Conceptual Physics
Newton's 3rd Law
Momentum

Lana Sheridan

De Anza College

July 11, 2017

Last time

- force
- Newton's 1st and 2nd laws
- air resistance and falling objects (nonfree fall)
- friction

Warm Up Question

In the absence of air resistance, when you throw a ball straight up at 10 m/s, how does its speed compare when it returns to you?

(A) the speed will be less than 10 m/s

(B) the speed will be exactly 10 m/s

(C) the speed will be greater than 10 m/s

[1] Hewitt, page 63.

Warm Up Question

In the absence of air resistance, when you throw a ball straight up at 10 m/s, how does its speed compare when it returns to you?

(A) the speed will be less than 10 m/s
(B) the speed will be exactly 10 m/s $\leftarrow$
(C) the speed will be greater than 10 m/s

[1] Hewitt, page 63.

Warm Up Question

In the absence of air resistance, when you throw a ball straight up at 10 m/s, how does its speed compare when it returns to you?

Now, imagine there is air resistance. How does that effect the speed when it returns to you?

(A) the speed will be less than 10 m/s

(B) the speed will be exactly 10 m/s

(C) the speed will be greater than 10 m/s

[1] Hewitt, page 63.

Warm Up Question

In the absence of air resistance, when you throw a ball straight up at 10 m/s, how does its speed compare when it returns to you?

Now, imagine there is air resistance. How does that effect the speed when it returns to you?

(A) the speed will be less than 10 m/s
(B) the speed will be exactly 10 m/s
(C) the speed will be greater than 10 m/s

Think of a feather.

[1] Hewitt, page 63.

Warm Up Question

In the absence of air resistance, when you throw a ball straight up at 10 m/s, how does its speed compare when it returns to you?

Now, imagine there is air resistance. How does that effect the speed when it returns to you?

(A) the speed will be less than 10 m/s $\leftarrow$

(B) the speed will be exactly 10 m/s

(C) the speed will be greater than 10 m/s

Think of a feather.

[1] Hewitt, page 63.

Overview

- Newton's third law
- action reaction pairs of forces
- non-inertial frames
- introduce momentum
- impulse and force
- conservation of momentum

Newton’s Third Law

Newton’s Third Law (as commonly stated):
“For every action, there is an equal and opposite reaction.”

Newton's Third Law

Newton's Third Law (as commonly stated):
"For every action, there is an equal and opposite reaction."

A little more formally:

Newton III

If two objects (1 and 2) interact the force that object 1 exerts on object 2 is equal in magnitude and opposite in direction to the force that object 2 exerts on object 1.

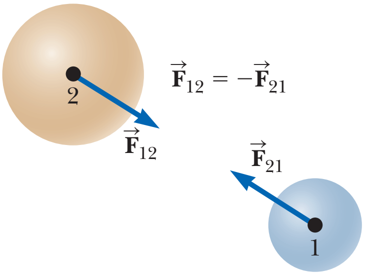
$$\mathbf{F}_{1\to 2} = -\mathbf{F}_{2\to 1}$$

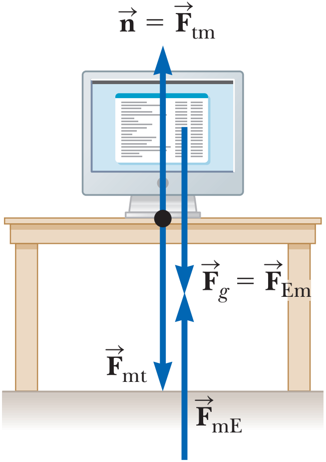
Newton's Third Law

Main idea: you cannot push on something, without having it push back on you.

If object 1 pushes on (or interacts with) object 2, then the force that object 1 exerts on object 2, and the force that object 2 exerts on object 1 form an **action reaction pair**.

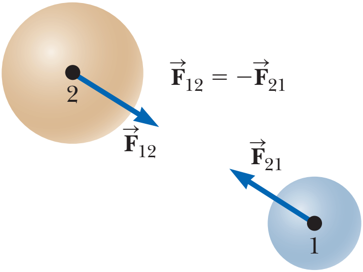
Newton's Third Law: Action Reaction Pairs





Defining a System

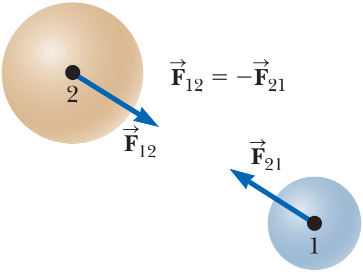
Consider these particles which exert a force on each other:



They are attracted. Each will accelerate toward the other.

Defining a System

Consider these particles which exert a force on each other:



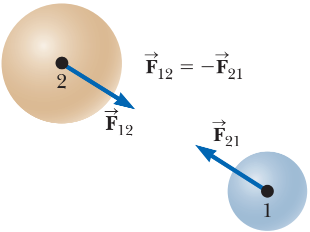
They are attracted. Each will accelerate toward the other.

But wait: do they cancel? $\mathbf{F}_{1\to2} = -\mathbf{F}_{2\to1} \Rightarrow \mathbf{F}_{1\to2} + \mathbf{F}_{2\to1} = 0$

Is the net force zero? How could particle 1 accelerate towards particle 2?

Defining a System

Consider these particles which exert a force on each other:



Is the net force zero?

No! The forces act on different objects. To find if particle 1 accelerates, we find the net force **on particle 1**. We do not consider forces on particle 2.

The only force on particle 1 is $\mathbf{F}_{2\rightarrow 1}$, so the net force is not zero: it accelerates.

Action and Reaction

Why when we fire a cannon does the cannon ball move much faster forward than the cannon does backwards?

Why when we drop an object does it race downwards much faster than the Earth comes up to meet it?

Action and Reaction

Why when we fire a cannon does the cannon ball move much faster forward than the cannon does backwards?

Why when we drop an object does it race downwards much faster than the Earth comes up to meet it?

The masses of each object are very different!

From Newton's second law

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

If m is smaller, a is bigger. If m is very, very big (like the Earth), the acceleration is incredibly small.

Force Diagrams

Question. Do the two forces shown in the diagram that act on the monitor form an action-reaction pair under Newton's third law?

(A) Yes.

(B) No.

Force Diagrams

Question. Do the two forces shown in the diagram that act on the monitor form an action-reaction pair under Newton's third law?

(A) Yes.

(B) No. $\leftarrow$

Accelerated Frames

Newton's first law and frames of reference

You are driving a car and push on the accelerator pedal. An object on your dashboard comes flying off toward you, without any force on it. Was Newton's first law violated?

Newton's first law and frames of reference

You are driving a car and push on the accelerator pedal. An object on your dashboard comes flying off toward you, without any force on it. Was Newton's first law violated?

Newton I (alternate version)

If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

A zero-acceration reference frame is called an *inertial reference frame*.

Newton's first law and frames of reference

You are driving a car and push on the accelerator pedal. An object on your dashboard comes flying off toward you, without any force on it. Was Newton's first law violated?

Newton I (alternate version)

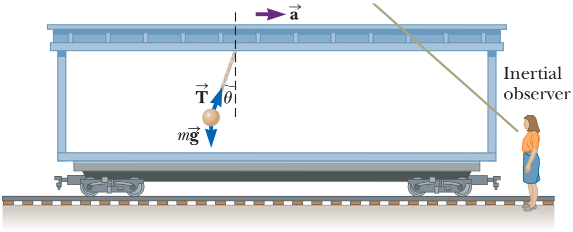
If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

A zero-acceration reference frame is called an *inertial reference frame*.

In your car, you are **not in an inertial frame**; you are in an accelerating frame.

Inertial and Non-intertial Observers

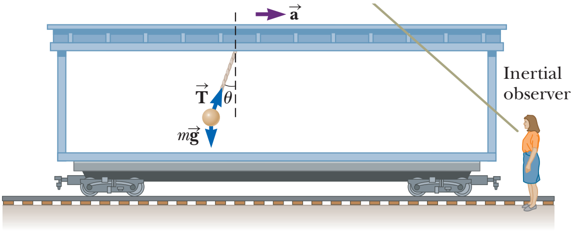
Inertial observer, not on accelerating train car:



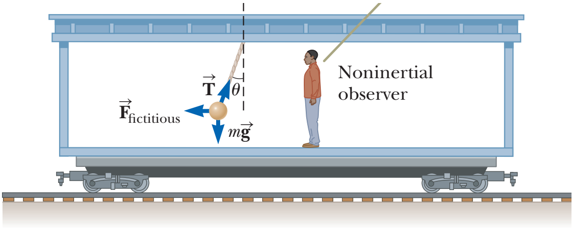
[1]Figures from Serway & Jewett, Physics for Scientists and Engineers, 9th ed.

Inertial and Non-intertial Observers

Inertial observer, not on accelerating train car:



Non-inertial observer, on accelerating train car:



[1]Figures from Serway & Jewett, Physics for Scientists and Engineers, 9th ed.

Inertial and Non-intertial Observers

The two perspectives give equivalent results!

Inertial and Non-intertial Observers

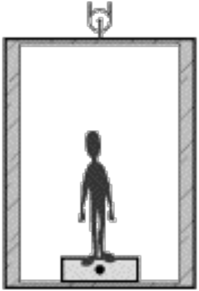
The two perspectives give equivalent results!

However, this only happened because the accelerating observer included an extra force in his description.

$$\mathbf{F}_{\text{ficticious}} = -m\,\mathbf{a}$$

That force needed to be there for him to explain his observations, but it may not be clear to him what caused it.

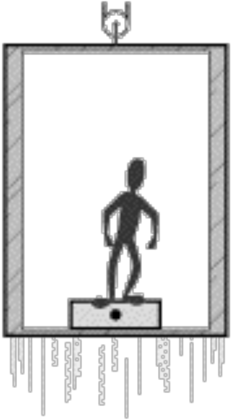
Elevators, the Normal Force, and Accelerated Frames



$$\mathbf{a} = 0$$

Elevator is at rest or moving with constant velocity. You feel the same as you normally do. Your weight and normal force are both of magnitude mg.

Elevators, the Normal Force, and Accelerated Frames



$\uparrow a$

$$\mathbf{a} = +5\,\mathbf{j}$$

Elevator could be moving upward increasing speed **or** downward decreasing speed. You feel as if your weight has increased.

Suppose your mass is $m = 60$ kg.

Your weight is -600 N $\mathbf{j}$, but the normal force is
$\mathbf{n} = m(g+5)\,\mathbf{j} = 900$ N $\mathbf{j}$.

Elevators, the Normal Force, and Accelerated Frames

$\downarrow a$

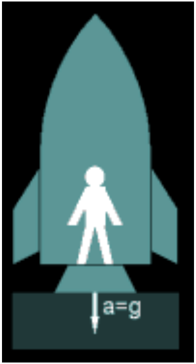
$$\mathbf{a} = -5\,\mathbf{j}$$

Elevator could be moving upward and slowing down **or** moving downward increasing speed. You feel as if your weight has decreased.

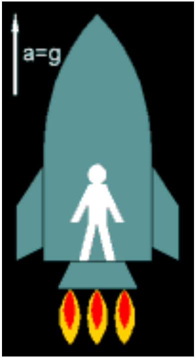
Your weight is still -600 N $\mathbf{j}$, but the normal force is $\mathbf{n} = m(g-5)\,\mathbf{j} = 300$ N$\mathbf{j}$.

Equivalence of gravitational acceleration

A rocket on Earth. A person onboard feels a normal force $n = mg$ acting upward from the floor.



A rocket accelerating in space. A person onboard feels a normal force $n = ma = mg$ (if $a = g$) acting upward from the floor.



[1]Figures from http://www.ex-astris-scientia.org

Review Questions

What physics is involved when you feel pushed back into your seat when in an airplane that is accelerating down the runway so it can takes off?

Consider a pair of forces on a person standing still: gravity acts downwards, and the support of the floor holds the person up. Are these force equal and opposite? Are they an action-reaction pair?

One piece of notation: Delta

Suppose we have a quantity, say x, and we want to know by how much it changed.

It has some initial value x_i and some final value x_f.

Then the change is just the difference between the initial and final values:

$$\Delta x = x_f - x_i$$

One piece of notation: Delta

Suppose we have a quantity, say x, and we want to know by how much it changed.

It has some initial value x_i and some final value x_f.

Then the change is just the difference between the initial and final values:

$$\Delta x = x_f - x_i$$

We use the Greek letter Δ (capital delta) to represent a change.

Δx is the change in x, Δt is the change in t, and so on.

Momentum

Momentum is the product of mass and velocity:

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

Usually, momentum is written with the symbol p.

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

[1] http://science360.gov/obj/video/1a6a8602-2e8b-4eab-93e2-b6d5a9e697ed/force-impulse-collisions

Momentum

Momentum is the product of mass and velocity:

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

Usually, momentum is written with the symbol p.

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

Is it a scalar or a vector?

[1] http://science360.gov/obj/video/1a6a8602-2e8b-4eab-93e2-b6d5a9e697ed/force-impulse-collisions

Momentum

Momentum is the product of mass and velocity:

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

Usually, momentum is written with the symbol p.

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

Is it a scalar or a vector? Vector!

[1]http://science360.gov/obj/video/1a6a8602-2e8b-4eab-93e2-b6d5a9e697ed/force-impulse-collisions

Momentum

Momentum is the product of mass and velocity:

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

Usually, momentum is written with the symbol p.

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

Is it a scalar or a vector? Vector!

Units?

[1] http://science360.gov/obj/video/1a6a8602-2e8b-4eab-93e2-b6d5a9e697ed/force-impulse-collisions

Momentum

Momentum is the product of mass and velocity:

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

Usually, momentum is written with the symbol p.

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

Is it a scalar or a vector? Vector!

Units? kg m/s

[1] http://science360.gov/obj/video/1a6a8602-2e8b-4eab-93e2-b6d5a9e697ed/force-impulse-collisions

Momentum

Momentum was so important for Newton's understanding of motion that he called it *the* "quantity of motion".

Momentum is related to force.

Momentum

Momentum was so important for Newton's understanding of motion that he called it *the* "quantity of motion".

Momentum is related to force.

This is where our intuition about momentum comes from:

Is it harder to stop a bowling ball or a tennis ball if they are both approaching you at the same speed?

Is it harder to stop a bullet or a tossed marble?

Change in Momentum and Impulse

The bullet and the bowling ball are harder to stop because they have more momentum.

Can we be more precise about “hard to stop”?

Change in Momentum and Impulse

The bullet and the bowling ball are harder to stop because they have more momentum.

Can we be more precise about “hard to stop”?

Yes! “Hard to stop” can be measured as how much force must be applied for how much time to stop the motion.

To stop something, we must change its momentum: $\Delta\mathbf{p}$

If we apply a constant force $\mathbf{F}$ for an amount of time Δt:

$$\Delta\mathbf{p} = \mathbf{F}\,\Delta t$$

Change in Momentum and Impulse

For some reason, we also give the change in momentum a special name:

Impulse

Impulse is the change in momentum.

$$\text{Impulse} = \Delta \mathbf{p}$$

and so

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

(assuming the force $\mathbf{F}$ is constant)

Impulse and Newton's Second Law

$$\text{Impulse} = \Delta \mathbf{p}$$

Recall, $\mathbf{p} = m\mathbf{v}$, so we can also write:

$$\text{Impulse} = \Delta(m\mathbf{v})$$

Impulse and Newton's Second Law

$$\text{Impulse} = \Delta \mathbf{p}$$

Recall, $\mathbf{p} = m\mathbf{v}$, so we can also write:

$$\text{Impulse} = \Delta(m\mathbf{v})$$

If the mass of an object m is constant, then only its velocity changes. In this case:

$$\text{Impulse} = m\,\Delta\mathbf{v}$$

Impulse and Newton's Second Law

Remember, for a constant force applied for a time interval Δt:

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

Combining these expressions for impulse:

$$\text{Impulse} = \mathbf{F}\ \Delta t = m\ \Delta \mathbf{v}$$

Impulse and Newton's Second Law

$$\text{Impulse} = \mathbf{F}\ \Delta t = m\ \Delta\mathbf{v}$$

If we divide both sides by Δt:

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

Impulse and Newton's Second Law

$$\text{Impulse} = \mathbf{F}\ \Delta t = m\ \Delta \mathbf{v}$$

If we divide both sides by Δt:

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

But acceleration is the change in velocity divided by the change in time! This is Newton's second law:

$$\mathbf{F} = m\,\mathbf{a}$$

The fact that impulse is the force times time implies Newton's second law.

Impulse

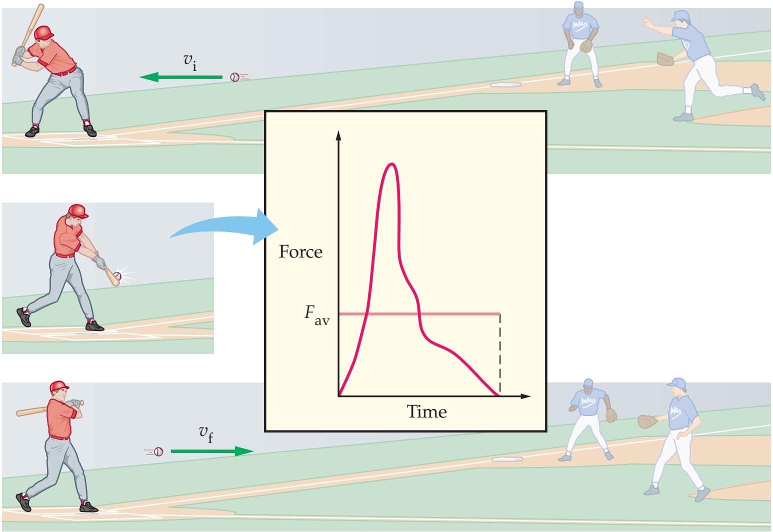
If the force on an object is not constant, we can still write:

$$\text{Impulse} = \mathbf{F}_{\text{avg}} \Delta t$$

where $\mathbf{F}_{\text{avg}}$ is the **average force** on the object over the time interval Δt.

Impulse from Changing Force

$$\text{Impulse} = \mathbf{F}_{\text{avg}} \Delta t$$



[1]Figure from Walker, "Physics".

Changing momentum examples

A golf ball: hitting a golf ball off a tee, the club exerts a force which accelerates the golf ball. Its momentum increases.

A baseball: a catcher catches a pitch, the glove provides a force decelerating the ball and bringing the baseball to a stop. Its momentum decreases.

Force-time trade-off

Why is an elastic line used for bungee jumping, and not a steel cable?

Force-time trade-off

Why is an elastic line used for bungee jumping, and not a steel cable?

Assume either one just brings you to rest. It must decrease your momentum by a large amount.

Force-time trade-off

Why is an elastic line used for bungee jumping, and not a steel cable?

Assume either one just brings you to rest. It must decrease your momentum by a large amount.

Suppose you have mass 60 kg. At the end of your fall you could have a velocity 25 m s^{-1} downward. What is your change of momentum as you are brought to rest?

Force-time trade-off

Why is an elastic line used for bungee jumping, and not a steel cable?

Assume either one just brings you to rest. It must decrease your momentum by a large amount.

Suppose you have mass 60 kg. At the end of your fall you could have a velocity 25 m s^{-1} downward. What is your change of momentum as you are brought to rest?

$$\Delta \mathbf{p} = \mathbf{p}_f - \mathbf{p}_i = 1500 \text{ kg m s}^{-1} \text{ upward}$$

Force-time trade-off

Why is an elastic line used for bungee jumping, and not a steel cable?

Assume either one just brings you to rest. It must decrease your momentum by a large amount.

Suppose you have mass 60 kg. At the end of your fall you could have a velocity 25 m s^{-1} downward. What is your change of momentum as you are brought to rest?

$$\Delta \mathbf{p} = \mathbf{p}_f - \mathbf{p}_i = 1500 \text{ kg m s}^{-1} \text{ upward}$$

A steel cable will bring you to rest in a fraction of a second. That is a force of well over 1500 N!

A bungee line will bring you to rest over a period of several seconds: force $\sim$ 500 N: comparable to the force of gravity on you. A much more pleasant experience.

Force-time trade-off

The idea that changing the momentum of an object over a longer period of time reduces the force on the object is very important in engineering.

In particular, it is a principle used in design to improve safety.

Conservation of Momentum

Momentum has a very important property.

We say that it obeys a **conservation law**.

That means that in any interaction, the *total momentum* of all objects interacting does not change.

$$\begin{array}{ccc} \text{total momentum} & = & \text{total momentum} \\ \text{before interaction} & & \text{after interaction} \end{array}$$

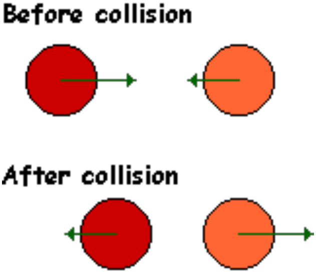
Equivalently, there is zero change in the total momentum:

$$\Delta \mathbf{p}_{\text{net}} = \sum (\Delta \mathbf{p}) = 0$$

Conservation of Momentum

Even though the total momentum does not change, individual objects may see their momentum change.

For example, consider two colliding balls:



The momentum of each ball changes in the collision, but the sum of their momenta is the same before and after.

[1] Image from http://www.compuphase.com.

Conservation of Momentum

This is actually a consequence of Newton's Third Law:

$$\mathbf{F}_{1\to 2} = -\mathbf{F}_{2\to 1}$$

Multiply by the interaction time:

$$\mathbf{F}_{1\to 2}\ \Delta t = -\mathbf{F}_{2\to 1}\ \Delta t$$

Conservation of Momentum

This is actually a consequence of Newton's Third Law:

$$\mathbf{F}_{1\to 2} = -\mathbf{F}_{2\to 1}$$

Multiply by the interaction time:

$$\mathbf{F}_{1\to 2}\,\Delta t = -\mathbf{F}_{2\to 1}\,\Delta t$$

But that is impulse! The magnitudes of the impulses are the same (directions opposite).

$$\text{Impulse}_2 = \text{Impulse}_1$$

Impulse is the change in momentum, so:

$$\Delta\mathbf{p}_2 = -\Delta\mathbf{p}_1$$

Conservation of Momentum

This is actually a consequence of Newton's Third Law:

$$\mathbf{F}_{1\to 2} = -\mathbf{F}_{2\to 1}$$

Multiply by the interaction time:

$$\mathbf{F}_{1\to 2}\ \Delta t = -\mathbf{F}_{2\to 1}\ \Delta t$$

But that is impulse! The magnitudes of the impulses are the same (directions opposite).

$$\text{Impulse}_2 = \text{Impulse}_1$$

Impulse is the change in momentum, so:

$$\Delta \mathbf{p}_2 = -\Delta \mathbf{p}_1$$

Adding them gives zero! No change in total momentum!

$$\Delta \mathbf{p}_{\text{net}} = \Delta \mathbf{p}_2 + \Delta \mathbf{p}_1 = 0$$

Bouncing

Does a ball that strikes a block and stops dead impart more or less momentum to the block than a ball that bounces? (Assume masses and velocities are the same.)

Bouncing

Does a ball that strikes a block and stops dead impart more or less momentum to the block than a ball that bounces? (Assume masses and velocities are the same.)

The bouncing ball must impart more momentum to the block, because its momentum change is bigger!

Bouncing

Does a ball that strikes a block and stops dead impart more or less momentum to the block than a ball that bounces? (Assume masses and velocities are the same.)

The bouncing ball must impart more momentum to the block, because its momentum change is bigger!

Suppose it bounces back with the same speed it had initially, but in the opposite direction:

$$\Delta \mathbf{p}_{\text{ball}} = m(\mathbf{v}_f - \mathbf{v}_i)$$

Bouncing

Does a ball that strikes a block and stops dead impart more or less momentum to the block than a ball that bounces? (Assume masses and velocities are the same.)

The bouncing ball must impart more momentum to the block, because its momentum change is bigger!

Suppose it bounces back with the same speed it had initially, but in the opposite direction:

$$\begin{aligned} \Delta \mathbf{p}_{\text{ball}} &= m(\mathbf{v}_f - \mathbf{v}_i) \\ &= m\big(\mathbf{v} - (-\mathbf{v})\big) \end{aligned}$$

Bouncing

Does a ball that strikes a block and stops dead impart more or less momentum to the block than a ball that bounces? (Assume masses and velocities are the same.)

The bouncing ball must impart more momentum to the block, because its momentum change is bigger!

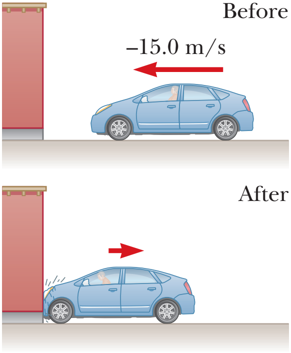
Suppose it bounces back with the same speed it had initially, but in the opposite direction:

$$\begin{aligned}\Delta \mathbf{p}_{\text{ball}} &= m(\mathbf{v}_f - \mathbf{v}_i) \\ &= m\big(\mathbf{v} - (-\mathbf{v})\big) \\ &= \underline{2m\mathbf{v}}\end{aligned}$$

Crash test example

In a particular crash test, a car of mass 1500 kg collides with a wall. The initial and final velocities of the car are:

$$\mathbf{v}_i = -15.0\ \mathbf{i}\ \mathrm{m/s}$$
$$\text{and } \mathbf{v}_f = 5.00\ \mathbf{i}\ \mathrm{m/s}.$$



If the collision lasts 0.150 s, find the impulse caused by the collision and the average net force exerted on the car.

What would the net force be if the car stuck to the wall after the collision?

[1]Serway & Jewett, Physics for Scientists and Engineers, 9th ed, page 255.

Crash test example

Impulse?

$$\mathbf{I} = \Delta \mathbf{p}$$

Crash test example

Impulse?

$$
\begin{aligned}
\mathbf{I} &= \Delta \mathbf{p} \\
&= m(\mathbf{v}_f - \mathbf{v}_f) \\
&= (1500\ \text{kg})(5.00 - (-15.0)\ \text{m/s})\ \mathbf{i} \\
&= \underline{3.00 \times 10^4\ \mathbf{i}\ \text{kg m/s}}
\end{aligned}
$$

Crash test example

Impulse?

$$\begin{aligned} \mathbf{I} &= \Delta \mathbf{p} \\ &= m(\mathbf{v}_f - \mathbf{v}_f) \\ &= (1500 \text{ kg})(5.00 - (-15.0) \text{ m/s}) \ \mathbf{i} \\ &= \underline{3.00 \times 10^4 \ \mathbf{i} \text{ kg m/s}} \end{aligned}$$

Average net force?

Crash test example

Impulse?

$$\begin{aligned} \mathbf{I} &= \Delta \mathbf{p} \\ &= m(\mathbf{v}_f - \mathbf{v}_f) \\ &= (1500 \text{ kg})(5.00 - (-15.0) \text{ m/s}) \text{ } \mathbf{i} \\ &= \underline{3.00 \times 10^4 \text{ } \mathbf{i} \text{ kg m/s}} \end{aligned}$$

Average net force?

$$\mathbf{F}_{\text{net,avg}} = \frac{\mathbf{I}}{\Delta t}$$

Crash test example

Impulse?

$$\begin{aligned}\mathbf{I} &= \Delta\mathbf{p} \\ &= m(\mathbf{v}_f - \mathbf{v}_f) \\ &= (1500 \text{ kg})(5.00 - (-15.0) \text{ m/s}) \ \mathbf{i} \\ &= \underline{3.00 \times 10^4 \ \mathbf{i} \text{ kg m/s}}\end{aligned}$$

Average net force?

$$\begin{aligned}\mathbf{F}_{\text{net,avg}} &= \frac{\mathbf{I}}{\Delta t} \\ &= \frac{3.00 \times 10^4 \ \mathbf{i} \text{ kg m/s}}{0.150 \text{ s}} \\ &= \underline{2.00 \times 10^5 \ \mathbf{i} \text{ N}}\end{aligned}$$

If car does not recoil:

$$\mathbf{F}_{\text{net,avg}} = \underline{1.50 \times 10^5 \ \mathbf{i} \text{ N}}$$

Crash test example

Conclusion: designing a car to deform and not recoil in a collision can reduce the forces involved.

[1] Image from http://northdallasgazette.com

Question

12. A man claims that he can hold onto a 12.0-kg child in a head-on collision as long as he has his seat belt on. Consider this man in a collision in which he is in one of two identical cars each traveling toward the other at 60.0 mi/h relative to the ground. The car in which he rides is brought to rest in 0.10 s. (a) Find the magnitude of the average force needed to hold onto the child. (b) Based on your result to part (a), is the man's claim valid? (c) What does the answer to this problem say about laws requiring the use of proper safety devices such as seat belts and special toddler seats?

Question

(a) Average force to hold child:

Question

(a) Average force to hold child:

$$F_{\text{net,avg}} = \frac{|\mathbf{I}|}{\Delta t}$$

Question

(a) Average force to hold child:

$$\begin{aligned} F_{\text{net,avg}} &= \frac{|\mathbf{I}|}{\Delta t} \\ &= \frac{m|v_f - v_i|}{\Delta t} \\ &= \frac{(12)(60 \text{ mi / h})(1609 \text{ m/mi})}{(0.10 \text{ s})(3600 \text{ s/h})} \\ &= \underline{3.2 \times 10^3 \text{ N}} \end{aligned}$$

Question

(a) Average force to hold child:

$$\begin{aligned}
F_{\text{net,avg}} &= \frac{|\mathbf{I}|}{\Delta t} \\
&= \frac{m|v_f - v_i|}{\Delta t} \\
&= \frac{(12)(60 \text{ mi / h})(1609 \text{ m/mi})}{(0.10 \text{ s})(3600 \text{ s/h})} \\
&= \underline{3.2 \times 10^3 \text{ N}}
\end{aligned}$$

(b) man's claim?

Question

(a) Average force to hold child:

$$
\begin{aligned}
F_{\text{net,avg}} &= \frac{|\mathbf{I}|}{\Delta t} \\
&= \frac{m|v_f - v_i|}{\Delta t} \\
&= \frac{(12)(60 \text{ mi / h})(1609 \text{ m/mi})}{(0.10 \text{ s})(3600 \text{ s/h})} \\
&= \underline{3.2 \times 10^3 \text{ N}}
\end{aligned}
$$

(b) man's claim?
It seems unlikely that he will be able to exert 3200 N of force on the child.

Question

(a) Average force to hold child:

$$
\begin{aligned}
F_{\text{net,avg}} &= \frac{|\mathbf{I}|}{\Delta t} \\
&= \frac{m|v_f - v_i|}{\Delta t} \\
&= \frac{(12)(60 \text{ mi / h})(1609 \text{ m/mi})}{(0.10 \text{ s})(3600 \text{ s/h})} \\
&= \underline{3.2 \times 10^3 \text{ N}}
\end{aligned}
$$

(b) man's claim?
It seems unlikely that he will be able to exert 3200 N of force on the child.

(c) Secure your toddler with a child safety seat!

Summary

- action-reaction pairs
- non-inertial frames
- momentum
- conservation of momentum

Essay Homework due Wed, July 19th.

- Describe the design features of cars that make them safer for passengers in collisions. Comment on how the design of cars has changed over time to improve these features. In what other circumstances might people be involved in collisions? What is / can be done to make those collisions safer for the people involved? Make sure use physics principles (momentum, impulse) in your answers!

Homework Hewitt,

- Ch 5, onward from page 78. Ranking 1, 3; Exercises: 1, 31, 33; Problems 3, 5
- Ch 6, onward from page 96. Plug and chug: 1, 3, 5, 7; Ranking: 1; Exercises: 5, 7, 19, 31, 47