum of the ball.

B. pushing on the dashboard of a car won't have any effect on the momentum of the car.

* Story + Sailboat Demo →

C. Holding a fan and blowing wind into the sail of a sailboat won't have any effect of momentum of the sailboat.

(Internal Forces cancel!)

~ All of these examples come in balanced pairs that cancel within the object, therefore no change in momentum!

~ Let's look at the Rifle-Bullet system as an example fig. 7.8 on pg. 92

This can be confussing!!

- Look at figure
- Read the example
- The key is to look at the total Rifle-Bullet system together; not as seperate objects.

Illustrations of The Law of Cons. of Momentum...

Explosion equation:

$$M_{1B}V_{1B} + M_{2B}V_{2B} = \emptyset$$

Recall: Example
"Bullet & The Rifle" System

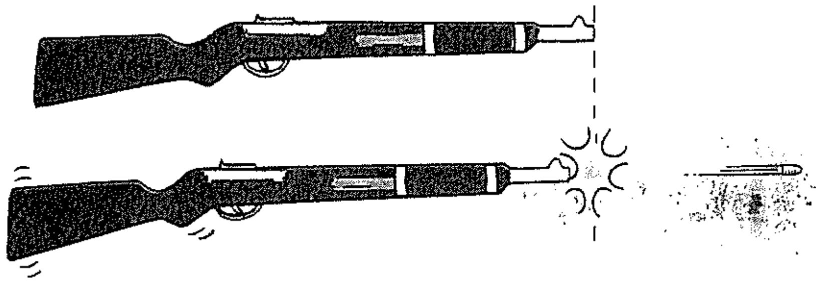


Figure 7.8 ▲
The momentum before firing is zero. After firing, the net momentum is still zero because the momentum of the rifle is equal and opposite to the momentum of the bullet.

Questions

1. Newton's second law states that if no net force is exerted on a system, no acceleration occurs. Does it follow that no change in momentum occurs?
2. Newton's third law states that the force a rifle exerts on a bullet is equal and opposite to the force the bullet exerts on the rifle. Does it follow that the *impulse* the rifle exerts on the bullet is equal and opposite to the *impulse* the bullet exerts on the rifle?

Answers

1. Yes, because no acceleration means that no change occurs in velocity or in momentum (mass × velocity). Another line of reasoning is simply that no net force means there is no net impulse and thus no change in momentum.
2. Yes, because the rifle acts on the bullet and the bullet reacts on the rifle during the same *time* interval. Since time is equal and force is equal and opposite for both, the impulse, *Ft,* is also equal and opposite for both. Impulse is a vector quantity and can be canceled.

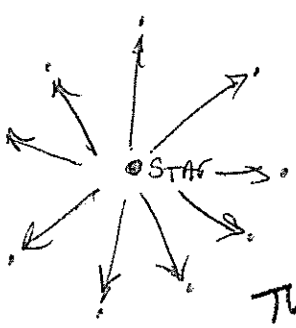
~ The momentum of a <u>system</u> cannot change unless it is acted on by external forces. ~~A~~

~ A system will have the same momentum before some internal interaction as it has after the interaction occurs. (The Law of Cons. of Mom.)

* <u>Conserved</u>: when any quantity in physics does not change, we say it is conserved. Momentum is a perfect example of a quantity that is conserved. (saved; accounted for)

* <u>The Law of Conservation of Momentum:</u>

"In the absence of an external force, the momentum of a system remains unchanged."



~ More Examples:
- A. atomic nuclei undergoing radioactive decay
- B. Cars colliding
- C. Stars exploding (Supernova)

Think of it this way —

It's like accounting. If you start with $10 dollars, no matter what you subtract when you buy something, you better be able to account for every cent spent. And it all better add up to $10 dollars. If it does, then the value of your $10 dollars is conserved, and you know where every cent went. Nothing is lost.

(See Q's on pg. 93)

7.4 Cont.

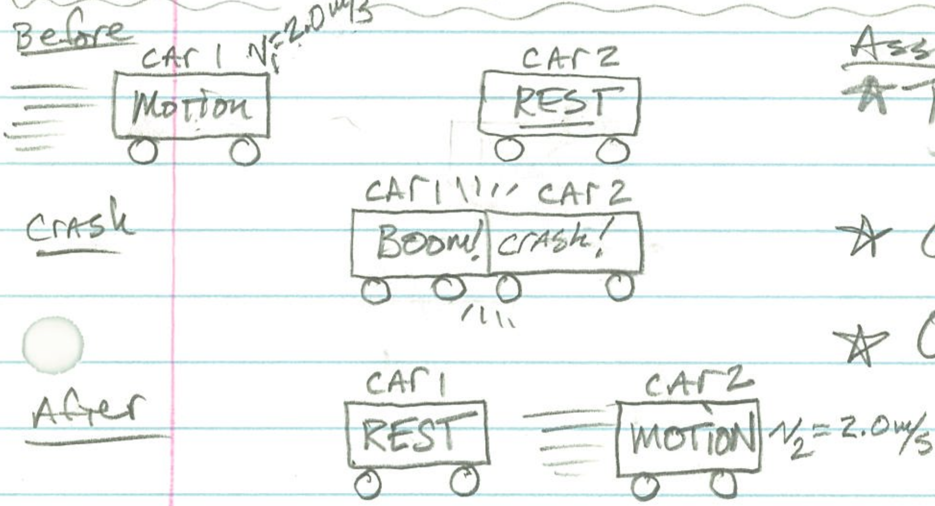
Newton's 3rd Law: Action & Reaction

"For Every Action Force, There is an equal and opposite Reaction Force. Forces come in pairs."

Momentum

~ Momentum has this idea too!

momentum of a system... Before Collision = momentum of the system After Collision



Assumptions:

★ The masses are the same.

★ Car 1 $v_1 = 2.0$ m/s (Before collision

★ Q: Car 2 velocity After collision equals?

$v_2 = 2.0$ m/s

The Law of Conservation of Momentum:

"The Momentum (p) of a System before an interaction, is equal to the momentum (p) of a system after an interaction."

Physics

Name
Date
Period

CH.7: Momentum

7.5 Collisions (and explosions)

"The Law of Conservation of Momentum" ~ Collisions of objects show the conservation of momentum very well...

~ Whenever objects collide in the absence of external forces, the net momentum of both objects before collision equals the net momentum of both objects after collision.

(use Newtonian Demonstrator) net momentum$_{\text{before collision}}$ = net momentum$_{\text{after collision}}$

* Elastic Collisions: When objects collide without being permanently deformed and without generating heat, the collision is said to be an elastic collision. (aka "non-sticky Collisions")

(See fig. 7.9) ~ Colliding objects bounce perfectly in perfect ellastic collisions. (Recall: Ideal World Conds ("IWC") vs. Real World Conds. ("RWC"))

Example: In Space

~ The sum of the momentum vectors are the same before and after each collision.

(use Newtonian Demonstrator)

(Elastic Coll. Equation) $\underbrace{m_{1B}V_{1B} + m_{2B}V_{2B}}_{\text{Before}} = \underbrace{m_{1A}V_{1A} + m_{2A}V_{2A}}_{\text{After}}$

* Inelastic Collisions: whenever colliding objects become tangled or couple together, an inelastic collision occurs (aka "Sticky Collisions")

$\underbrace{m_{1B}V_{1B} + m_{2B}V_{2B}}_{\text{Before}} = \underbrace{(m_{1A} + m_{2A})\,V_{1+2A}}_{\text{After}}$

(See fig. 7.10) ~ Momentum conservation holds true even when the colliding objects become distorted and generate heat during the collision.

(1)

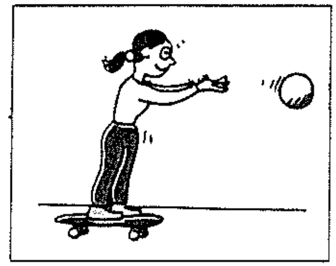
Explosion →

$m_{1B}V_{1B} + m_{2B}V_{2B} = \emptyset$

DOING PHYSICS

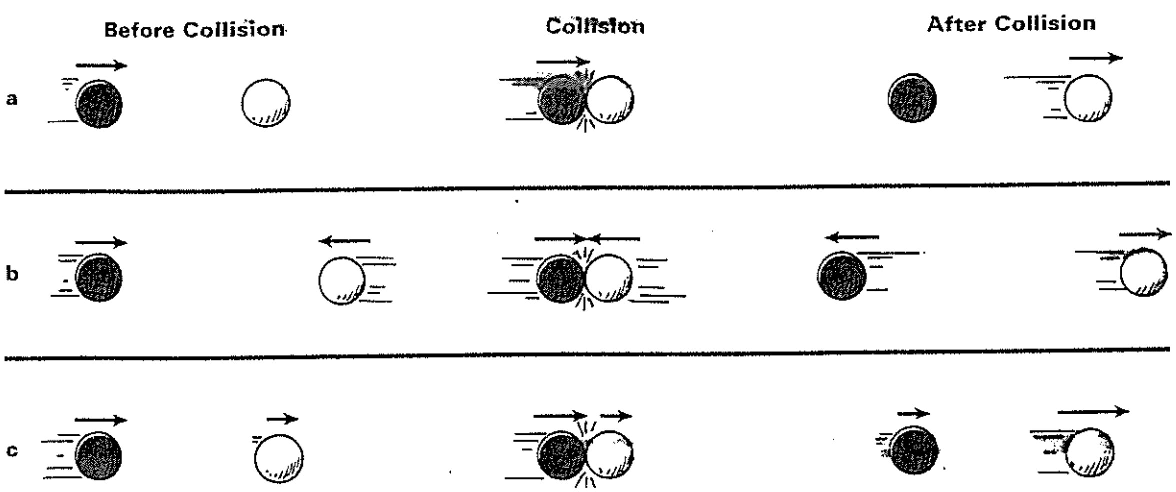
Skateboards and Momentum

Stand at rest on a skateboard and throw a massive object forward or backward. Notice that you recoil in the opposite direction. The recoil is understandable because the momentum before the throw is zero and the net momentum just after the throw is also zero. Your recoil momentum is equal and opposite to the momentum of the thrown object. Observe that momentum is conserved. Now repeat the throwing motion with the same object, but this time don't let go of it. Do you still recoil? Explain.



Activity

Figure 7.9 ▼
Elastic collisions. (a) A moving ball strikes a ball at rest. (b) A head-on collision between two moving balls. (c) A collision of two balls moving in the same direction. In all cases, momentum is simply transferred or redistributed without loss or gain.



Elastic Collisions

Inelastic Collisions

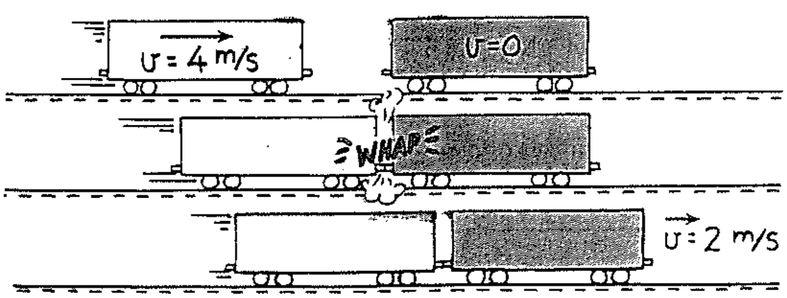


Figure 7.10 ▲
Inelastic collision. The momentum of the freight car on the left is shared with the freight car on the right.

(after looking at fig. 7.10)

net momentum$_{\text{before collision}}$ = net momentum$_{\text{after collision}}$

or

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

Inelastic Collision:

plug in the data, $m_{1B}V_{1B} + m_{2B}V_{2B} = (m_{1A} + m_{2A})V_{1+2A}$

$$(m)(4 m/s) + (m)(0 m/s) = (2m)(V_{after})$$

solve for (V_{after})

$$\frac{(m)(4m/s) + (m)(0 m/s)}{(2m)} = (V_{after})$$

$$\boxed{2 m/s = (V_{after})}$$

The initial momentum is shared by both cars without loss or gain. Momentum is conserved!

CH. 7 Momentum (The equations)

☆ Momentum – "Inertia in motion." Has all 3 of Newton's laws of motion w/in it.

Formulas / Equations:

		Units	
Momentum	$\rho = m \times v$	$\rho = kg \cdot m/s$	(momentum)
		$m = \_\_ kg$	(mass)
		$v = \_\_ m/s$	(velocity)
Impulse	$\text{Impulse} = \Delta Ft$	$F = \_\_ N$	(Force)
		$t = \_\_ s$	(time)
	$\Delta I = \Delta \rho$	$I = \_\_ N \cdot s$	(Impulse)
	$\Delta Ft = \Delta mv$		

Explosions

$$m_{1_B} v_{1_B} + m_{2_B} v_{2_B} = 0$$

Collisions

"non-sticky collisions" (Elastic Collisions)

$$m_{1_B} v_{1_B} + m_{2_B} v_{2_B} = m_{1_A} v_{1_A} + m_{2_A} v_{2_A}$$

"Sticky Collisions" (Inelastic Collisions)

$$m_{1_B} v_{1_B} + m_{2_B} v_{2_B} = (m_{1_A} + m_{2_A}) v_{1+2_A}$$

Explosion Example Problem #1:

$$m_{1B}V_{1B} + m_{2B}V_{2B} = 0$$

Knowns:

$m_1 = 0.5kg$

$m_2 = 1.0kg$

$V_{1B} = 0.0m/s$

$V_{2B} = 0.0m/s$

$V_{1A} = -1.0m/s$

$V_{2A} = +\,?$

Solve for V_{2A}

$- \leftarrow \quad \rightarrow +$

$$m_{1B}V_{1B} + m_{2B}V_{2B} = 0$$

$$\frac{+m_{1A}V_{1A}}{-m_{2A}} = \frac{-\cancel{m_{2A}}V_{2A}}{-\cancel{m_{2A}}}$$

$$\boxed{\frac{+m_{1A}V_{1A}}{-m_{2A}} = V_{2A}}$$

Plug & chug

$$\frac{+(0.5kg)(-1.0m/s)}{-(1.0kg)} = V_{2A}$$

$$\frac{-0.5kg\cdot m/s}{-1.0kg} = V_{2A}$$

$$\boxed{+0.5m/s = V_{2A}}$$

Explosion Example Problem #2:
w/ imaginary dynamite!

$$M_{1B}V_{1B} + M_{2B}V_{2B} = 0$$

Knowns:

$m_1 = 2.0\,kg$

$m_2 = 4.0\,kg$

$V_{1B} = 0\,m/s$

$V_{2B} = 0\,m/s$

$V_{1A} = -10\,m/s$

$V_{2A} = +\ ?$

Solve for V_{2A}:

$- \longleftarrow \qquad \longrightarrow +$

$$m_{1B}V_{1B} + m_{2B}V_{2B} = 0$$

$$\frac{+m_{1A}V_{1A}}{-m_{2A}} = \frac{-\cancel{m_{2A}}V_{2A}}{-\cancel{m_{2A}}}$$

$$\boxed{\frac{+m_{1A}V_{1A}}{-m_{2A}} = V_{2A}}$$

Plug & Chug

$$\frac{+(2.0\,kg)(-10\,m/s)}{-(4.0\,kg)} = V_{2A}$$

$$\frac{-20\,\cancel{kg}\cdot m/s}{-4.0\,\cancel{kg}} = V_{2A}$$

$$\boxed{V_{2A} = +5.0\,m/s}$$

Elastic Collision Example Problem #1:

$$m_{1B}V_{1B} + m_{2B}V_{2B} = m_{1A}V_{1A} + m_{2A}V_{2A}$$

Solve the equation for V_{2A} (1st!):

$$\frac{m_{1B}V_{1B} + m_{2B}V_{2B} - m_{1A}V_{1A}}{m_{2A}} = \frac{\cancel{m_{2A}}V_{2A}}{\cancel{m_{2A}}}$$

$$\boxed{\frac{m_{1B}V_{1B} + m_{2B}V_{2B} - m_{1A}V_{1A}}{m_{2A}} = V_{2A}}$$

Knowns:

$m_1 = 1.0\ kg$

$m_2 = 1.0\ kg$

$V_{1B} = 2.0\ m/s$

$V_{2B} = 0\ m/s$

$V_{1A} = 0\ m/s$

$V_{2A} = ?$

Now Plug & chug!!

$$\frac{(1.0\ kg)(2.0\ m/s) + 0 - 0}{(1.0\ kg)} = V_{2A}$$

$$\frac{(2.0\ \cancel{kg} \cdot m/s)}{(1.0\ \cancel{kg})} = V_{2A}$$

$$\boxed{2.0\ m/s = V_{2A}}$$

Elastic Collision Example Problem #2:

$$m_{1B}V_{1B} + m_{2B}V_{2B} = m_{1A}V_{1A} + m_{2A}V_{2A}$$

$$\frac{m_{1B}V_{1B} + m_{2B}V_{2B} - m_{1A}V_{1A}}{m_{2A}} = \frac{\cancel{m_{2A}}V_{2A}}{\cancel{m_{2A}}}$$

$$\boxed{\frac{m_{1B}V_{1B} + m_{2B}V_{2B} - m_{1A}V_{1A}}{m_{2A}} = V_{2A}}$$

$$\frac{(1.0kg)(2.0m/s) + 0 - 0}{(2.0kg)} = V_{2A}$$

$$\frac{2.0\,\cancel{kg}\cdot m/s}{2.0\,\cancel{kg}} = V_{2A}$$

$$\boxed{+1.0\,m/s = V_{2A}}$$

Knowns:

$m_1 = 1.0kg$

$m_2 = 2.0kg$

$V_{1B} = 2.0m/s$

$V_{2B} = 0\,m/s$

$V_{1A} = 0\,m/s$

$V_{2A} = ?$

★ Harder more "Real-World"

Elastic Collision Example Problem #3:

$$m_{1B}V_{1B} + m_{2B}V_{2B} = m_{1A}V_{1A} + m_{2A}V_{2A}$$

$$\frac{m_{1B}V_{1B} + m_{2B}V_{2B} - m_{1A}V_{1A}}{m_{2A}} = \frac{\cancel{m_{2A}}V_{2A}}{\cancel{m_{2A}}}$$

Knowns:

$m_1 = 1.0\,kg$

$m_2 = 2.0\,kg$

$V_{1B} = 3.75\,m/s$

$V_{2B} = 0.0\,m/s$

$V_{1A} = -0.25\,m/s$

$V_{2A} = +\,?$

$$\boxed{\frac{m_{1B}V_{1B} + m_{2B}V_{2B} - m_{1A}V_{1A}}{m_{2A}} = V_{2A}}$$

$$\frac{(1.0\,kg)(3.75\,m/s) + 0 - (1.0\,kg)(-0.25\,m/s)}{(2.0\,kg)} = V_{2A}$$

$$\frac{(3.75\,kg \cdot m/s) + 0 + (0.25\,m/s)}{2.0\,kg} = V_{2A}$$

$$\frac{(4.0\,\cancel{kg} \cdot m/s)}{(2.0\,\cancel{kg})} = V_{2A}$$

$$\boxed{+2.0\,m/s = V_{2A}}$$

Inelastic Collision Example Problem #1: (~~RailRoad~~ Cars)

$$m_{1B}V_{1B} + m_{2B}V_{2B} = (m_{1A} + m_{2A})\,V_{1+2A}$$

Knowns:

★ Railroad Car example from text.

$m_1 = 1000\ kg$

$m_2 = 1000.0\ kg$

$V_{1B} = 4.0\ m/s$

$V_{2B} = 0\ m/s$

$V_{1+2A} = ?$

Solve equation for V_{1+2A}:

$$\frac{m_{1B}V_{1B} + m_{2B}V_{2B}}{(m_{1A} + m_{2A})} = \frac{\cancel{(m_{1A} + m_{2A})}\,V_{1+2A}}{\cancel{(m_{1A} + m_{2A})}}$$

$$\boxed{\frac{m_{1B}V_{1B} + m_{2B}V_{2B}}{(m_{1A} + m_{2A})} = V_{1+2A}}$$

$$\frac{(1000\,kg)(4.0\,m/s) + 0}{(2000\,kg)} = V_{1+2A}$$

$$\frac{4000\,\cancel{kg}\cdot m/s}{2000\,\cancel{kg}} = V_{1+2A}$$

$$\boxed{+2.0\,m/s = V_{1+2A}}$$

Inelastic Collision Example Problem #2:

(Fish Problem) (see pg. 97 in text book)

$$m_{1B}V_{1B} + m_{2B}V_{2B} = (m_{1A} + m_{2A})V_{1+2A}$$

Knowns:

(Big Fish) $m_1 = 6.0\,kg$

(Small Fish) $m_2 = 2.0\,kg$

$V_{1B} = 1.0\,m/s$

$V_{2B} = 0\,m/s$

$V_{1+2A} = ?$

Solve for V_{1+2A}:

$$\frac{m_{1B}V_{1B} + m_{2B}V_{2B}}{(m_{1A} + m_{2A})} = \frac{\cancel{(m_{1A} + m_{2A})}V_{1+2A}}{\cancel{(m_{1A} + m_{2A})}}$$

$$\boxed{\frac{m_{1B}V_{1B} + m_{2B}V_{2B}}{m_{1A} + m_{2A}} = V_{1+2A}}$$

$$\frac{(6.0\,kg)(1.0\,m/s) + 0}{8.0\,kg} = V_{1+2A}$$

$$\frac{6.0\,\cancel{kg}\cdot m/s}{8.0\,\cancel{kg}} = V_{1+2A}$$

$$\boxed{+0.75\,m/s = V_{1+2A}}$$

Physics

CH. 7: Momentum

7.5 Collisions continued ("Ideal World Conds ("IWC") vs. "Real World Conds. ("RWC"))

~ Most collisions usually involve some external force.

Elastic Collisions

Example: Billiard balls do not continue indefinitely with the momentum given to them. The rolling balls encounter friction with the table and the air.

Another Example - Bowling

~ However, during the actual collision these forces are negligible.

Inelastic Collision (lots of friction)

~ another example, the net momentum of two trucks colliding is the same before and just after the collision. The combined wreck slides along the pavement and friction provides an impulse to decrease this momentum.

(No Friction)

~ However two space vehicles docking in space, have the same net momentum just before and just after contact. This is an idealized collision. The only thing affecting the collision is gravity (microgravity). There is no air resistance in space!

Demo with Air Track

(See Fig. 7.11 and Questions on pg. 96)

~ Go over the Fish story in Problem Solving on pg. 97

(1) ~ See Next Time Question 7-1 (Jocko & The Ball)

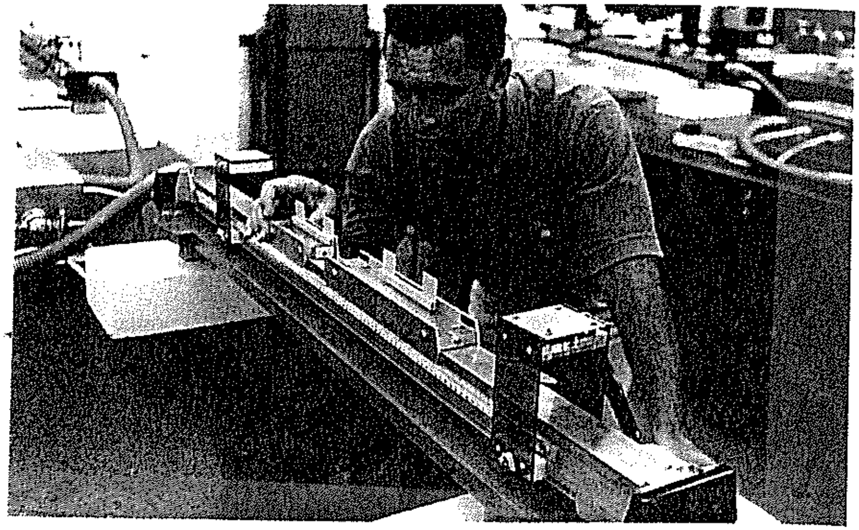


Figure 7.11 ▶
Conservation of momentum is nicely demonstrated with the use of an air track. Many small air jets provide a nearly frictionless cushion of air for the gliders to slide on.

Questions

Refer to the gliders on the air track in Figure 7.11 to answer the questions.

1. Suppose both gliders have the same mass. They move toward each other at the same speed and experience an elastic collision. Describe the motion after the collision.
2. Suppose both gliders have the same mass and stick together when they collide. The gliders move toward each other at equal speed. Describe their motion after the collision.
3. Suppose one glider is at rest and is loaded so that it has three times the mass of the moving glider. Again, the gliders stick together when they collide. Describe their motion after the collision.

Answers

1. Since the collision is elastic, the gliders reverse directions after colliding and move away from each other at a speed equal to their initial speed.
2. Before the collision, the gliders have equal and opposite momenta because their equal masses are moving in opposite directions at the same speed. The net momentum of the two gliders as a system is zero. Since momentum is conserved, their net momentum after sticking together must also be zero. They slam to a dead halt.
3. Before collision, the net momentum equals the momentum of the unloaded, moving glider. After the collision, the net momentum is the same as before, but now the gliders are stuck together and moving as a single unit. The mass of the stuck-together gliders is four times that of the unloaded glider. Thus, the postcollision velocity of the stuck-together gliders is one-fourth of the unloaded glider's velocity before collision. This velocity is in the same direction as before, since the direction as well as the amount of momentum is conserved.

Problem Solving

Consider a 6-kg fish that swims toward and swallows a 2-kg fish that is at rest. If the larger fish swims at 1 m/s, what is its velocity immediately after lunch? Momentum is conserved from the instant before lunch until the instant after (in so brief an interval, water resistance does not have time to change the momentum), so we can write

$$\text{net momentum}_{\text{before lunch}} = \text{net momentum}_{\text{after lunch}}$$

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(0\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$

$$6\text{ kg·m/s} = (8\text{ kg})(v_{\text{after}})$$

$$v_{\text{after}} = \frac{6\text{ kg·m/s}}{8\text{ kg}}$$

$$v_{\text{after}} = \frac{3}{4}\text{ m/s}$$

We see that the small fish has no momentum before lunch because its velocity is zero. Using simple algebra we see that after lunch the combined mass of the two-fish system is 8 kg and its speed is $\frac{3}{4}$ m/s in the same direction as the large fish's direction before lunch.

Suppose the small fish is not at rest but is swimming toward the large fish at 2 m/s. Now we have opposing directions. If we consider the direction of the large fish as positive, then the velocity of the small fish is –2 m/s. We pay attention to the negative sign and see that

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(-2\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$

$$(6\text{ kg·m/s}) + (-4\text{ kg·m/s}) = (8\text{ kg})(v_{\text{after}})$$

$$\frac{2\text{ kg·m/s}}{8\text{ kg}} = v_{\text{after}}$$

$$v_{\text{after}} = \frac{1}{4}\text{ m/s}$$

The negative momentum of the small fish is very effective in slowing the large fish. If the small fish were swimming at –3 m/s, then both fish would have equal and opposite momenta. Zero momentum before lunch would equal zero momentum after lunch, and both fish would come to a halt.

More interestingly, suppose the small fish swims at –4 m/s.

Emphasize the negative sign for the opposite direction. Stress the vector nature of momentum.

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(-4\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$

$$(6\text{ kg·m/s}) + (-8\text{ kg·m/s}) = (8\text{ kg})(v_{\text{after}})$$

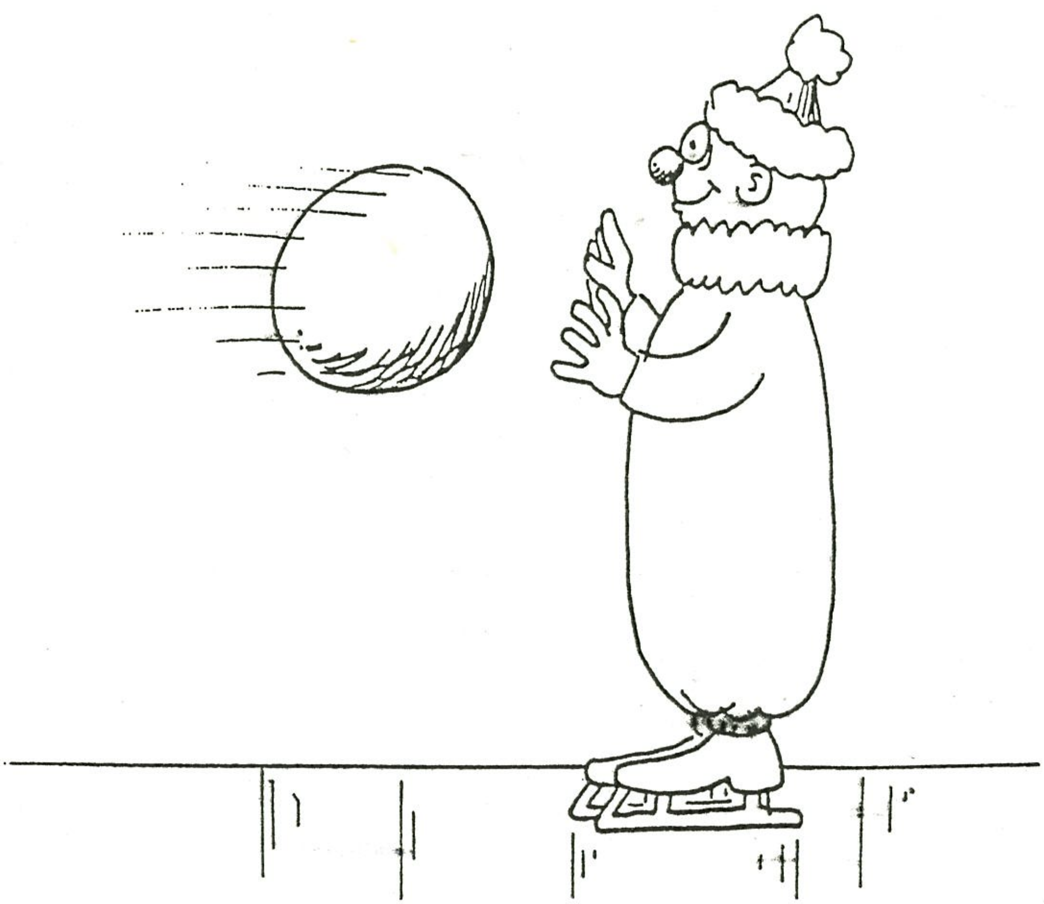
$$\frac{-2\text{ kg·m/s}}{8\text{ kg}} = v_{\text{after}}$$

$$v_{\text{after}} = -\frac{1}{4}\text{ m/s}$$

The minus sign tells us that after lunch the two-fish system moves in a direction opposite to the large fish's direction before lunch.

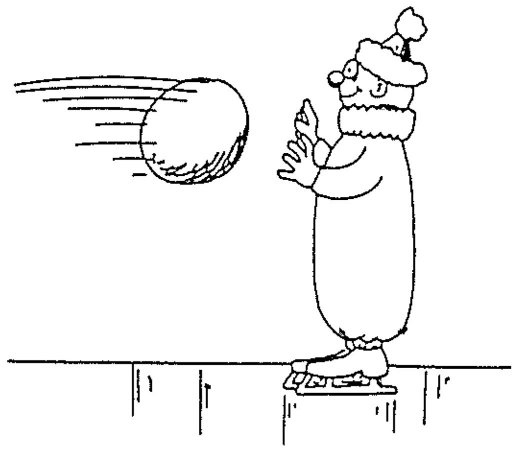
7-1 Conceptual **PHYSICS**
Next-Time Question

JOCKO, WHO HAS A MASS OF 60 kg AND STANDS AT REST ON ICE, CATCHES A 20 kg BALL THAT IS THROWN TO HIM AT 10 km/h. HOW FAST DOES JOCKO AND THE BALL MOVE ACROSS THE ICE?



Conceptual PHYSICS Next-Time Question

JOCKO, WHO HAS A MASS OF 60 kg AND STANDS AT REST ON ICE, CATCHES A 20 kg BALL THAT IS THROWN TO HIM AT 10 km/h. HOW FAST DOES JOCKO AND THE BALL MOVE ACROSS THE ICE?



ANSWER:

THE MOMENTUM BEFORE THE CATCH IS ALL IN THE BALL, 20 kg × 10 km/h = 200 kg·km/h. THIS IS ALSO THE MOMENTUM AFTER THE CATCH, WHERE THE MOVING MASS IS 80 kg--- 60 kg FOR JOCKO AND 20 kg FOR THE CAUGHT BALL.

$$80\text{ kg} \times v = 200\text{ kg}\cdot\text{km/h}$$

$$v = \frac{200\text{ kg}\cdot\text{km/h}}{80\text{ kg}} = 2.5\text{ km/h}$$

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~ Perfectly elastic collisions are not common in the everyday world. We find in practice that some heat is generated during collisions.

- Heat
- Sound
- friction

Example: ~ Drop a ball and bounce it off the floor. Both the ball and the floor are a bit warmer. (Can you feel it!)
~ Even a superball will not bounce to its initial height. Why?

~ However, at an atomic level perfectly elastic collisions are commonplace. Electrically charged particles bounce off one another w/out generating heat. They don't even touch! How is this possible? They bounce but they don't touch? You'll see later why.

— In space you can have "Ideal World" examples of momentum conservation. ("IWC")

— macro-scale examples on Earth are "Real World," hence momentum leaks through heat, sound, and friction. ("RWC")

— At the atomic level (or scale) you can have "Ideal World Conds." or Collisions.

Physics

CH. 7 Momentum

7.6 Momentum Vectors

[Vectors
$\longrightarrow$ direction ($\rightarrow$)
|— magnitude —|]

~ Momentum is conserved even when interacting objects don't move along the same straight line.

-graphical
-Pyth. Theorem
-Trig.

~ To analyze momentum in any direction we use the vector techniques we've previously learned. (use graphical techniques or mathematical techniques)

~ keep in mind like velocity, momentum is a vector quantity. It has magnitude & direction, so it can easily be represented by a vector.

Recall: $p = m \cdot v$

and can be represented by a $\longrightarrow$.

~ Let's look at three examples.

(Fig. 7.12 on pg. 98) (The resultant is $\sqrt{2}$ times the momentum of each car before the collision)

(Fig. 7.13 on pg. 99)

(Fig. 7.14 on pg. 99)

Big Idea!

~ Conservation of momentum, and in Chap. 8 the conservation of energy, are two of the most powerful tools of mechanics (the study of motion, matter, and energy interactions). The application of mechanics helps to understand the interactions of subatomic particles to entire galaxies. (micro to megascale)

-micro - macro - mega

The End

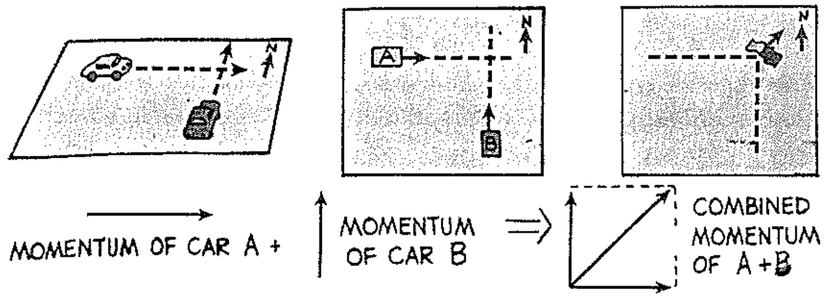


Figure 7.12 ▲
Momentum is a vector quantity. The momentum of the wreck is equal to the vector sum of the momenta of car A and car B before the collision.

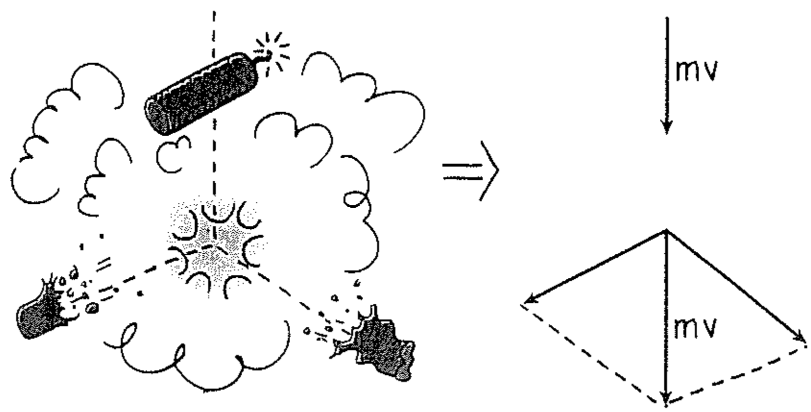
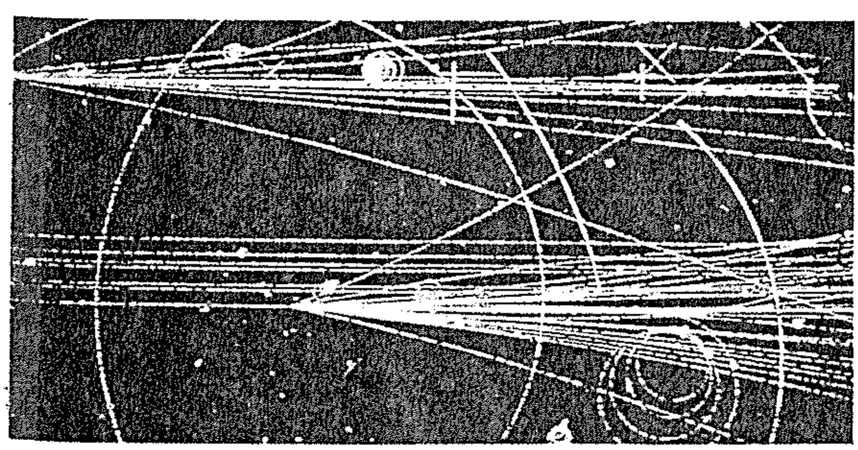


Figure 7.13 ▲
When the firecracker bursts, the vector sum of the momenta of its fragments add up to the firecracker's momentum just before bursting.



◀ **Figure 7.14**
Momentum is conserved for the high-speed elementary particles, as shown by the tracks they leave in a bubble chamber. The relative mass of the particles is determined by, among other things, the paths they take after collision.