MOMENTUM

Objectives

• Define momentum. (8.1)

• Define impulse and describe

 how it affects changes in

 momentum. (8.2)

• Explain why an impulse is

 greater when an object bounces

 than when the same object

 comes to a sudden stop. (8.3)

• State the law of conservation

 of momentum. (8.4)

• Describe how the conservation

 of momentum applies to

 collisions. (8.5)

• Describe how the vector nature

 of momentum affects the law

 of conservation of momentum.

 (8.6)

8 MOMENTUM

THE BIG

IDEA

Momentum is conserved

for all collisions as long

as external forces don’t

interfere.

discover!

MATERIALS

five marbles, ruler

 When a

marble or marbles collide

with the marbles at rest, the

momentum is the same before

and after the collision. As a

result, the same number of

marbles emerges at the same

speed on the other side.

EXPECTED OUTCOME

ANALYZE AND CONCLUDE

 ave you ever wondered how a tae kwon do expert

 can break a stack of cement bricks with the blow

 of a bare hand? Or why falling on a wooden floor

hurts less than falling on a cement floor? Or why follow-

through is important in golf, baseball, and boxing? To

understand these things, you need to recall the concept

of inertia introduced and developed when we discussed

Newton’s laws of motion. Inertia was discussed both in

terms of objects at rest and objects in motion. In this chap-

ter we are concerned only with the concept of inertia in

motion—momentum.

H

discover!

How Does a Collision Affect the Motion

of Marbles?

1. Place five marbles, all identical in size and

 shape, in the center groove of a ruler. Launch

 a sixth marble toward the five stationary

 marbles. Note any changes in the marbles’

 motion.

2. Now launch two marbles at four stationary

 marbles. Then launch three marbles at three

 stationary marbles, and so on. Note any

 changes in the marbles’ motion.

3. Remove all but two marbles from the groove.

 Roll these two marbles at each other with

 equal speeds. Note any changes in the

 marbles’ motion.

1. When one marble collides

 with 5 marbles, the colliding

 marble stops and one

 marble emerges at the same

 speed on the other side.

 When 2 marbles collide

 with 4 marbles, 2 marbles

 emerge at the same speed.

 The pattern continues with

 more marbles.

2. The speed and number of

 marbles

3. Three marbles move to the

 right and two marbles move

 to the left.

Analyze and Conclude

1. Observing How did the approximate speed

 of the marbles before each collision compare

 to after each collision?

2. Drawing Conclusions What factors determine

 how the speed of the marbles changes in a

 collision?

3. Predicting What do you think would hap-

 pen if three marbles rolling to the right and

 two marbles rolling to the left with the same

 speed were to collide?

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8.1 Momentum

FIGURE 8.1

A truck rolling down a

hill has more momentum

than a roller skate with

the same speed. But if

the truck is at rest and

the roller skate moves,

then the skate has more

momentum.

Key Term

momentum

 Teaching Tip State that just

as a large truck and a roller skate

have different masses, a moving

large truck and a moving roller

skate have different momenta.

Define and discuss momentum as

moving mass—inertia in motion.

 Ask Will a large truck always

have more momentum than a

roller skate? No, a large truck at

rest has no momentum. A moving

roller skate has momentum.

 A moving object

CHECK can have a large

momentum if it has a large mass,

a high speed, or both.

CONCEPT

8.1 Momentum

We know that it’s harder to stop a large truck than a small car when

both are moving at the same speed. We say the truck has more

momentum than the car. By momentum, we mean inertia in motion.

More specifically, momentum is the mass of an object multiplied by

its velocity.

momentum

or, in abbreviated notation,

momentum

momentum

mass

mv

speed

When direction is not an important factor, we can say

which we still abbreviate mv.

 A moving object can have a large momentum if it has a large

mass, a high speed, or both. A moving truck has more momentum

than a car moving at the same speed because the truck has more

mass. But a fast car can have more momentum than a slow truck.

And a truck at rest has no momentum at all. Figure 8.1 compares the

momentum of a truck to that of a roller skate.

CONCEPT

mass

velocity

Can you think of a case

where the roller skate and

the truck shown in Figure

8.1 would have the same

momentum?

Answer: 8.1

Teaching Resources

• Reading and Study

 Workbook

• PresentationEXPRESS

• Interactive Textbook

• Next-Time Question 8-1

• Conceptual Physics Alive!

 DVDs Momentum

8.2 Impulse Changes

Momentum

Key Term

impulse

 Common Misconceptions

Impulse equals momentum.

 Impulse equals change in

momentum.

FACT

......

CHECK

What factors affect an object’s momentum?

8.2 Impulse Changes Momentum

If the momentum of an object changes, either the mass or the veloc-

ity or both change. If the mass remains unchanged, as is most often

the case, then the velocity changes and acceleration occurs. What pro-

duces acceleration? We know the answer is force. The greater the force

acting on an object, the greater its change in velocity, and hence, the

greater its change in momentum.

CHAPTER 8

MOMENTUM

 Teaching Tip Derive the

impulse–momentum relationship.

Equate the two definitions of

acceleration: F/m 5 Dv/t. A simple

algebraic rearrangement yields

Ft 5 D(mv).

......

think!

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 Teaching Tip Choose

your examples of changing

momentum in careful sequence.

First, describe those where

the objective is to increase

momentum (e.g., pulling a sling

shot or arrow in a bow all the

way back, the effect of a long

cannon for maximum range,

and driving a golf ball). Second,

describe cases in which the

objective is to minimize a force

when decreasing momentum

(e.g., pulling your hand backward

when catching a ball, driving into

a haystack vs. into a concrete

wall, and falling on a spongy

surface rather than on a rigid

one). Last, describe examples

where the objective is to

maximize forces when decreasing

momentum (e.g., karate chops).

The derivation of

Ft(mv) is given in

Appendix G, Note 8.2.

ImpulseThe change in momentum depends on the force that

acts and the length of time it acts. As Figure 8.2 shows, 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 an object’s momentum.

FIGURE 8.2

When you push with the

same force for twice the

time, you impart twice

the impulse and produce

twice the change in

momentum.

 The quantity force

hand notation,

time interval is called impulse. In short-

impulse

Ft

The greater the impulse exerted on something, the greater will be the

change in momentum. The exact relationship8.2 is

impulse

change in momentum

 or

Ft(mv)

 The impulse–momentum relationship helps us to analyze a

variety of situations where the momentum changes. Consider the

familiar examples of impulse in the following cases of increasing and

decreasing momentum.

Increasing Momentum To increase the momentum of an object,

it makes sense to apply the greatest force possible for as long as pos-

sible. 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 fol-

low through with their swing.

 The forces involved in impulses usually vary from instant to

instant. Look at Figure 8.3. 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. The force then

diminishes as the ball comes up to speed and returns to its original

shape. So when we speak of such forces in this chapter, we mean the

average force.

Many interactions that are

explainable by Newton’s third

law can also be explained

by momentum conservation.

Newton’s laws flow nicely into

momentum and its conservation.

FIGURE 8.3

The force of impact on a

golf ball varies throughout

the duration of impact.

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FIGURE 8.4

If the change in momentum occurs over

a long time, the force of impact is small.

 Teaching Tip Use the loose

coupling between railroad cars

as a very good example of the

impulse–momentum relationship.

The slack in the coupling of

railroad cars is evident when a

locomotive either brings a long

train from rest into motion, or

when it brings a moving train

to rest.

Decreasing Momentum If you were in a car that was out of

control and had to choose between hitting a haystack, as in Figure

8.4 or a concrete wall as in Figure 8.5, 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 contact

time—the time during which your momentum is brought to zero. A

longer contact time reduces the force and decreases the resulting

deceleration. For example, if the time is extended 100 times, the force

of impact is reduced 100 times. Whenever we wish the force to be

small, we extend the time.

 We know that a padded dashboard in a car is safer than a rigid

metal one and that airbags save lives. You 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 mak-

ing contact with the ball. When you extend the time of contact, you

reduce the force of the catch.

think!

When a dish falls, will the

impulse be less if it lands

on a carpet than if it lands

on a hard floor?

Answer: 8.2.1

In both cases a cascade of clanks

is heard as each car in turn is

engaged. Without the loose

coupling, a locomotive might

simply sit still and spin its wheels.

The friction force between the

wheels and the track is simply

inadequate to set the entire mass

of the train in motion. There is,

however, enough friction to set

one car in motion so the slack

allows the locomotive to get

one car going. Then, when the

coupling is tight, the next car is

set in motion. When the coupling

for two cars is tight, the third

car is set in motion, and so on

until the whole train is given

momentum. The slack allows the

required impulse to be broken

into a series of smaller impulses,

so that the friction between the

locomotive wheels and the track

can do the job.

 Ask Why is falling on a floor

with more give less dangerous

than falling on a floor with less

give? Because the floor with

more give allows a greater time

for the impulse that reduces

the momentum of fall to zero.

A greater time for a change in

momentum results in less force.

FIGURE 8.5

If the change in momentum occurs over a

short time, the force of impact is large.

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 Teaching Tip Have your

students design and construct a

case to hold an egg that is to be

dropped from a three- or four-

story building without breaking.

Be sure students see that the

key consideration is maximizing

the time of impact in order to

minimize the force of impact.

The design cannot include means

to increase air resistance, so all

cases should strike the ground

with about the same speed. By

requiring the masses of all cases

to be the same, the impulses

of all will be the same upon

impact. The force of impact, of

course, should be minimized by

maximizing the time of impact.

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(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

twice their original length during the fall.

Whether body A acts

on body B, or body

B acts on body A,

in accordance with

Newton’s third law,

both have the same

amount of impulse Ft.

 When jumping from an elevated position down to the ground,

you should bend your knees when your feet make contact with the

ground. By doing so you extend the time during which your momen-

tum decreases by 10 to 20 times that of a stiff-legged, abrupt land-

ing. 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 hitting the

mat by relaxing his muscles and spreading the impulse 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 stopping time.

 When a boxer gets punched, the impulse provided by the boxer’s

jaw must counteract the momentum of the punch. As Figure 8.6a

shows, when the boxer moves away from the punch, he increases the

time of contact and reduces the force. When the boxer moves toward

the punch, as in Figure 8.6b, the time of contact is reduced and the

force is increased.

 The change in

CHECK momentum depends

on the force that acts and the

length of time it acts.

CONCEPT

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Teaching Resources

• Reading and Study

 Workbook

• Problem-Solving Exercises in

 Physics 5-1

• Laboratory Manual 23

• Transparency 11

• PresentationEXPRESS

• Interactive Textbook

think!

If the boxer in Figure 8.6

is able to make the con-

tact time five times lon-

ger by “riding” with the

punch, how much will the

force of the punch impact

be reduced?

Answer: 8.2.2

FIGURE 8.6

The impulse provided by a boxer’s jaw counteracts

the momentum of the punch. a. The boxer moves

away from the punch. b. The boxer moves toward

the punch. Ouch!

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8.3 Bouncing

 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 enough. A deeper explanation is needed.

 To bring the dish or its fragments to rest, the carpet or the side-

walk must provide an impulse, which you know involves two vari-

ables—force and time. Since time is longer hitting the carpet than

hitting the sidewalk, a smaller force results. The shorter time hitting

the sidewalk results in a greater stopping force. The safety net used

by circus acrobats is a good example of how to achieve the impulse

needed for a safe landing. The safety net reduces the stopping force

on a fallen acrobat by substantially increasing the time interval of the

contact.

 Sometimes a difference in 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.

A flower pot dropped

onto your head

bounces quickly. Ouch!

If bouncing took a

longer time, as with

a safety net, then the

force of the bounce

would be much smaller.

 Teaching Tip Explain that the

magnitude of an impact force

when bouncing occurs depends

on impact time. For an elastic

collision where momentum is

reversed, and D(mv) is twice

that of merely halting, impulse

is doubled. Although impulse is

greater for bouncing, impact may

or may not depend on time.

 Teaching Tip Explain that if

the impulse is over a short time,

impact force is large.

A karate expert does not pull

back upon striking his target.

He strikes in such a way that

his hand is made to bounce

back, yielding up to twice the

impulse to his target.

......

CONCEPT What factors affect how much an object’s

CHECK

momentum changes?

Demonstration

Tape some toothpicks to one

side of a floppy disk box. Fire

a dart from a dart gun against

the smooth side of the box.

The dart sticks and the box

slides an observed distance

across the table. Then repeat,

but with the box turned

around so the dart hits the

toothpick side. When the

dart hits, it bounces. Note the

appreciably greater distance

the box slides!

8.3 Bouncing

If a flower pot falls from a shelf onto your head, you

may be in trouble. If it bounces from your head,

you may be in more serious trouble. Why? Because

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. Suppose, for example, that you catch the fall-

ing pot with your hands. You provide an impulse

to reduce its momentum to zero. If you throw the

pot upward again, you have to provide additional

impulse. It takes a greater impulse to catch the pot

and throw it back up than merely to catch it. This

increased amount of impulse is supplied by your

head if the pot bounces from it. The karate expert in

Figure 8.7 strikes the bricks in such a way that her

hand is made to bounce back, yielding as much as

twice the impulse to the bricks.

FIGURE 8.7

Cassy imparts a large impulse to the bricks in

a short time and produces considerable force.

 The impulse required

CHECK 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.

CONCEPT

......

CHAPTER 8

MOMENTUM

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8.4 Conservation of

Momentum

Key Term

law of conservation of momentum

Either Newton’s third law or

momentum conservation can be

considered fundamental. That

is, momentum conservation can

be a consequence of Newton’s

third law, or just as well,

Newton’s third law can be a

consequence of momentum

conservation.

FIGURE 8.8

The curved blades of the

Pelton Wheel cause water to

bounce and make a U-turn,

producing a large impulse

that turns the wheel.

 Teaching Tip Distinguish

between external forces

and internal forces (e.g., the

difference between sitting

inside a car and pushing on the

dashboard and standing outside

and pushing against the outside

of the car). Point out that only

an external force will produce a

change in the momentum of the

car. When F 5 0, D(mv) 5 0.

 Teaching Tip Discuss the

idea of isolating a system when

applying the conservation of

momentum. We isolate a system

in space by imagining a dotted

boundary line around the

perimeter of the system, and

we isolate a system in time by

considering only the duration of

the interaction.

 The fact that impulses are greater when bouncing takes place was

used with great success during the California Gold Rush. The water-

wheels used in gold mining operations were not very effective. A man

named Lester A. Pelton saw that the problem had to do with the flat

paddles on the waterwheel. He designed the curve-shaped paddle

that is shown in Figure 8.8. This paddle caused the incoming water

to make a U-turn upon impact with the paddle. Because the water

“bounced,” the impulse exerted on the waterwheel was increased.

Pelton patented his idea and probably made more money from his

invention, the Pelton Wheel, than any of the gold miners earned.

Physics can indeed make you rich!

CHECK

......

CONCEPT How does the impulse of a bounce compare to

stopping only?

8.4 Conservation of Momentum

From Newton’s second law you know that to accelerate an object,

a net force must be applied to it. This chapter says much the same

thing, but in different language. If you wish to change the momen-

tum of an object, exert an impulse on it.

 In either case, the force or impulse must be exerted on the object

by something outside the object. Internal forces won’t work. For

example, the molecular forces within a basketball have no effect on

the momentum of the basketball, just as a push against the dash-

board of a car you’re sitting in does not affect the momentum of the

car. Molecular forces within the basketball and a push on the dash-

board are internal forces. They come in balanced pairs that cancel

within the object. To change the momentum of the basketball or the

car, an outside push or pull is required. If no outside force is present,

no change in momentum is possible.

FIGURE 8.9

Show that where momentum

may be conserved for a particular

system, it may not be conserved

for part of the system.

Teacher Howie Brand

shows that the block

topples when the swing-

ing dart bounces from

it. When he removes the

rubber head of the dart

so it doesn’t bounce

when it hits the block, no

toppling occurs.

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 Consider the cannon being fired in Figure 8.10. The force on

the cannonball inside the cannon barrel is equal and opposite to the

force causing the cannon to recoil. Recall Newton’s third law about

action and reaction forces. These forces are internal to the system

comprising the cannon and the cannonball, so they don’t change

the momentum of the cannon–cannonball system. Before the firing,

the system is at rest and the momentum is zero. After the firing the

net momentum, or total momentum, is still zero. Net momentum

is neither gained nor lost. Let’s consider the effects of internal and

external forces carefully.

FIGURE 8.10

The momentum before fir-

ing is zero. After firing, the

net momentum is still zero

because the momentum

of the cannon is equal and

opposite to the momentum

of the cannonball.

Most of the cannon-

ball’s momentum is

in speed; most of the

recoiling cannon’s

momentum is in mass.

 mv .So mv

 Momentum, like the quantities velocity and force, has both direc-

tion and magnitude. It is a vector quantity. Like velocity and force,

momentum can be canceled. So, although the cannonball in the

preceding example gains momentum when fired and the recoiling

cannon gains momentum in the opposite direction, the cannon–can-

nonball system gains none. The momenta (plural form of momen-

tum) of the cannonball and the cannon are equal in magnitude and

opposite in direction. Therefore, these momenta cancel each other

out for the system as a whole. No external force acted on the system

before or during firing. Since no net force acts on the system, there

is no net impulse on the system and there is no net change in the

momentum.

 In every case, the momentum of a system cannot change unless it

is acted on by external forces. A system will have the same momentum

before some internal interaction as it has after the interaction occurs.

When momentum, or any quantity in physics, does not change, we say

it is conserved. The law of conservation of momentum describes the

momentum of a system. The law of conservation of momentum

states that, in the absence of an external force, the momentum of a

system remains unchanged. If a system undergoes changes wherein

all forces are internal as for example in atomic nuclei undergoing

radioactive decay, cars colliding, or stars exploding, the net momen-

tum of the system before and after the event is the same.

 Teaching Tip Consider a

dropped rock in free fall. If the

system is taken to be the rock,

then momentum is not conserved

as it falls because an external

force acts on the system (its

vector is seen to penetrate the

dotted border of the system).

This external force, gravity,

produces an impulse on the rock

that changes its momentum. If

the system is instead considered

to be the rock and Earth, then

the interaction between the

rock and Earth is internal to the

system (there is no penetrating

vector). For this larger system,

momentum is conserved. That

is, the momentum of Earth as it

“races up” to meet the falling

rock is equal and opposite to

the momentum of the rock as it

drops to meet Earth (at its center

of mass). The momentum of any

interaction is always conserved

if you make your system big

enough.

Demonstration

For: Links on momentum

Visit: www.SciLinks.org

Web Code: csn – 0804

think!

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?

Answer: 8.4

Use the popular swinging balls

apparatus to demonstrate

momentum conservation.

Show students that when the

balls on one

side are lifted

and released

so they make

contact with

the others, the

momentum

of balls is the

same before and after the

collision—the same number

of balls emerge at the same

speed on the other side.

CHECK

......

CONCEPT What does the law of conservation of

momentum state?

CHAPTER 8

MOMENTUM

 The law of

CHECK conservation of

momentum states that, in the

absence of an external force,

the momentum of a system

remains unchanged.

CONCEPT

......

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discover!

MATERIALS

skateboard, heavy

object

 You only

move when you release the

object.

EXPECTED OUTCOME

 In both Steps 1 and 2,

the total momentum is zero.

In order for momentum to be

conserved in Step 1, you must

move in the opposite direc-

tion that the object moves. In

order for the total momentum

to be conserved in Step 2, you

must stay at rest because the

object does not move away.

THINK

A conservation law

is constancy during

change. Conservation

laws are a source of

deep insights into the

simple regularity of

nature and are often

considered the most

fundamental of physical

laws.

discover!

How Are Motion and Conservation

of Momentum Related?

1. Stand at rest on a skateboard and

 throw a massive object forward or

 backward. What do you notice?

2. Repeat the throwing motion in Step

 1, but this time don’t let go of the

 object. What do you notice?

3. Think How is the difference in your motion in Steps 1 and 2 related

 to conservation of momentum?

8.5 Collisions

Teaching Resources

• Reading and Study

 Workbook

• Probeware Lab Manual 6

• PresentationEXPRESS

• Interactive Textbook

The collision of objects clearly shows the conservation of momen-

tum. Whenever objects collide in the absence of external forces,

the net momentum of both objects before the collision equals the

net momentum of both objects after the collision.

net momentum before collision

net momentum after collision

8.5 Collisions

Key Terms

elastic collision, inelastic collision

 Common Misconceptions

Momentum is conserved only when

collisions are perfectly elastic.

 Even in an inelastic collision,

the net momentum before the

collision is equal to the net

momentum after the collision.

FACT

FIGURE 8.11

Colliding objects bounce

perfectly in elastic collisions.

a. A moving ball strikes a

ball at rest. b. Two moving

balls collide head-on.

c. Two balls moving in the

same direction collide.

Elastic Collisions When a moving billiard ball collides head-on

with a ball at rest, the first ball comes to rest and the second ball

moves away with a velocity equal to the initial velocity of the first

ball. We see that momentum is transferred from the first ball to

the second ball. When objects collide without being permanently

deformed and without generating heat, the collision is said to be an

elastic collision. Colliding objects bounce perfectly in perfect elastic

collisions, as shown in Figure 8.11. Note that the sum of the momen-

tum vectors is the same before and after each collision.

Collision

After Collision

Before Collision

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Inelastic Collisions A collision in which the colliding objects

become distorted and generate heat during the collision is an

inelastic collision. Momentum conservation holds true even in inelas-

tic collisions. Whenever colliding objects become tangled or couple

together, a totally inelastic collision occurs. The freight train cars in

Figure 8.12 provide an example. Suppose the freight cars are of equal

mass m, and that one car moves at 4 m/s toward the other car that is

at rest. Can you predict the velocity of the coupled cars after impact?

From the conservation of momentum,

Momentum is con-

served for all collisions,

elastic and inelastic

(when there are no

external forces to

provide net impulse).

 Teaching Tip Distinguish

between elastic (bouncy) and

inelastic (sticky) collisions. Point

out that when no external forces

act on a system, no change in the

total momentum of that system

occurs.

 Teaching Tip For the case of

equal-mass carts in an inelastic

collision (Figure 8.12), go over

the equation in the middle of

the page in detail. Write similar

equations for the collisions you

demonstrate on the air track so

students will relate the equations

to visual examples. Have your

students write the equations

for other examples you show. In

writing the equations for head-

on collisions, be careful to show

velocities in one direction as

positive and oppositely-directed

velocities as negative. For

example, the equation for Figure

8.11b is [mv 1 m(2v)]before 5

[m(2v) 1 mv]after. In both the

before and after cases, the net

momentum is zero.

net momentum before collision

or, in equation form,

(net mv)before

(m)(4 m/s)

net momentum after collision

(net mv)after

(2m)(vafter)

(m)(0 m/s)

 Since twice as much mass is moving after the collision, can you

see that the velocity, vafter, must be one half of 4 m/s? Solving for the

velocity after the collision, we find vafter 2 m/s in the same direction

as the velocity before the collision, vbefore. The initial momentum is

shared by both cars without loss or gain. Momentum is conserved.

FIGURE 8.12

In an inelastic collision

between two freight cars,

the momentum of the

freight car on the left is

shared with the freight car

on the right.

 Most collisions usually involve some external force. Billiard balls

do not continue indefinitely with the momentum imparted to them.

The moving balls encounter friction with the table and the air. These

external forces are usually negligible during the collision, so the net

momentum does not change during collision. The net momentum of

two colliding trucks is the same before and just after the collision. As

the combined wreck slides along the pavement, friction provides an

impulse to decrease its momentum. Similarly, a pair of space vehicles

docking in orbit have the same net momentum just before and just

after contact. Since there is no air resistance in space, the combined

momentum of the space vehicles after docking is then changed only

by gravity.

For: Momentum activity

Visit: PHSchool.com

Web Code: csp – 1085

CHAPTER 8

MOMENTUM

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Demonstration

Show examples of momentum

conservation in both elastic

and inelastic collisions using

carts on an air track. If you

represent the collisions on the

board, use the exaggerated

symbol technique (big m,

little v, and vice versa).

FIGURE 8.13

An air track nicely demonstrates conservation of

momentum. Many small air jets provide a nearly fric-

tionless cushion of air for the gliders to slide on.

 Whenever objects

CHECK collide in the absence

of external forces, the net

momentum of both objects

before the collision equals the

net momentum of both objects

after the collision.

CONCEPT

Pucks and carts ride

nearly free of friction

on cushions of air on

air tracks like the one

shown in Figure 8.13.

Galileo worked hard

to produce smooth

surfaces to minimize

friction. How he would

have loved to experi-

ment with today’s air

tracks!

 Perfectly elastic collisions are not common in the everyday world.

We find in practice that some heat is generated during collisions.

Drop a ball and after it bounces from the floor, both the ball and the

floor are a bit warmer. Even a dropped superball will not bounce to

its initial height. At the microscopic level, however, perfectly elastic

collisions are commonplace. For example, electrically charged par-

ticles bounce off one another without generating heat; they don’t

even touch in the classic sense of the word. Later chapters will show

that the concept of touching needs to be considered differently at the

atomic level.

CONCEPT

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Teaching Resources

• Reading and Study

 Workbook

• Laboratory Manual 24, 25

• Concept-Development

 Practice Book 8-1

• Problem-Solving Exercises in

 Physics 5-2

• Transparency 12

• PresentationEXPRESS

• Interactive Textbook

CHECK

How does conservation of momentum

apply to collisions?

think!

Suppose one of the gliders in Figure 8.13 is loaded so it has three times the

mass of the other glider. The loaded glider is initially at rest. The unloaded

glider collides with the loaded glider and the two gliders stick together.

Describe the motion of the gliders after the collision. Answer: 8.5

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8.6 Momentum

do the math!

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?

Suppose the small fish is not at rest but is

swimming toward the large fish at 2 m/s.

What is the velocity of the larger fish

immediately after lunch?

If we consider the direction of the large fish

as positive, then the velocity of the small fish

is –2 m/s.

(net mv) before

(6 kg)(1 m/s)

(2 kg)( 2 m/s)

( 4 kg m/s)

2 kg m/s

 8 kg

(net mv) after

(6 kg

2 kg)(vafter)

Vectors

Resist making a big deal out

of this section unless you have

ample time on your hands and

your class is anxious for you to

set your academic plow deeper.

I think it is enough for students

to be exposed to the general

idea here and then move on.

Momentum is conserved from the instant before

lunch until the instant after (in so brief an inter-

val, water resistance does not have time to

change the momentum), so we can write

net momentum before lunch

(net mv) before

(6 kg)(1 m/s)

(2 kg)(0 m/s)

6 kg m/s

vafter

vafter

net momentum after lunch

(net mv) after

(6 kg

2 kg)(vafter)

(6 kg m/s)

(8 kg)(vafter)

vafter

1

 m/s

4

(8 kg)(vafter)

6 kg m/s

 8 kg

3

 m/s

4

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.

(net mv) before

(6 kg)(1 m/s)

(6 kg m/s)

(2 kg)( 4 m/s)

( 8 kg m/s)

2 kg m/s

 8 kg

(net mv) after

(6 kg

2 kg)(vafter)

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 com-

bined mass of the two-fish system is 8 kg and

 3its speed is 4 m/s in the same direction as the

large fish’s direction before lunch.

(8 kg)(vafter)

vafter

1

 m/s

4

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.

8.6 Momentum Vectors

Momentum is conserved even when interacting objects don’t move

along the same straight line. To analyze momentum in any direction,

we use the vector techniques we’ve previously learned. The vector

sum of the momenta is the same before and after a collision. We’ll

look at momentum conservation involving angles by briefly

considering the three following examples.

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MOMENTUM

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 Teaching Tip You may find

it helpful to review the rules of

vectors here.

 Teaching Tip Illustrate the

vector nature of momentum by

discussing Figures 8.14, 8.15, and

8.16.

 Teaching Tip When

discussing Figure 8.15, explain

that for collisions involving x and

y directions,

S(mvx)before 5 S(mvx)after and

S(mvy)before 5 S(mvy)after.

For the falling firecracker,

S(mvx)before 5 S(mvx)after 5 0,

so mvx of the piece that flies off

to the right equals 2mvx of the

piece that flies off to the left.

FIGURE 8.14

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.

 Notice in Figure 8.14 that the momentum of car A is directed

due east and that of car B is directed due north. If their momenta are

equal in magnitude, after colliding their combined momentum will

be in a northeast direction with a magnitude 2 times the momen-

tum either vehicle had before the collision (just as the diagonal of a

square is 2 times the length of a side).

FIGURE 8.15

When the firecracker bursts,

the vector sum of the

momenta of its fragments add

up to the firecracker’s momen-

tum just before bursting.

mv

mv

 The vector sum of

CHECK the momenta is the

same before and after a collision.

CONCEPT

Teaching Resources

• Concept-Development

 Practice Book 8-2

• Reading and Study

 Workbook

• PresentationEXPRESS

• Interactive Textbook

FIGURE 8.16

Momentum is conserved for

the high-speed elementary

particles, as shown by the

tracks they leave in a bubble

chamber.

 Figure 8.15 shows a falling firecracker that explodes into two

pieces. The momenta of the fragments combine by vector rules to

equal the original momentum of the falling firecracker.

 Figure 8.16 shows tracks made by subatomic particles in a bubble

chamber. The mass of these particles can be computed by applying

both the conservation of momentum and conservation of energy

laws—the conservation of energy law will be discussed in the next

chapter. The conservation laws are extremely useful to experimenters

in the atomic and subatomic realms. A very important feature of their

usefulness is that forces do not show up in the equations. Forces in

collisions, however complicated, are not a concern.

 Conservation of momentum and, as the next chapter will discuss,

conservation of energy are the two most powerful tools of mechanics.

Their application yields detailed information that ranges from under-

standing the interactions of subatomic particles to entire galaxies.

CONCEPT

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CHECK

What is true about the vector sum of

momenta in a collision?

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