ENERGY & MOMENTUM

IB PHYSICS | COMPLETED NOTES

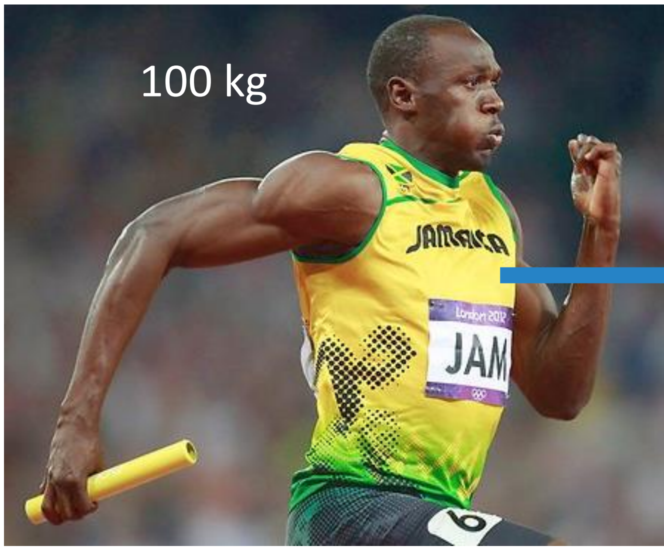
Calculating Energy

IB PHYSICS | ENERGY & MOMENTUM

Energy Calculations

Sub-topic 2.3 – Work, energy and power
$W = Fs\cos\theta$
$\boxed{E_K = \frac{1}{2}mv^2}$ **Kinetic Energy (KE)**
$E_P = \frac{1}{2}k\Delta x^2$
$\boxed{\Delta E_P = mg\Delta h}$ **Potential Energy (PE)**
$\text{power} = Fv$
$\text{Efficiency} = \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$

Who has more energy??

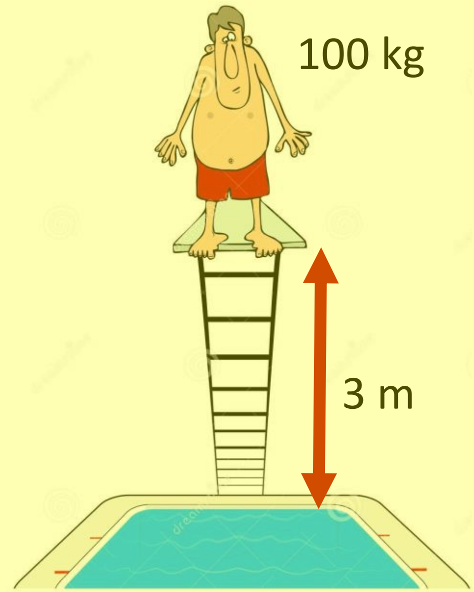


7.67 m/s

$$KE = \tfrac{1}{2}mv^2$$

$$= \tfrac{1}{2}(100)(7.67)^2$$

$$= \mathbf{2941\ J}$$



$$PE = mgh$$

$$= (100)(9.81)(3)$$

$$= \mathbf{2943\ J}$$

Understanding Relationships

$\boxed{E_K = \frac{1}{2}mv^2}$ **Kinetic Energy (KE)**

$\boxed{\Delta E_P = mg\Delta h}$ **Potential Energy (PE)**

How does PE change when you triple the height?

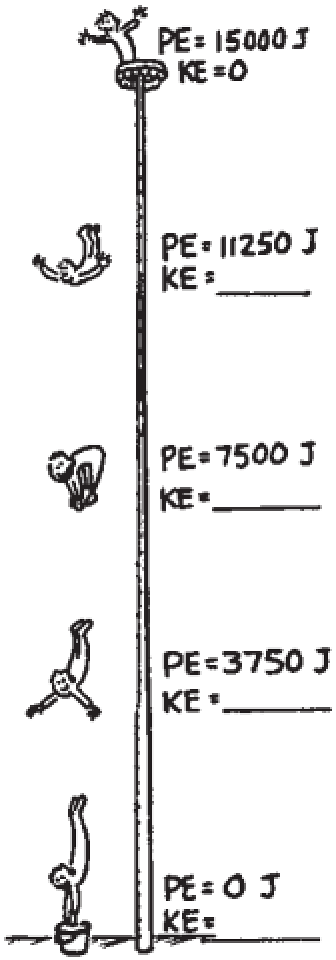
3 times PE

How does KE change when you triple the velocity?

$3^2 \rightarrow$ 9 times KE

Conservation of Mechanical Energy

Total Energy Before = Total Energy After



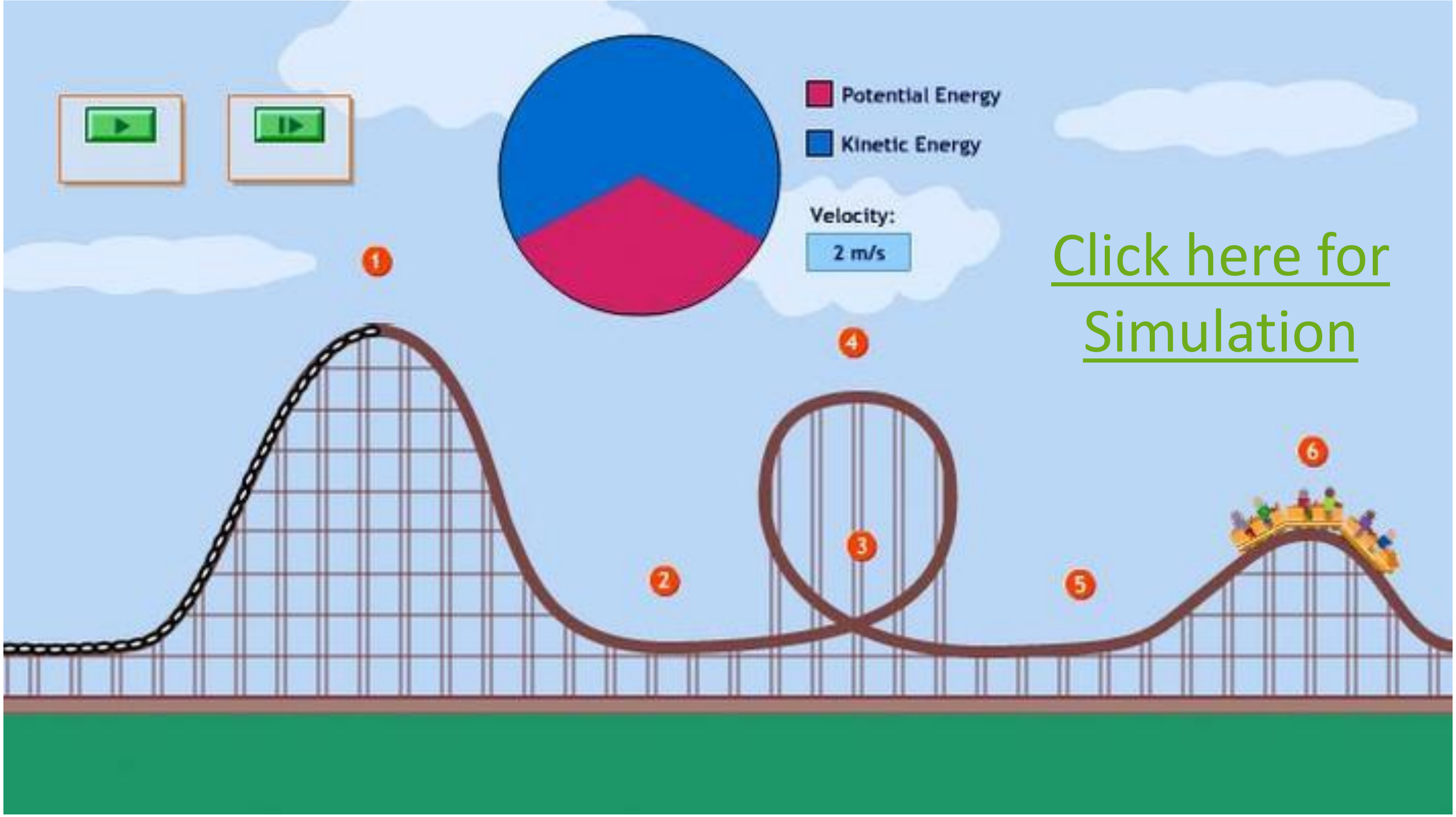
3750 J

7500 J

11250 J

15000 J

Conservation of Energy



[Click here for Simulation]

Conservation of Energy

A 2-kg ball is released from a height of 20 m. What is its velocity when its height has decreased to 5 m?

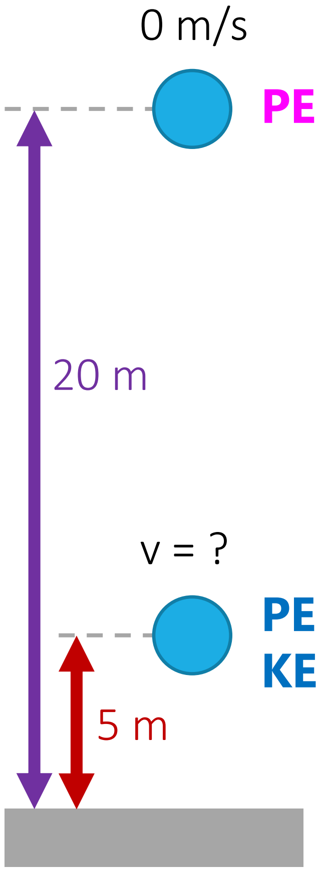
$$PE + \cancel{KE} = PE + KE$$

$$mgh = mgh + \frac{1}{2}mv^2$$

$$(2)(9.81)(20) = (2)(9.81)(5) + \frac{1}{2}(2)v^2$$

$$392.4 = 98.1 + v^2$$

$$\boxed{v = 17.2\ \mathrm{m}/s}$$



Try this

The height of the building Spider-Man (a.k.a. Peter Parker, a.k.a. Tobey McGuire) starts off on is 6 stories, or 18 meters high. The height of the building he wants to swing to is 1 story, or 3 meters high. Tobey McGuire is has a mass of approximately 72 kg. Use conservation of energy to calculate his speed when his feet touch the roof of the second building

$$PE + \cancel{KE} = PE + KE$$

$$mgh = mgh + \tfrac{1}{2}mv^2$$

$$(72)(9.81)(18) = (72)(9.81)(3) + \tfrac{1}{2}(72)v^2$$

$$12{,}714 = 2{,}119 + 36v^2$$

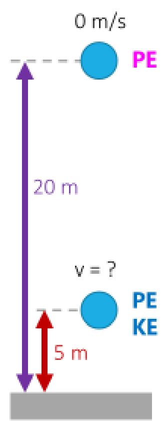
$$\boxed{v = \mathbf{17.2\ m/s}}$$

Notice any similarities??

The final velocity is the same in each example.
Same height change, mass doesn't matter!

Conservation of Energy

A 2-kg ball is released from a height of 20 m. What is its velocity when its height has decreased to 5 m?



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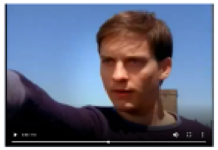

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$$12{,}714 = 2{,}119 + 36v^2$$

$$\boxed{v = 17.2\ \mathrm{m/s}}$$

Try this

*if you aren't given the mass, you should write out the equation and the mass will cancel

What is the velocity of a marble at point A?

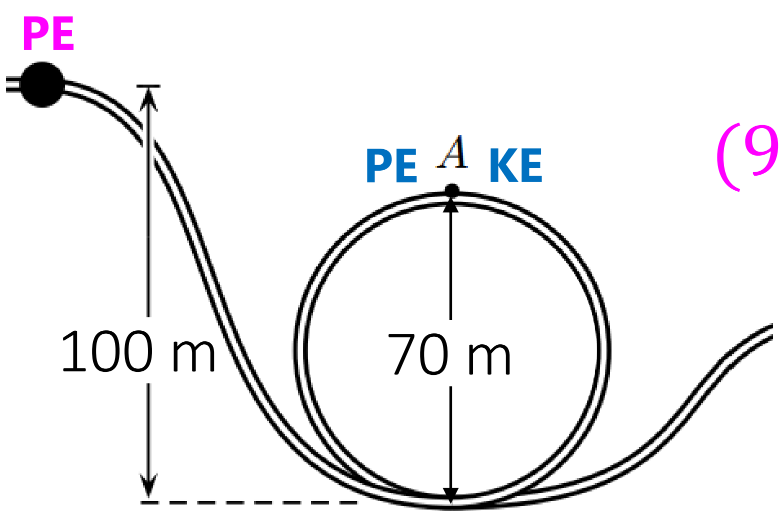
Initial Energy = Final Energy

$$PE + \cancel{KE} = PE + KE$$

$$\cancel{m}gh = \cancel{m}gh + \frac{1}{2}\cancel{m}v^2$$

$$(9.81)(100) = (9.81)(70) + \frac{1}{2}v^2$$

$$\boxed{v = 24.3\ \mathrm{m/s}}$$



No Mass? No Problem…

Water at the bottom of a waterfall has a velocity of 30 m/s after falling 16 meters. What is the water speed at the top?

PE
KE

$$PE + KE = \cancel{PE} + KE$$

$$\frac{1}{2}\cancel{m}v^2 + \cancel{m}gh = \frac{1}{2}\cancel{m}v^2$$

$$\frac{1}{2}v^2 + (9.81)(16) = \frac{1}{2}(30)^2$$

$$\boxed{\boldsymbol{v = 24.2\ \mathrm{m}/s}}$$

Lesson Takeaways

- ❑ I can describe and calculate kinetic energy and gravitational potential energy
- ❑ I can explain the implications of the conservation of energy and show that the total energy in a closed system is always the same
- ❑ I can interpret a scenario and set up an equality based on the energies present at different locations
- ❑ I can use the conservation of energy to solve for an unknown energy or variable in a problem

Work and Power

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Where did the energy come from?

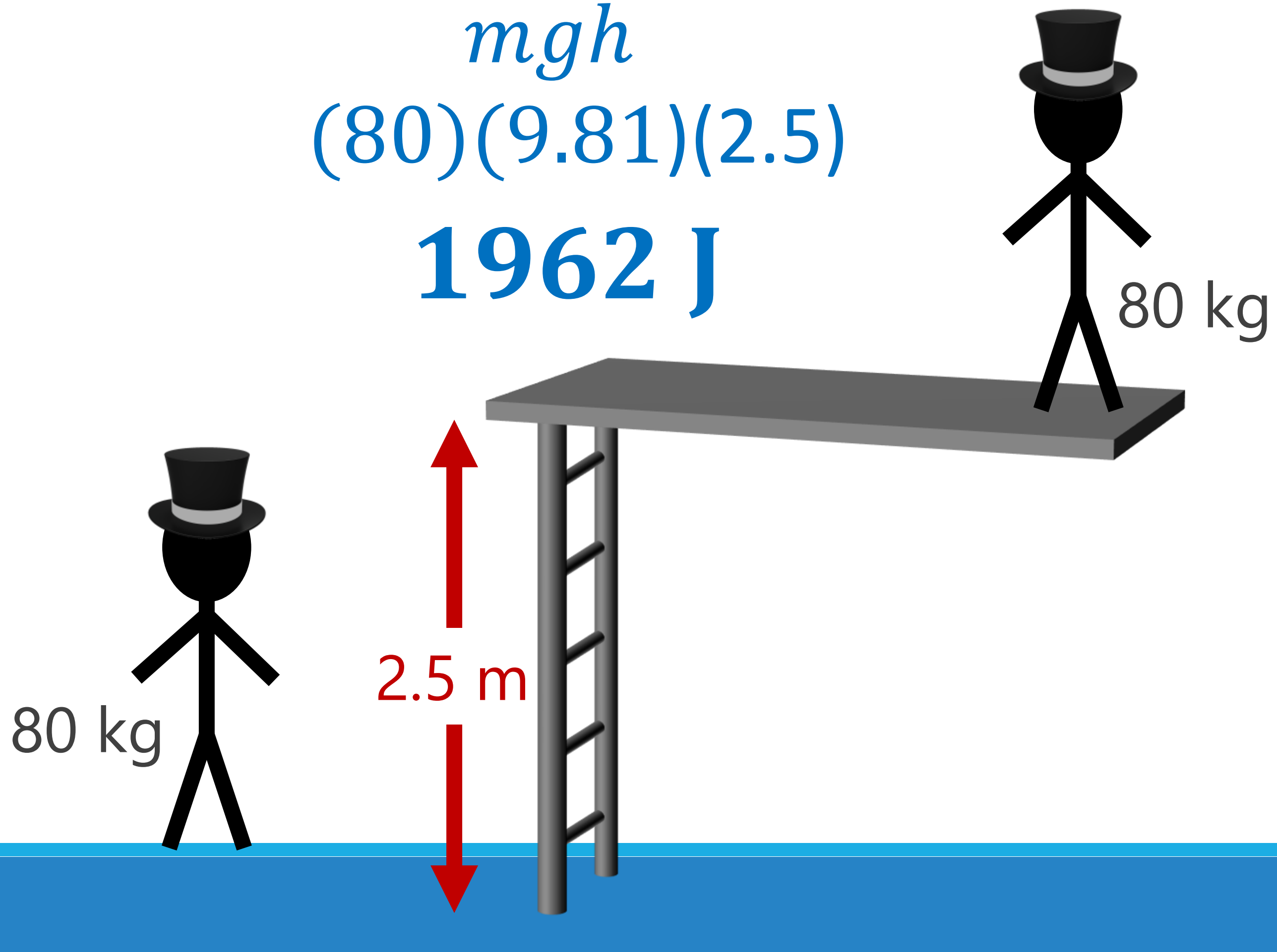
Initial Energy | Final Energy

0 J

mgh

$(80)(9.81)(2.5)$

1962 J



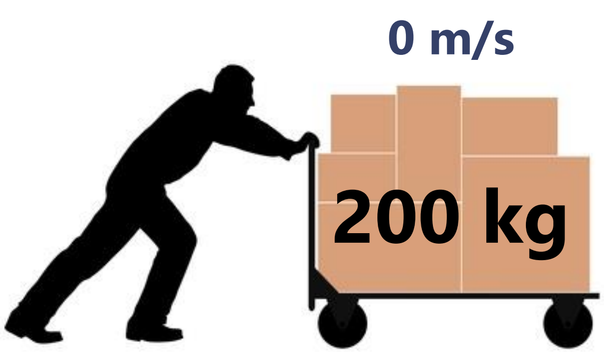
Where did the energy come from?

Initial Energy | Final Energy

0 J

$$\frac{1}{2}mv^2 = \frac{1}{2}(200)(5)^2$$

2500 J



Let's give it a name

When the energy is added to or removed from a system, we call it

Work

How does Science Define Work?

Work is done when a **force** is applied to an object and the object moves in the **same direction** as the applied force.

How do you Calculate Work

Work* = Force × Displacement

*When force is constant and in the same direction as the movement

Symbols	W	=	F	×	s
Units	Joules [J]	=	[N]	×	[m]

The things necessary for Work

- There must be a force
- There must be a displacement

What about direction?

Work at an Angle

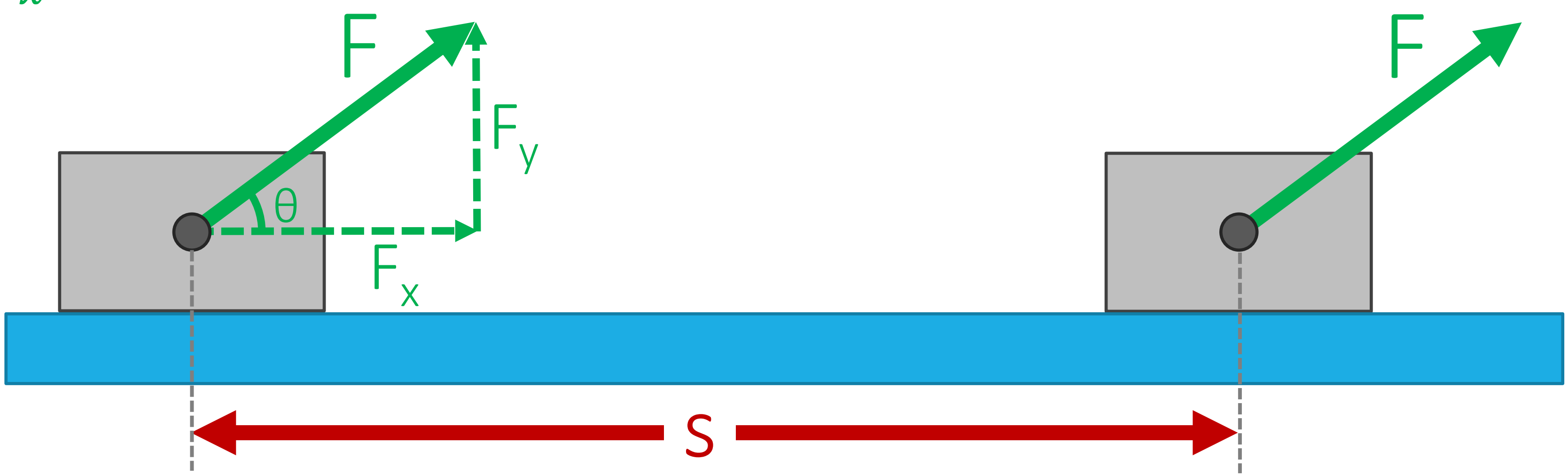
Must use the component of the force that is in the **same direction** as the motion

$$\cos\theta = \frac{F_x}{F}$$

$$F_x = F\cos\theta$$

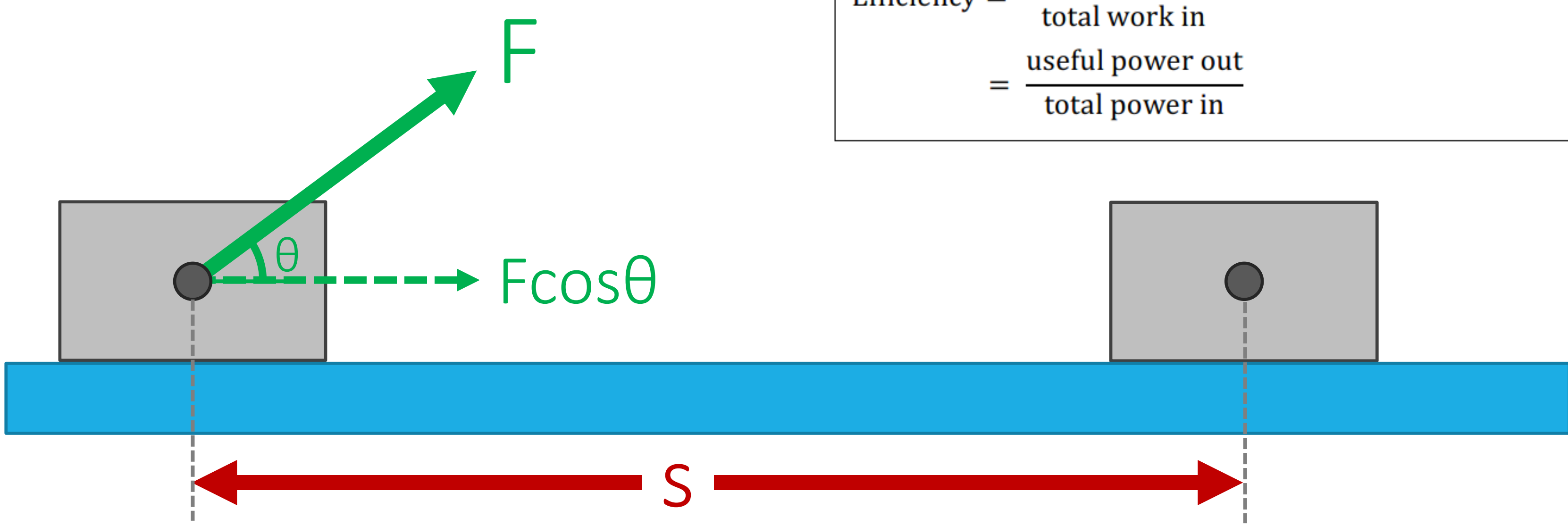
$$W = F_x s$$

$$\boldsymbol{W = F\cos\theta s}$$



Work at an Angle

$$W = Fs\cos\theta$$



Sub-topic 2.3 – Work, energy and power

$$\boxed{W = Fs\cos\theta}$$

$$E_K = \frac{1}{2}mv^2$$

$$E_P = \frac{1}{2}k\Delta x^2$$

$$\Delta E_P = mg\Delta h$$

$$\text{power} = Fv$$

$$\text{Efficiency} = \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$$

Does this always work?

$W = Fs\cos\theta$

$\theta = 90°$

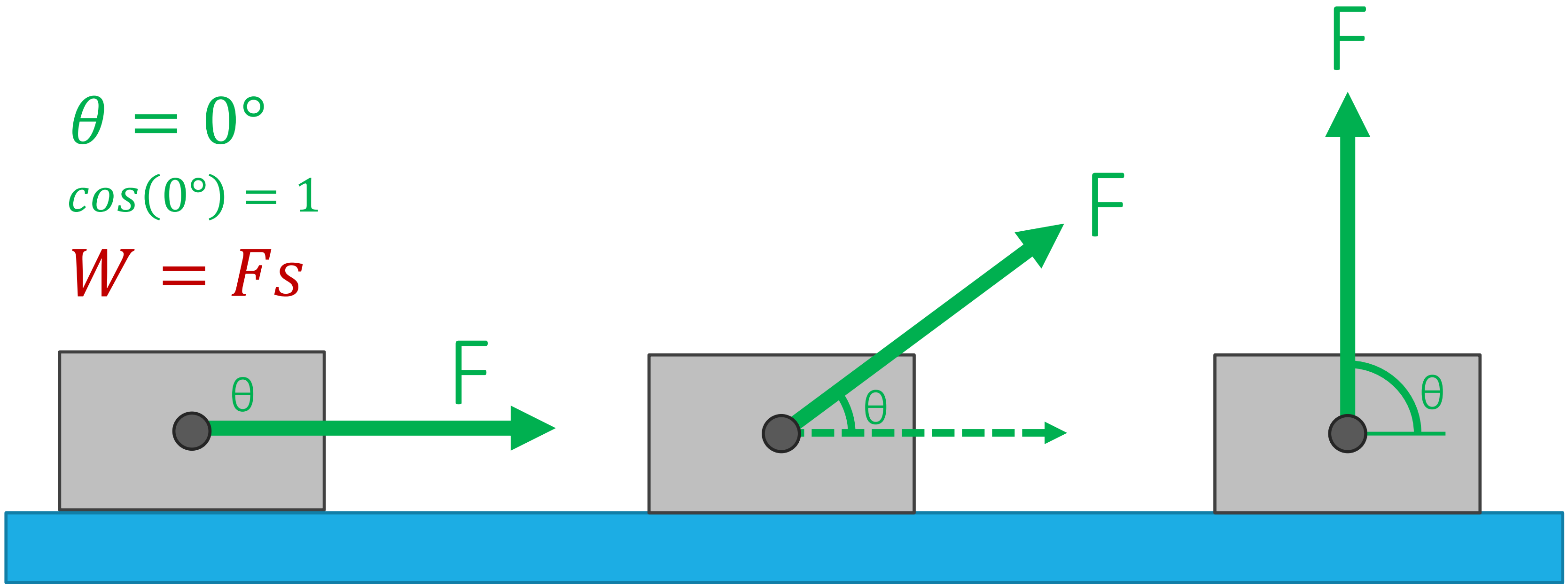
$cos(90°) = 0$

$W = 0\ \mathrm{J}$

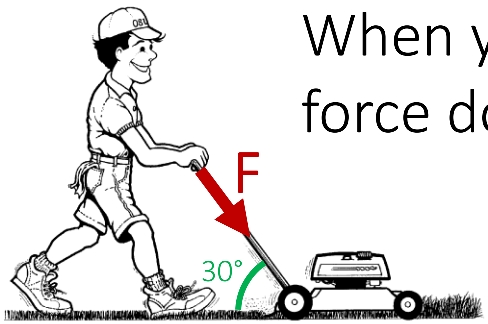
$\theta = 0°$

$cos(0°) = 1$

$W = Fs$



Try This



When you push a lawn mower, you are really applying a force down the angled handle bar as shown in this picture

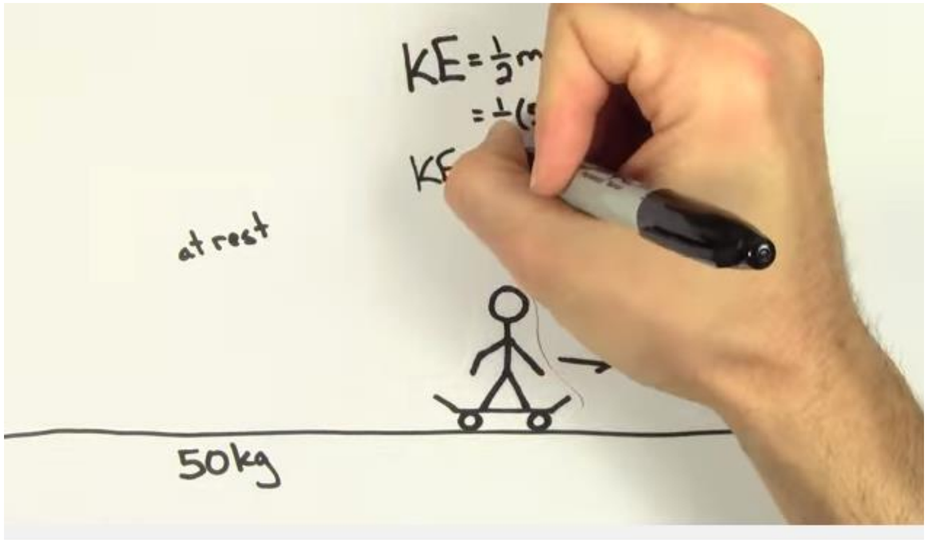
How much **work** do you do when you push a lawn mower 20 m with a force of 200 N directed at an angle of 30° with the ground?

$$W = Fs\, cos\theta = (200)(20)\cos(30°) = \mathbf{3464\ J}$$

Work-Energy Theorem

If energy is truly conserved, how can things ever start or stop moving?

Energy is still conserved (not created or destroyed), it's just being transferred in or out of the system/object that we are studying (gained or lost)



Work as the transfer of energy | Work and energy | Physics | Khan Academy

Work-Energy Theorem

Your engine applies 1000 N of force over a distance of 50 m. If you started from rest and your car has a mass of 2000 kg, how fast are you moving after travelling that distance?

Initial Energy

$\mathbf{0\ J}$

Final Energy

$\mathbf{50,000\ J}$

Work

$$Fs = (1000)(50)$$

$$\boldsymbol{W = 50,000\ \mathrm{J}}$$

$$\tfrac{1}{2}(2000)v^2 = 50,000$$

$$\boxed{\boldsymbol{v = 7.07\ m\ s^{-1}}}$$

Try This

A 75 kg skateboarder kicks off with an initial velocity of 2 m s^{-1} and comes to a stop after 15 m. What is the force of friction?

Initial Energy

$$\frac{1}{2}mv^2 = \frac{1}{2}(75)(2)^2$$

$$\mathbf{150\ J}$$

Final Energy

$$\mathbf{0\ J}$$

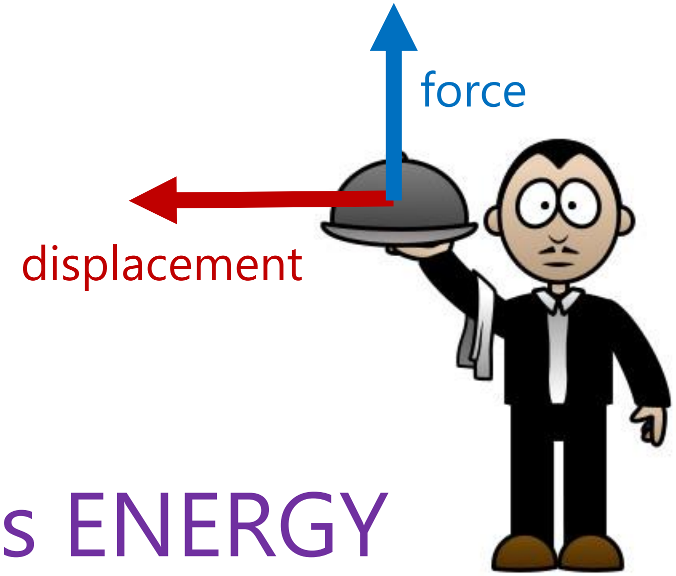
Work $\mathbf{150\ J} = Fs = F(15)$

$$\boxed{\boldsymbol{F = 10\ N}}$$

Think about it...

Is a waiter carrying a heavy tray of food at a constant velocity across a room doing any work on the tray?

No, the force is not in the same direction as the displacement

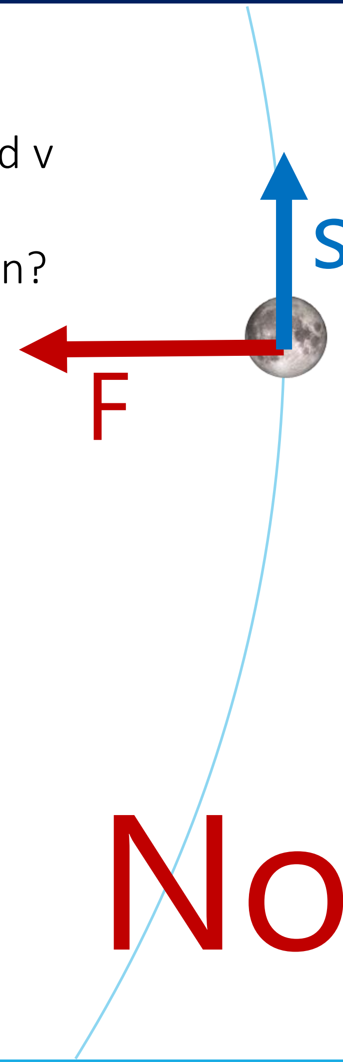


Doesn't change the tray's ENERGY

Think about it…

A particle of mass m is moving with constant speed v in uniform circular motion. What is the total work done by the centripetal force during one revolution?

A. Zero
B. $mv^2/2$
C. mv^2
D. $2\pi mv^2$



Is the earth’s gravity doing any work on the moon?

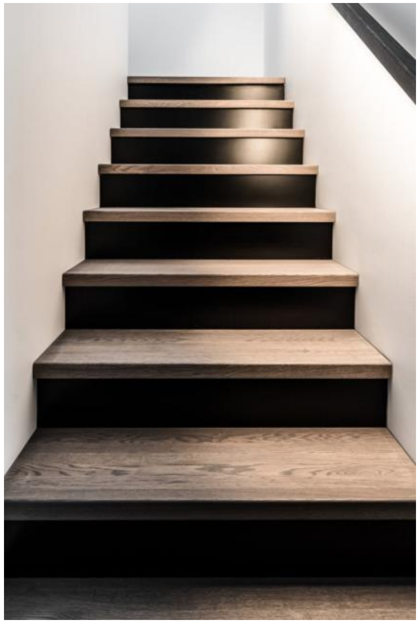
No

Think about it…

Two physics students, Maria and Paige, are going from the first floor to the second floor on their way to their next class.

- Maria walks up the 3 meter tall staircase in 15 seconds
- Paige runs up the 3 meter tall staircase in 5 seconds

If they both have a mass of 60 kg, which student does the most work?



Same

Work only depends on force and distance

What is Power?

Power is the **rate** at which **work** is done.

(how much work is done in a given amount of time)

How do you Calculate Power

Power = Work / Time

Symbols

$$P = W / t$$

Units

Watts

$$[W] = [J] / [s]$$

Say Watt?!?

Common Appliances	Estimated Watts
Blender	300-1000
Microwave	1000-2000
Waffle Iron	600-1500
Toaster	800-1500
Hair Dryer	1000-1875
TV 32" LED/LCD	50
TV 42" Plasma	240
Blu-Ray or DVD Player	15
Video Game Console (Xbox / PS4 / Wii)	40-140

We will be looking at power again this year when we discuss electricity…

Lesson Takeaways

- ❑ I can define and calculate the property of work
- ❑ I can calculate work when the force is at an angle to the direction of the motion
- ❑ I can equate work done on a system to the change in energy of an open system
- ❑ I can use the work-energy theorem to solve for an unknown
- ❑ I can identify situations where there is motion but no work being done

Elastic Potential Energy

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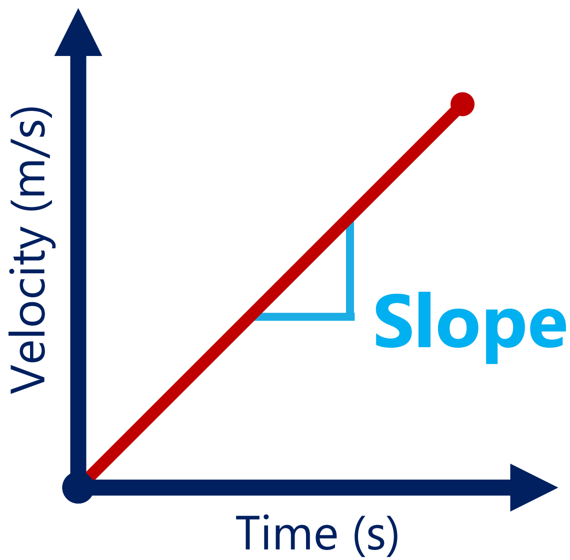
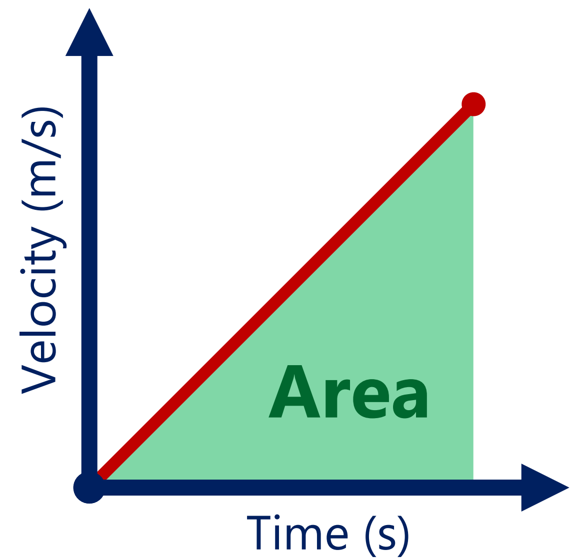
Calculating from a Graph





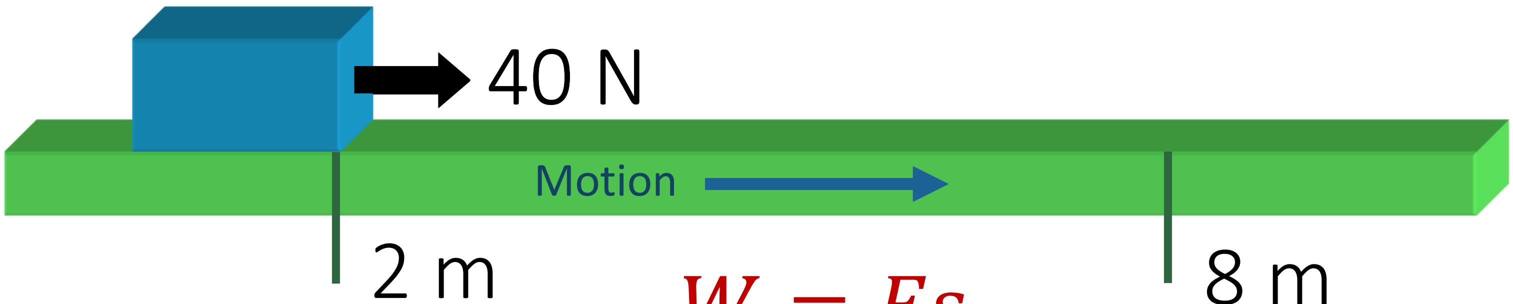
$$\frac{\Delta y}{\Delta x} = \frac{Velocity}{Time} = \frac{m/s}{s} = {}^{m}/_{s^2}$$

Acceleration

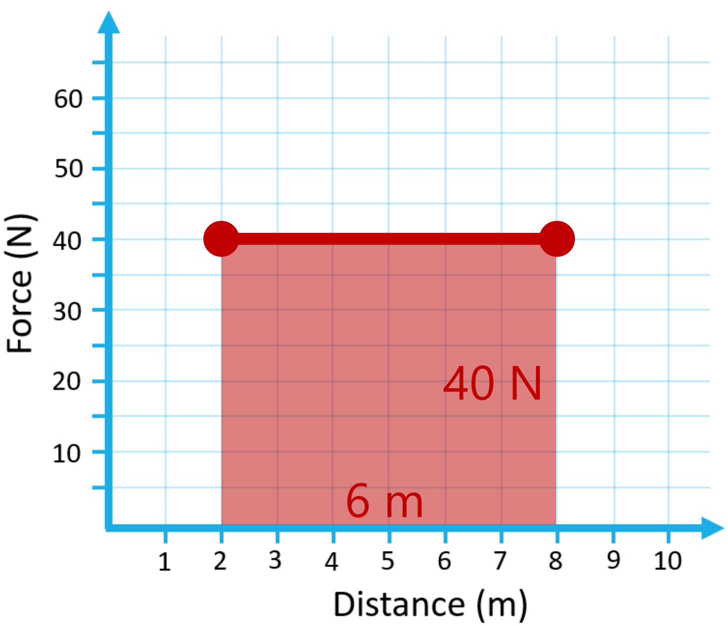
$$(x)(y) = (Velocity)(Time)$$
$$= \left(\frac{m}{s}\right)(s) = m$$

Displacement

Graph of Force vs Displacement



$$W = Fs$$



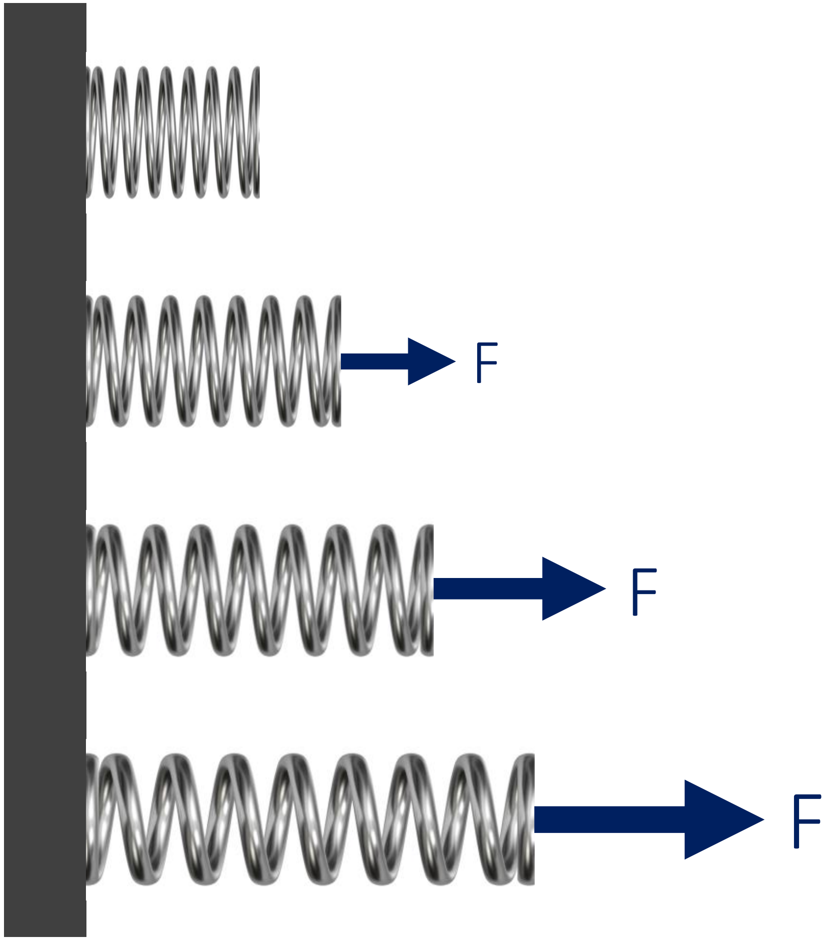
$$\begin{aligned} Area &= (6\ \mathrm{m})(40\ \mathrm{N}) \\ &= 240\ \mathrm{Nm} \\ &= \mathbf{240\ J} \end{aligned}$$

Work of a Varying Force

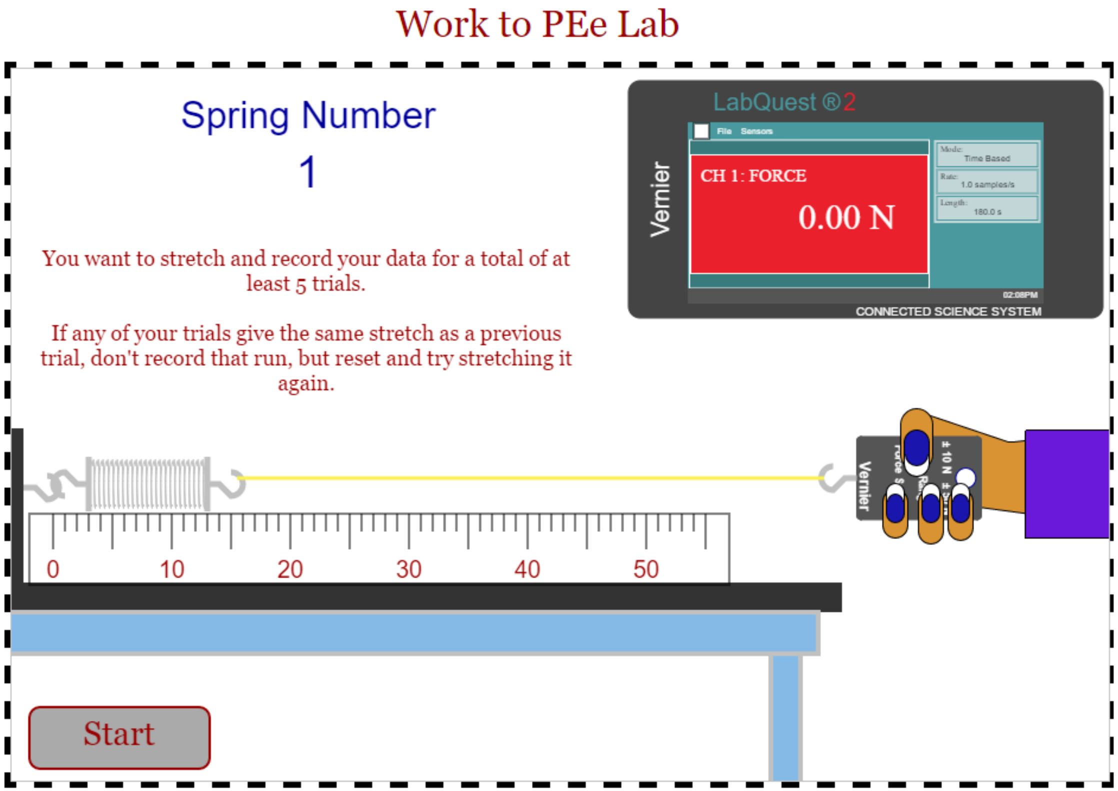
Our definition of work applies only for a constant force or an average force.

$$W = Fs\cos\theta$$

What if the force varies with displacement as with stretching a spring or rubber band?



What about a Varying Force?



[Click here for the simulation]()

Work of a Varying Force

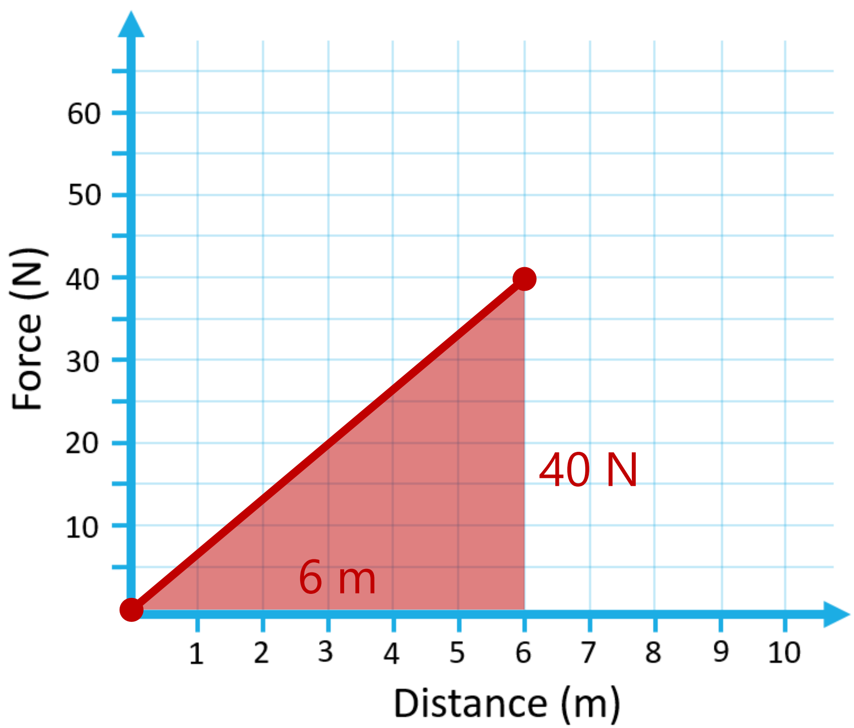
How can you calculate the work?

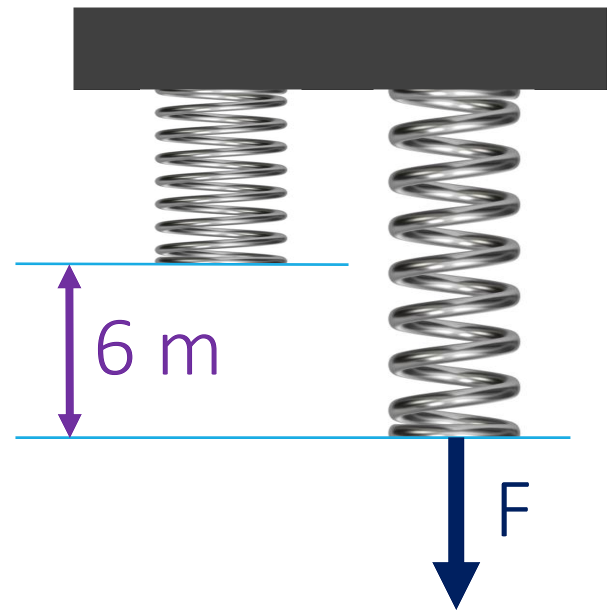
$$Area = \frac{1}{2}(10\text{ m})(40\text{ N})$$

$$= 200\text{ J}$$

Work of a Varying Force

What **work** is required to stretch this spring from x = 0 to x = 6 m?

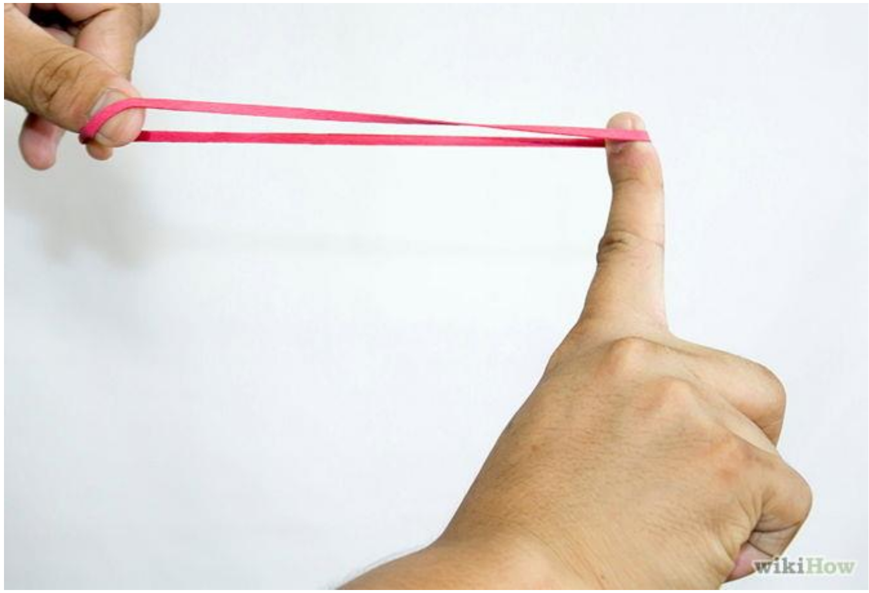




$$Work = \frac{1}{2}(6\ \mathrm{m})(40\ \mathrm{N})$$

$$= 120\ \mathrm{J}$$

Elastic Potential Energy



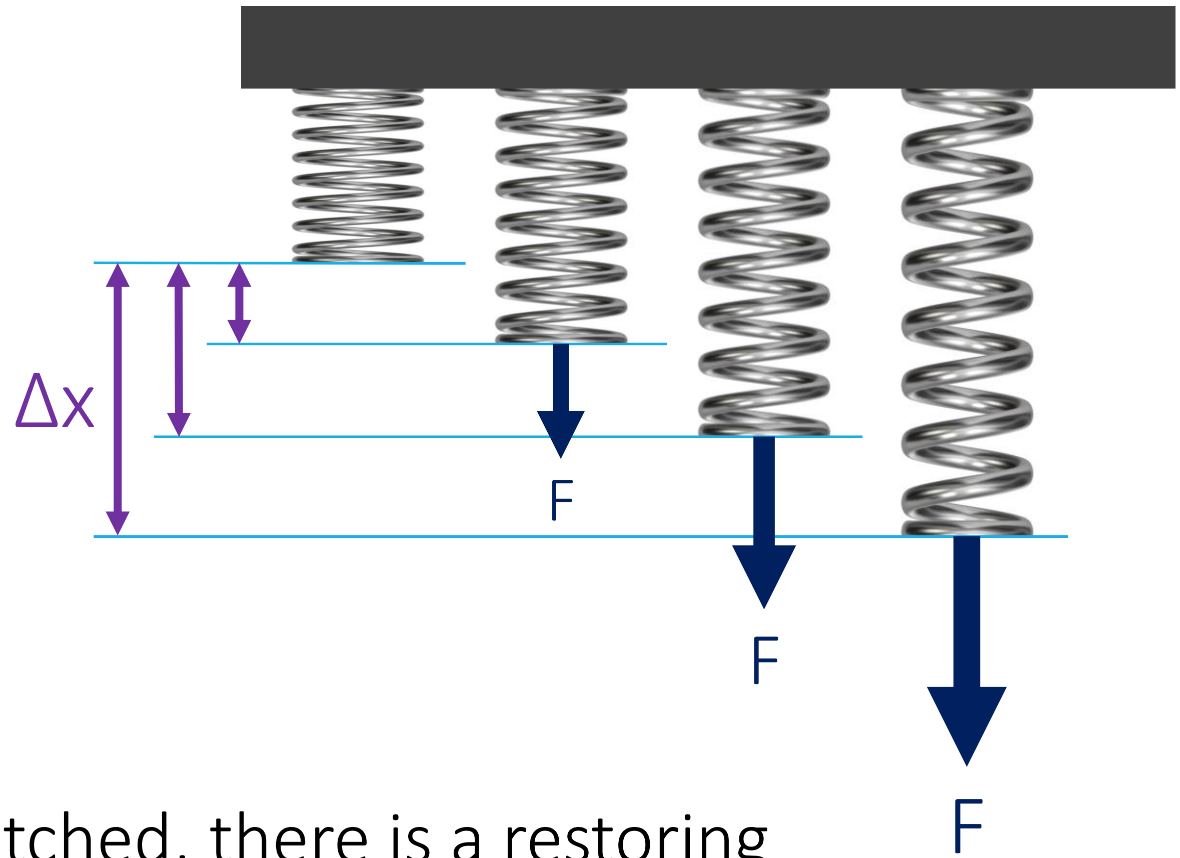
As the pull back distance increases elastic potential energy ___increases___

Hooke's Law

$$F = k\Delta x$$

**The spring constant k is a property of the spring*

$k \rightarrow [N\ m^{-1}]$



When a spring is stretched, there is a restoring force that is proportional to the displacement.

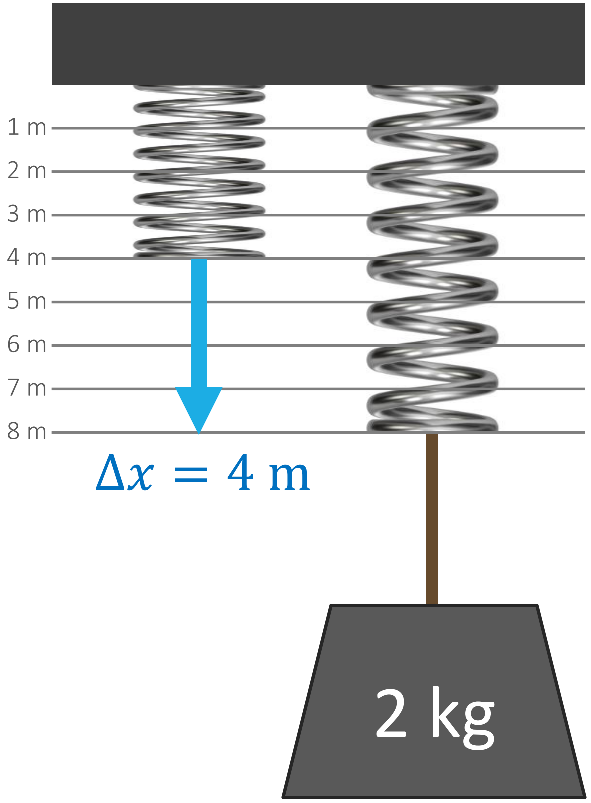
Try this...

A block with a mass of 2 kg is suspended from a spring and produces the displacement shown. What is the spring constant?

$$F = k\Delta x$$

$$(19.62\ \mathrm{N}) = k(4\ \mathrm{m})$$

$$\boxed{\boldsymbol{k = 4.9\ \mathrm{Nm}^{-1}}}$$



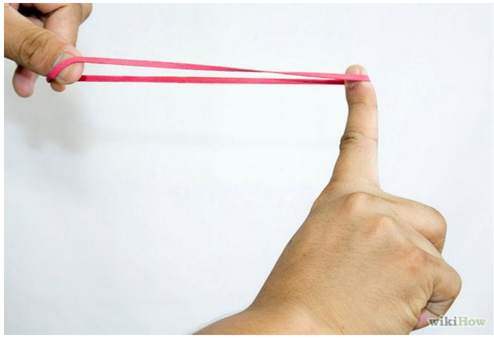
$$F_g = mg = (2)(9.81)$$

$$F_g = 19.62\ \mathrm{N}$$

Work and Energy

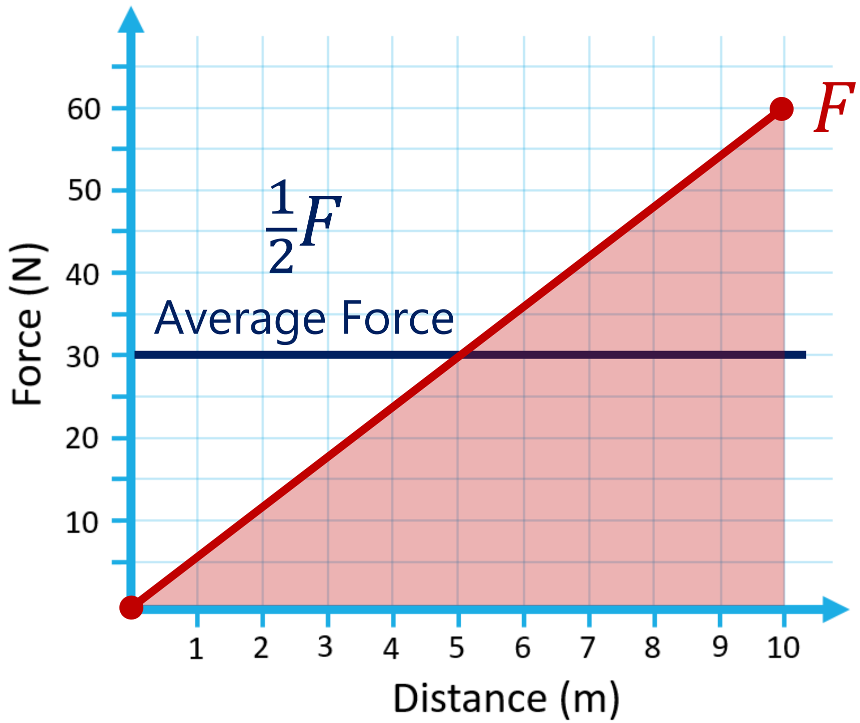
Work done on a system causes the system to gain or lose energy

Stretching or compressing a spring **stores energy**



Work of a Varying Force

Now that we know that F = kΔx, we can calculate the stored elastic potential energy with the work equation



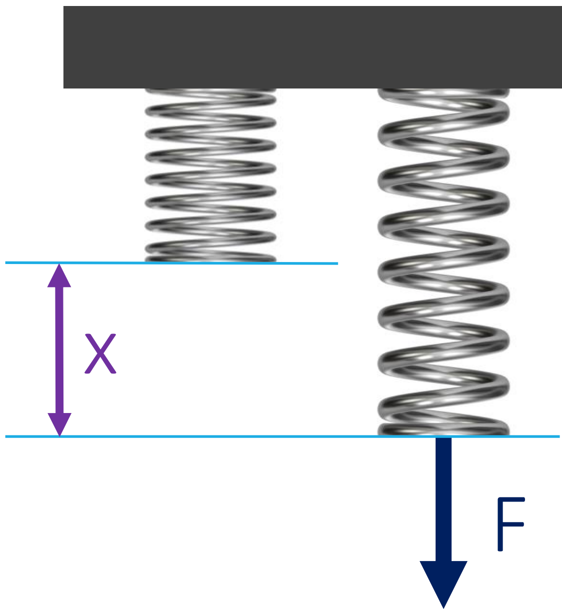
$$Work = Fs$$

$$= \left(\frac{1}{2}F\right)s$$

$$= \left(\frac{1}{2}k\Delta x\right)\Delta x$$

Elastic Potential $= \boldsymbol{\frac{1}{2}k\Delta x^2}$

Elastic Force and Work



$$F = k\Delta x$$

$$E_p = \frac{1}{2}k\Delta x^2$$

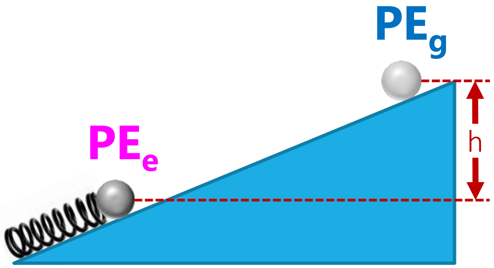
**The spring constant k is a property of the spring*

Data Booklet

Sub-topic 2.3 – Work, energy and power
$W = Fs\,cos\theta$
$E_K = \frac{1}{2}mv^2$ ← velocity KE
$E_P = \frac{1}{2}k\Delta x^2$ ← elastic PE_e
$\Delta E_P = mg\Delta h$ ← gravity PE_g
$\text{power} = Fv$
$\text{Efficiency} = \dfrac{\text{useful work out}}{\text{total work in}} = \dfrac{\text{useful power out}}{\text{total power in}}$

Conservation of Energy

How far up the 15° incline of a pinball table will a 0.1 kg pinball move after it is launched? The spring constant is 100 N/m and is compressed by 0.08 m.



$$\cancel{KE} + PE_e + \cancel{PE_g} = \cancel{KE} + \cancel{PE_e} + PE_g$$

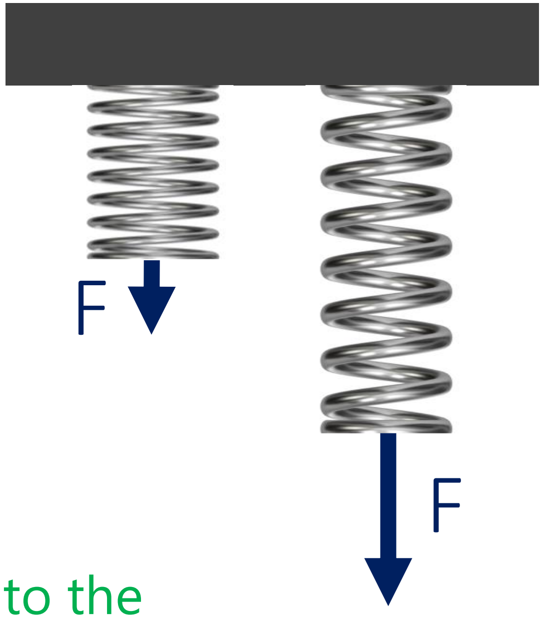
$$\frac{1}{2}k\Delta x^2 = mgh$$

$$\frac{1}{2}(100)(0.08)^2 = (0.1)(9.81)(h)$$

$$\boxed{\mathrm{h} = 0.33\ m}$$

Try this...

What **work** is required to stretch this spring ($k = 200\ \mathrm{N\ m^{-1}}$) from $\Delta x = 0.1$ m to $\Delta x = 0.4$ m?



Initial

$$\frac{1}{2}k\Delta x^2 = \frac{1}{2}(200)(0.1)^2 = 1\ \mathrm{J}$$

$$\frac{1}{2}k\Delta x^2 = \frac{1}{2}(200)(0.4)^2 = 16\ \mathrm{J}$$

Final

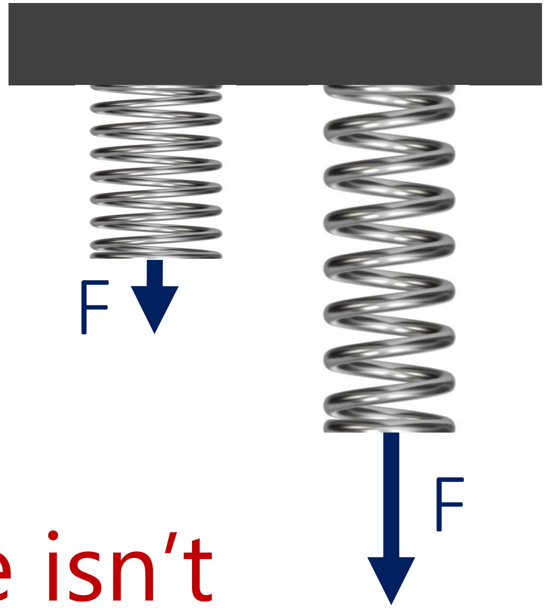
15 J

Added to the system through work on spring

$$\boxed{\boldsymbol{W = 15\ \mathrm{J}}}$$

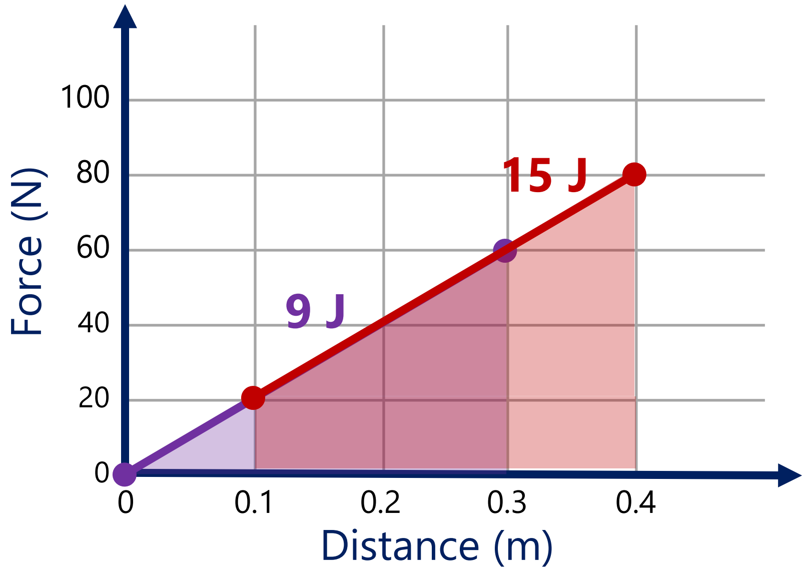
Try this...

What **work** is required to stretch this spring ($k = 200\ \text{N m}^{-1}$) from $\Delta x = 0.1$ m to $\Delta x = 0.4$ m?



Why not just use the stretch change?

$$\cancel{\tfrac{1}{2}k\Delta x^2 = \tfrac{1}{2}(200)(0.3)^2 = 9\ \text{J}}$$



The force isn't starting at zero!

$$\boxed{\boldsymbol{W = 15\ \text{J}}}$$

Example IB Question

An increasing force acts on a metal wire and the wire extends from an initial length l_0 to a new length l. The graph shows the variation of force with length for the wire. The energy required to extend the wire from l_0 to l is E. The wire then contracts to half its original extension. What is the work done by the wire as it contracts?

A. $0.25E$

B. $0.50E$

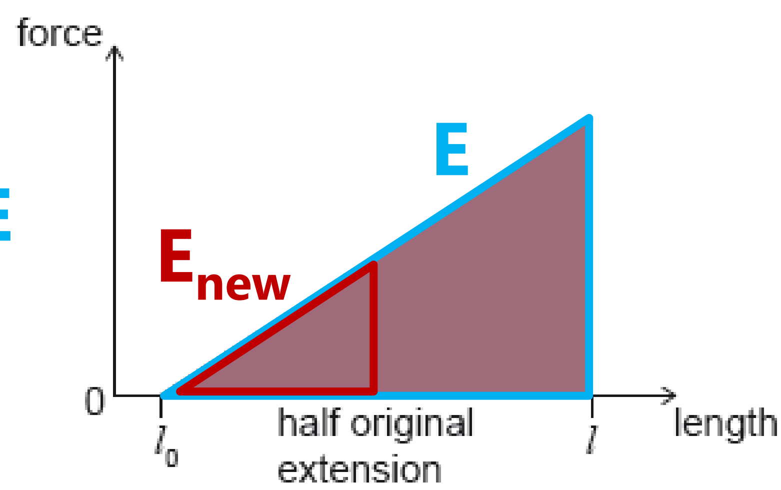
C. $\boxed{0.75E}$

D. E

$$E - E_{new}$$

$$E - 0.25E$$

$$\boxed{0.75E}$$



Lesson Takeaways

- ❑ I can calculate work as area bounded by a Force vs Distance graph
- ❑ I can use Hooke's Law to calculate the elastic force at a given displacement
- ❑ I can describe and calculate elastic potential energy

Conservation of Momentum

IB PHYSICS | ENERGY & MOMENTUM

What is Momentum??

“Inertia in Motion”

Which has more Momentum??

20000 kg

10 m/s

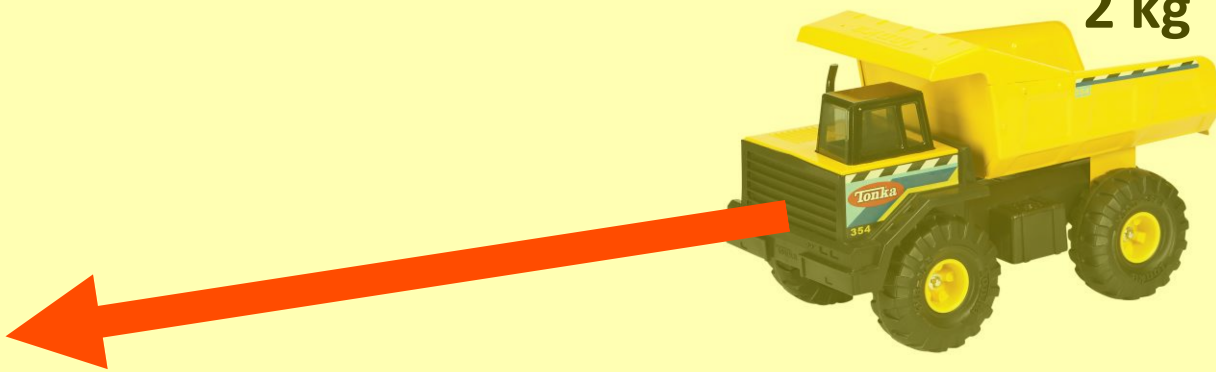
2 kg

10 m/s

Why?

More mass

Which has more Momentum??



Why?

More velocity

Momentum Equation

Momentum = mass × velocity

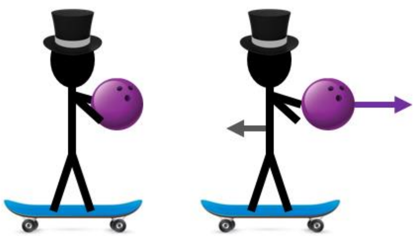
Symbols	$p = m \times v$
Units	$\text{kg m s}^{-1} = \text{kg} \times \text{m s}^{-1}$

IB Physics Data Booklet

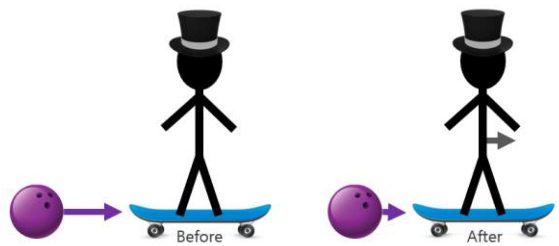
Sub-topic 2.4 – Momentum and impulse
$\boxed{p = mv}$ $F = \frac{\Delta p}{\Delta t}$ $E_K = \frac{p^2}{2m}$ $\text{Impulse} = F\Delta t = \Delta p$

Conservation of Momentum

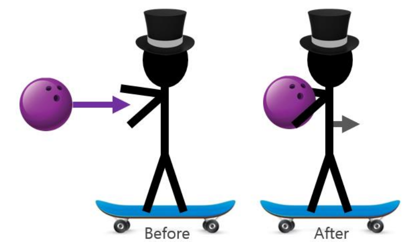
The total momentum of a system is constant



"Explosion"



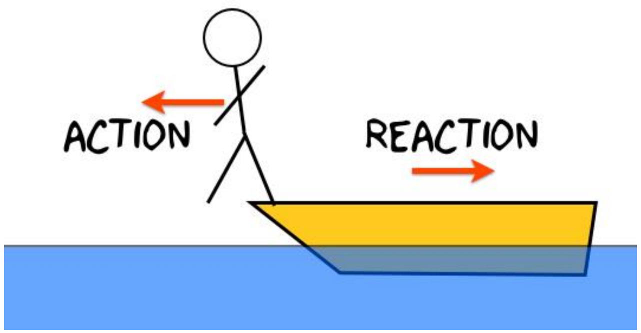
"Hit and Bounce"

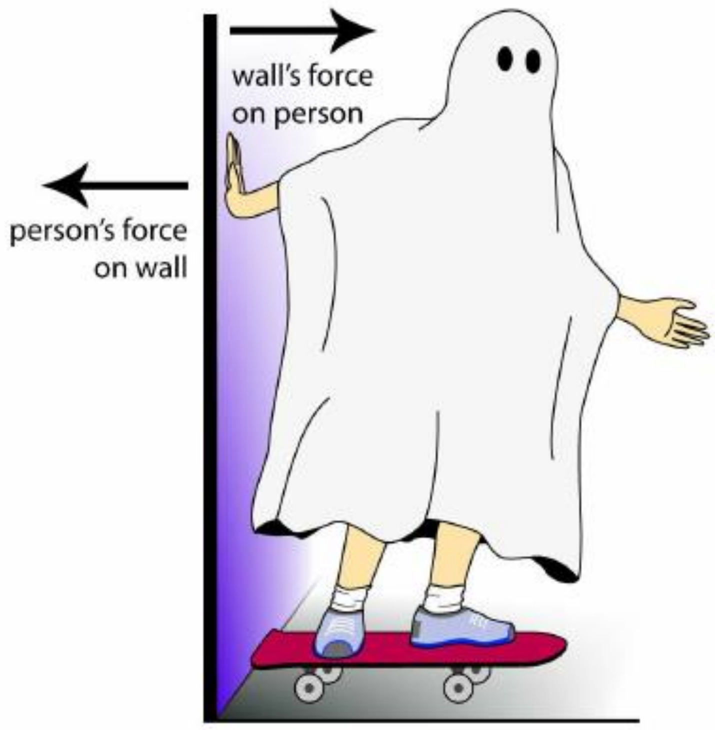


"Hit and Stick"

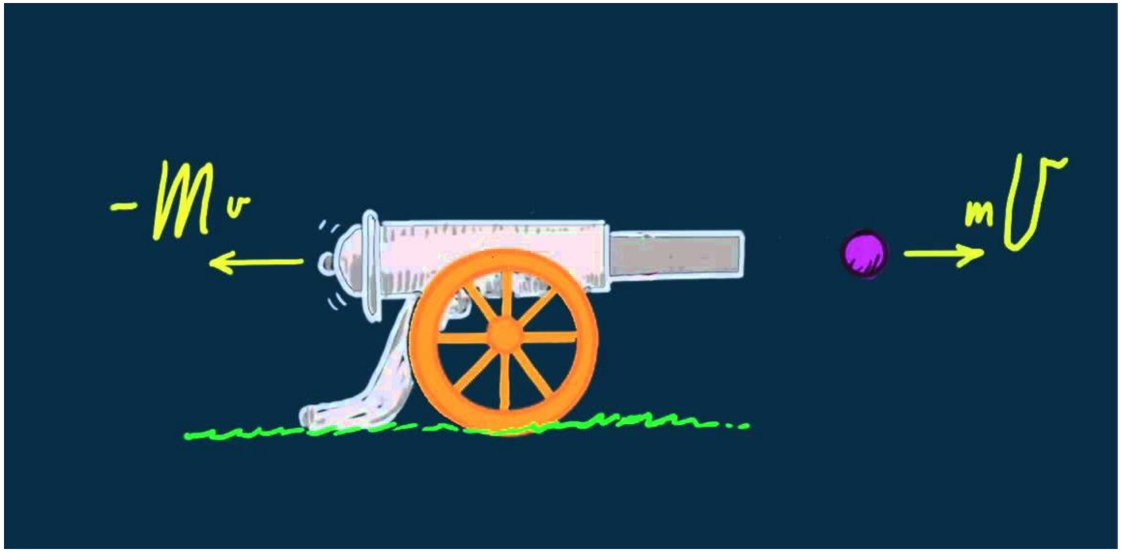
Newton's Third Law

For every action, there is an equal and opposite reaction





Conservation of Momentum



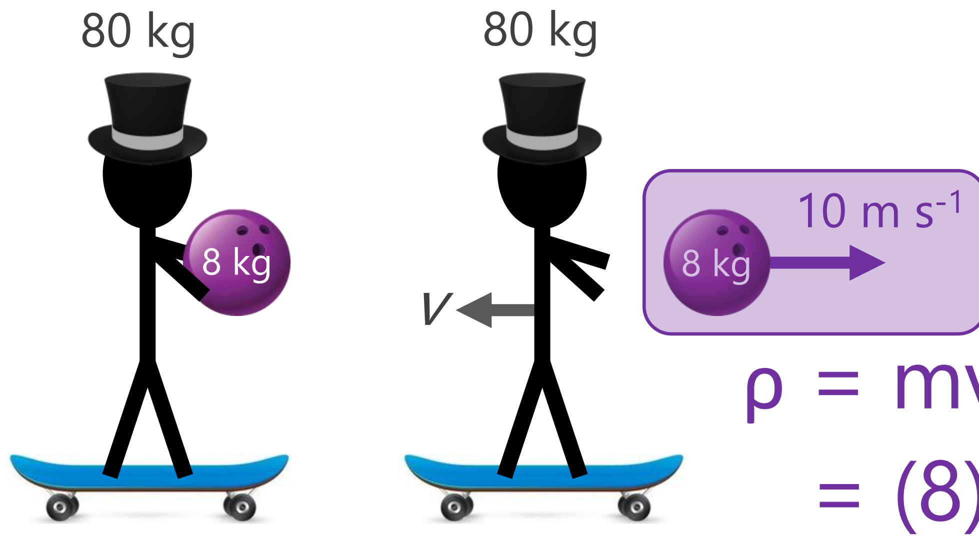
When a cannonball is fired out of a cannon, there is a recoil…

Equal and Opposite…

More mass → Less velocity

Less mass → More velocity

Explosion



$$\rho = mv$$
$$= (8)(10)$$
$$= 80 \text{ kg m s}^{-1}$$

$$mv = mv$$
$$(80)(v) = (8)(10)$$

$$\boxed{\mathbf{v = 1 \text{ m s}^{-1}}}$$

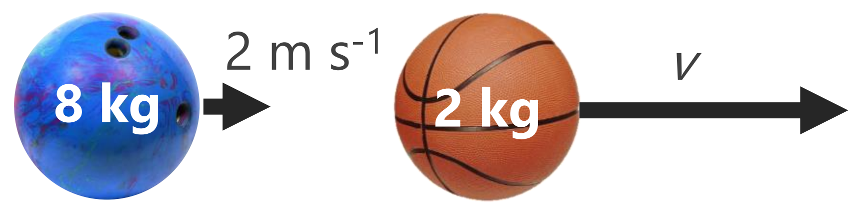
Hit and Bounce #1

Before After

$$(8)(10) + (2)(0) = (8)(2) + (2)(v)$$

$$80 + 0 = 16 + 2v$$

$$\boxed{v = 32\ \text{m s}^{-1}}$$



Hit and Bounce #2

Before After

$$(12)(8) + (18)(-4) = (12)(-5.5) + (18)(v)$$

$$96 + -72 = -66 + 18v$$

$$\boxed{v = 5\ \mathrm{m\ s^{-1}}}$$

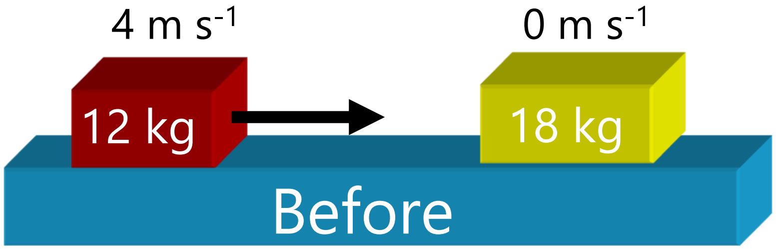
Hit and Stick

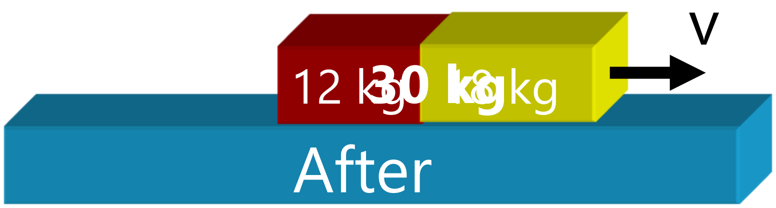
Before After

$$(12)(4) + (18)(0) = (30)(v)$$

$$96 + 0 = 30v$$

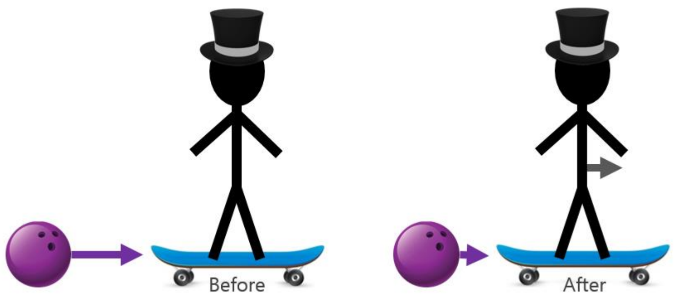
$$\boxed{v = 1.6\ \mathrm{m\ s^{-1}}}$$





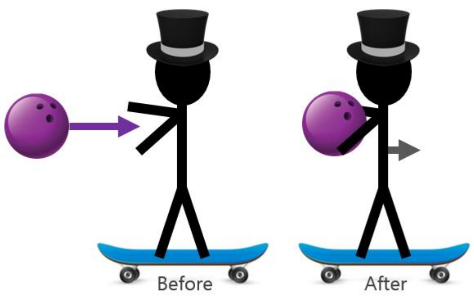
Elastic vs Inelastic

Elastic



Kinetic Energy is conserved

Inelastic



Kinetic Energy is <u>**not**</u> conserved

In both cases momentum is ALWAYS conserved

Try This...

A toy railcar of mass 2 kg travelling at 6 m s^{-1} collides with another railcar of mass 3 kg travelling at 4 m s^{-1} in the same direction. If after the collision the two trucks become joined together, what is their resulting velocity?

Before | After

$$(2)(6) + (3)(4) = (2+3)(v)$$

$$12 + 12 = 5v$$

$$\boxed{v = 4.8\ m\ s^{-1}}$$

Compare the total Kinetic Energy before and after:

Before

$$\frac{1}{2}(2)(6)^2 + \frac{1}{2}(3)(4)^2$$

$$36 + 24$$

$$\mathbf{60\ J}$$

After

$$\frac{1}{2}(2+3)(4.8)^2$$

$$\mathbf{57.6\ J}$$

System loses **2.4 J** of Kinetic Energy so it is an inelastic collision

Lesson Takeaways

- ❑ I can define and calculate momentum
- ❑ I can use the conservation of momentum to solve for missing variables in linear collisions
- ❑ I can describe the process required for explosion, hit and bounce, and hit and stick scenarios
- ❑ I can describe the difference between elastic and non-elastic collisions
- ❑ I can calculate the amount of energy retained in a non-elastic collision

Impulse

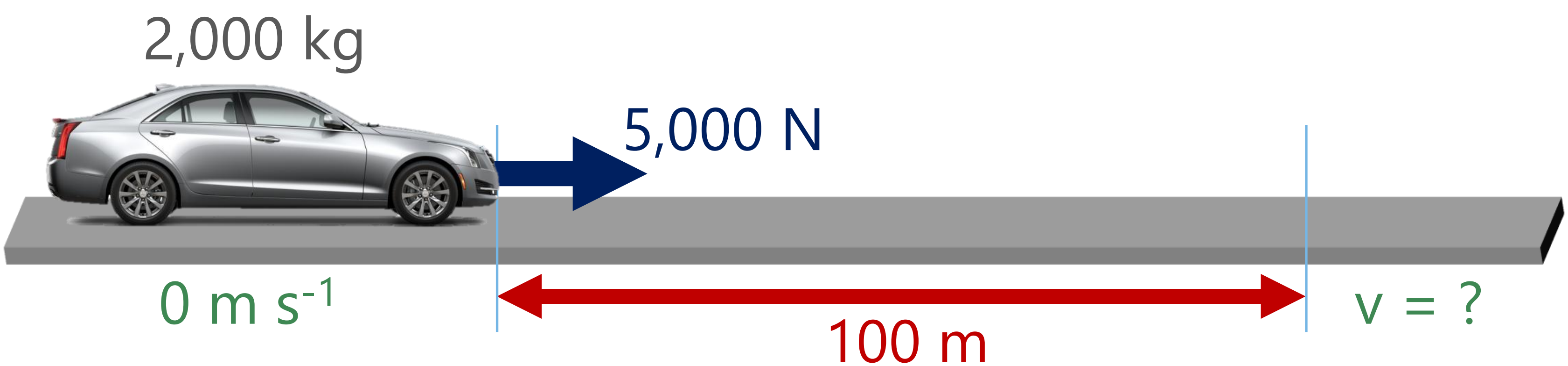
IB PHYSICS | ENERGY & MOMENTUM

IB Physics Data Booklet

Sub-topic 2.4 – Momentum and impulse
$\boxed{p = mv}$ $F = \dfrac{\Delta p}{\Delta t}$ $E_{\mathrm{K}} = \dfrac{p^2}{2m}$ $\text{Impulse} = F\Delta t = \Delta p$

Remember Work?

Work = Force × Distance



Initial Energy = 0 J

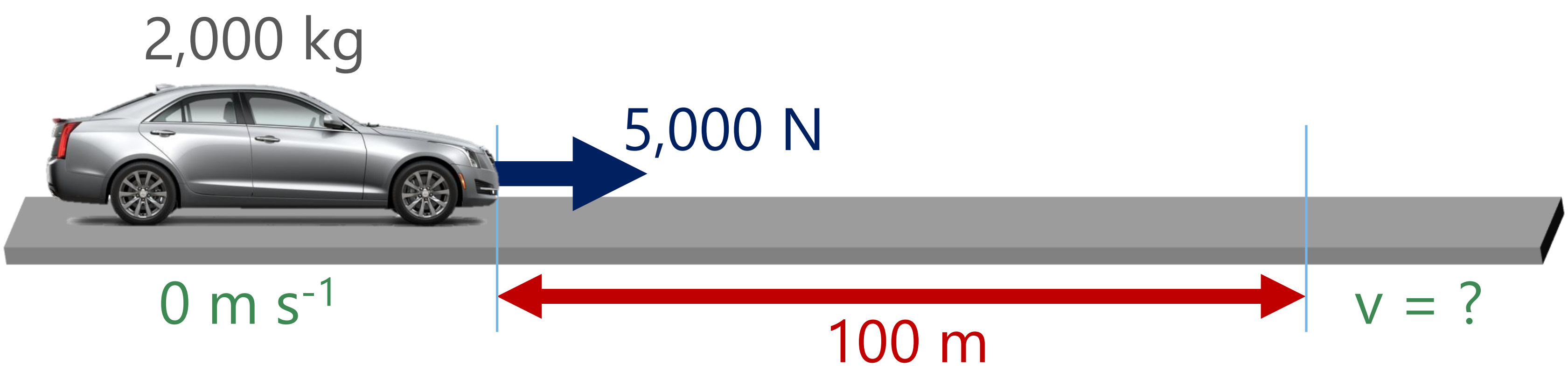
Work = (5,000 N)(100 m) = 500,000 J ← Energy added to system

Final Energy = 500,000 J = ½mv^2 = ½(2,000 kg)v^2

Final Velocity = v = 22.36 m s^{-1}

Introducing Impulse

Impulse = Force × ___Time___  8.94 s



Initial Momentum = 0 kg m s^{-1}

Impulse = (5,000 N)(8.94 s) = 44,700 kg m s^{-1} ← Momentum added to system

Final Momentum = 44,700 kg m s^{-1} = mv = (2,000 kg)v

Final Velocity = v = 22.35 m s^{-1}

Impulse

Work → Change in Energy

Impulse → Change in __Momentum__

What about Units? $[N] = [kg][m\ s^{-2}]$

Impulse = $F \times t = [N][s] = [kg][m\ s^{-2}][s]$

Impulse = **[N s]** or **$[kg\ m\ s^{-1}]$***

*same unit as momentum

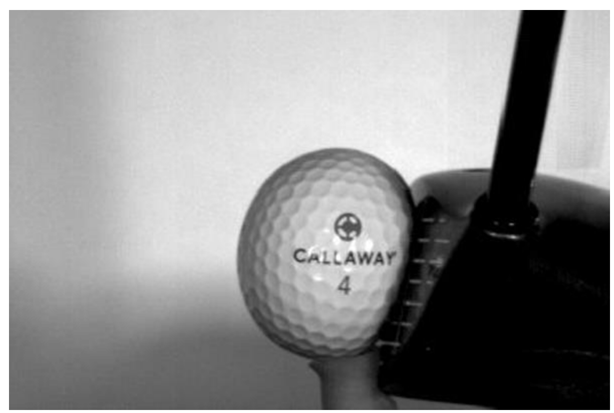
IB Physics Data Booklet

Sub-topic 2.4 – Momentum and impulse
$p = mv$ $\boxed{F = \frac{\Delta p}{\Delta t}}$ $E_K = \frac{p^2}{2m}$ $\boxed{\text{Impulse} = F\Delta t = \Delta p}$

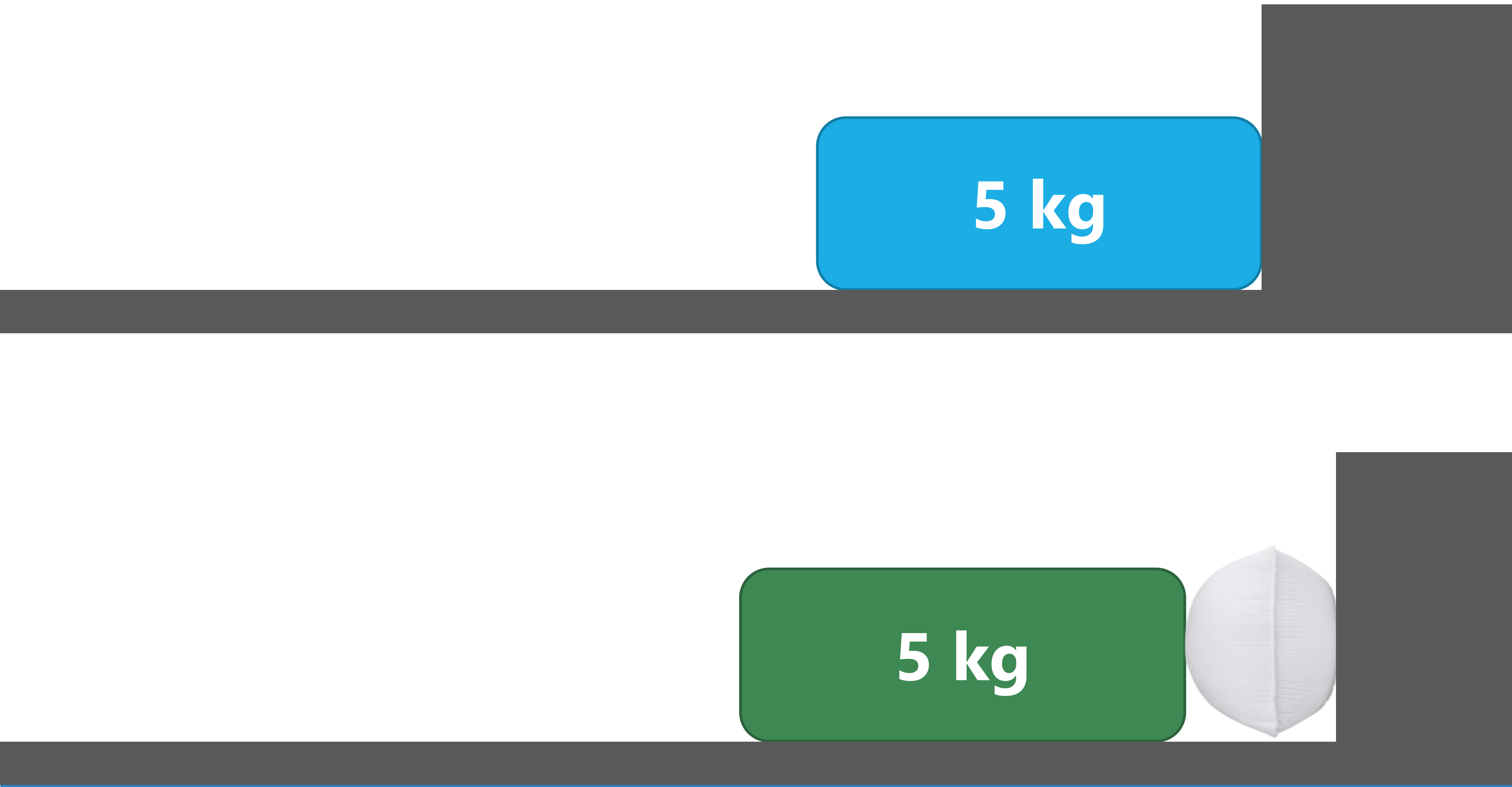
Same equation

Impulse and Momentum

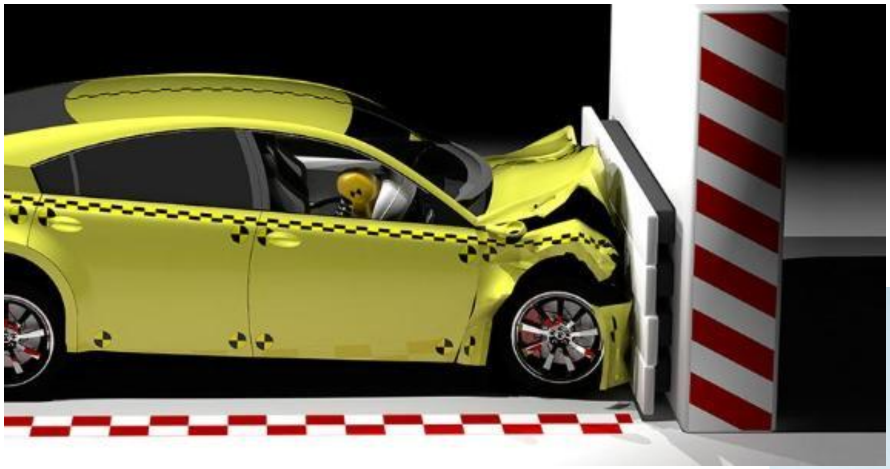
Impulse can act to increase or decrease an object's momentum

Final Velocity $0\ m/s$	Initial Velocity $0\ m/s$	Initial Velocity $0\ m/s$
		

How are these the same? different?



Impulse → Slowing Down



How can we decrease the force acting on an object?

Impulse and Momentum

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

Short Time

Large Force

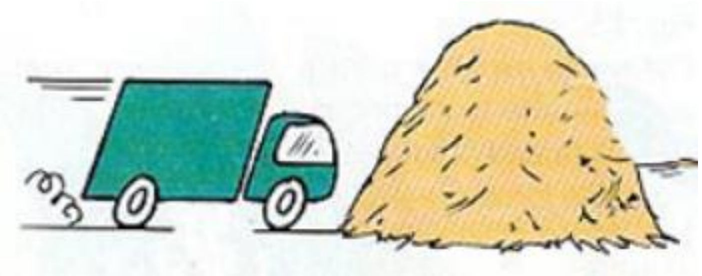
$F \times \Delta t$

$F \times \Delta t = F \times \Delta t$

Same Mass

Same Momentum

Same Impulse



Long Time

Small Force

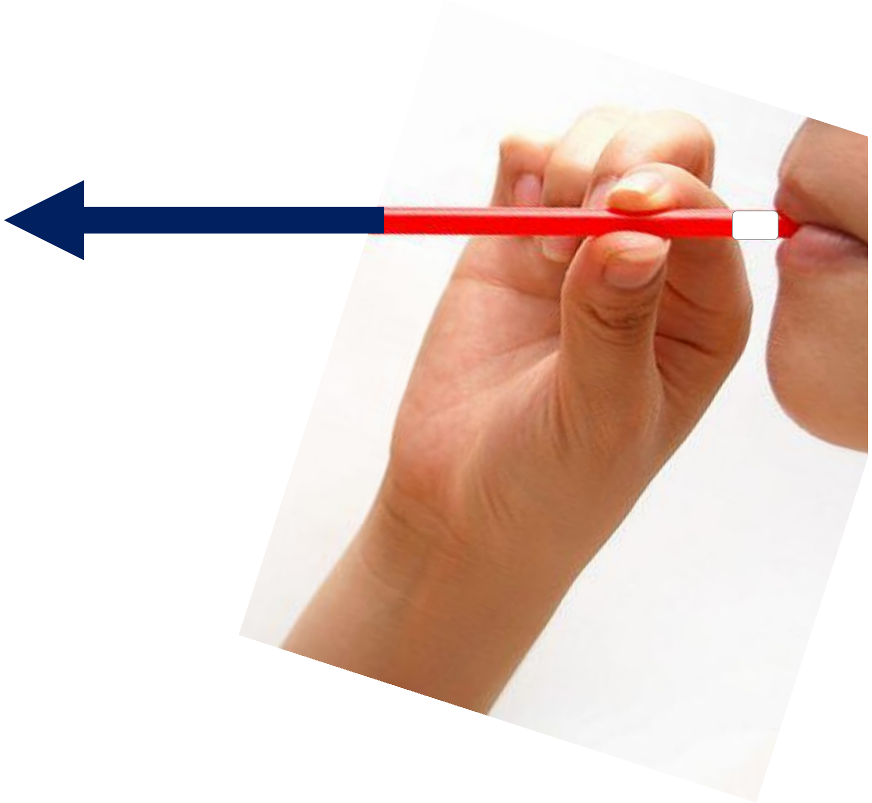
$F \times \Delta t$

Impulse to Speed Up

Should a cannon have a long or short barrel to produce to largest final velocity? Why?

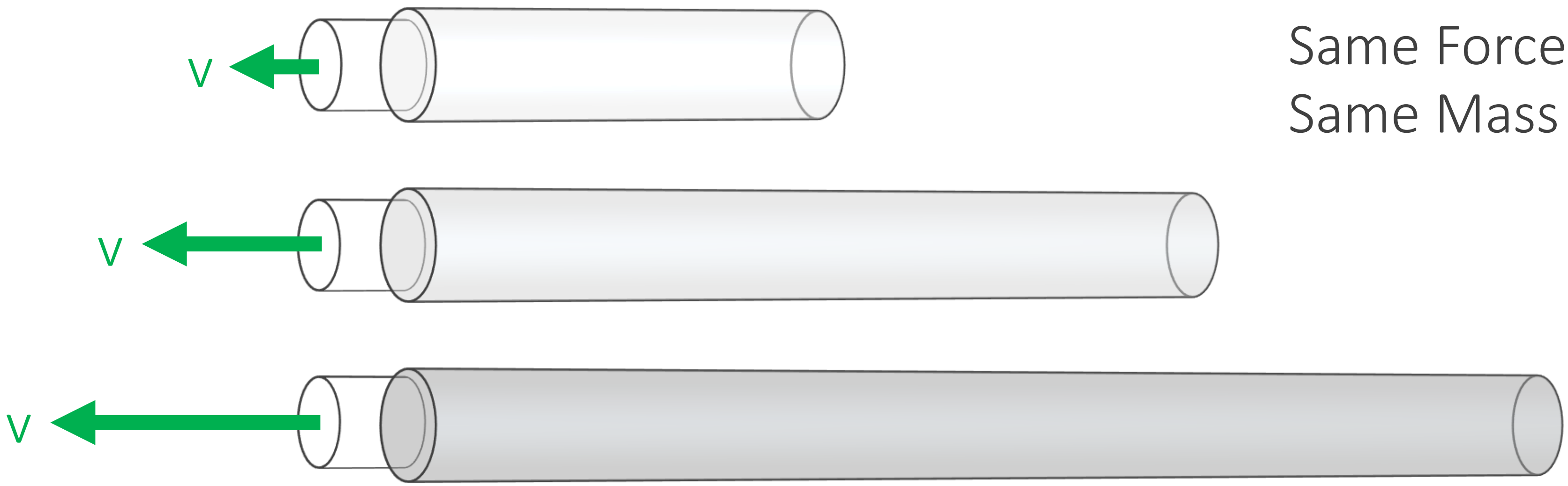
Both designs will experience the same force but the long barrel experiences that force for more time and creates a larger impulse / change in momentum

Marshmallow Shooter



Marshmallow Shooter

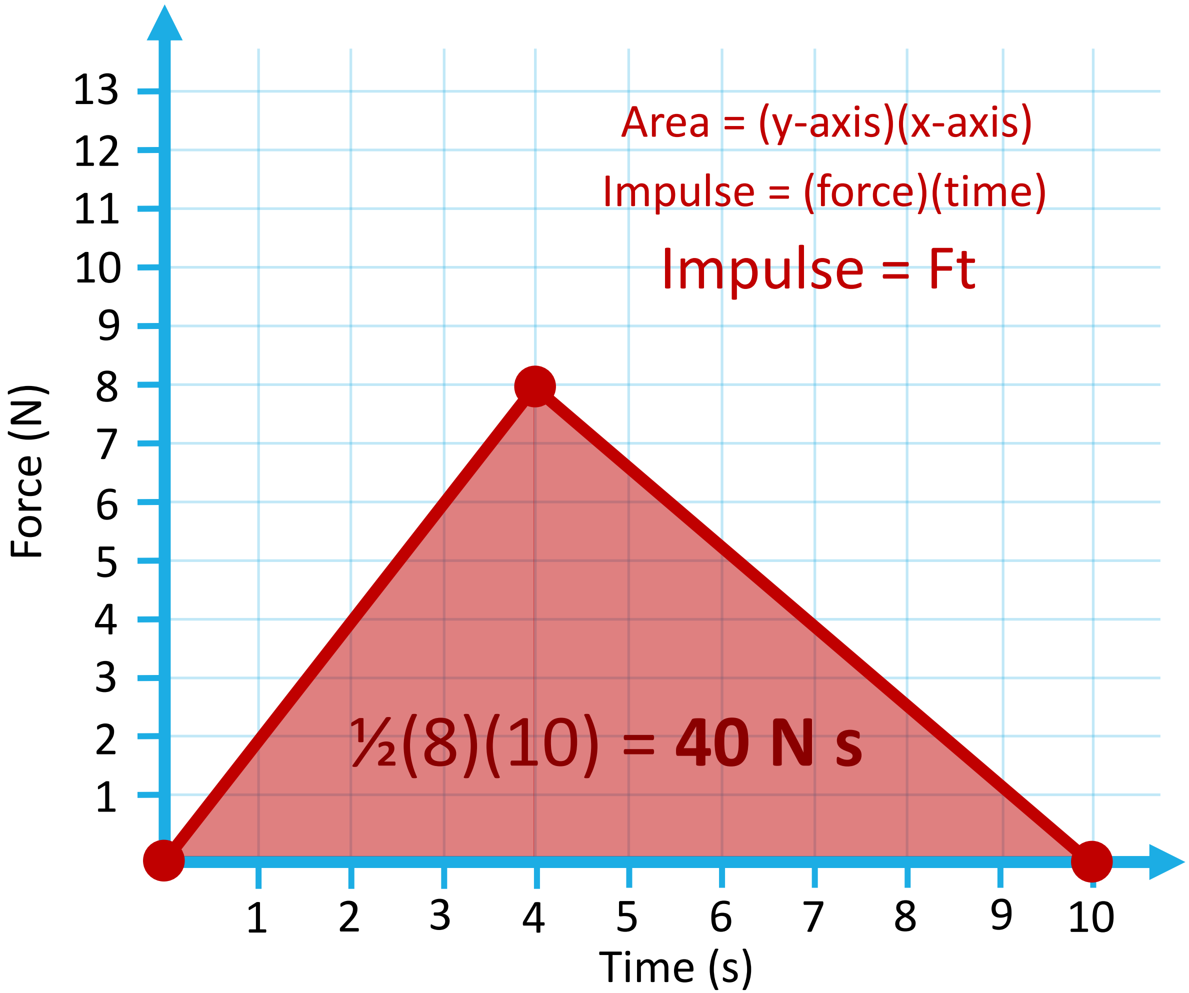
$$Impulse = F\Delta t = \Delta p = m\Delta v$$



Same Force
Same Mass

More Time → More Velocity

What if the force isn't constant?

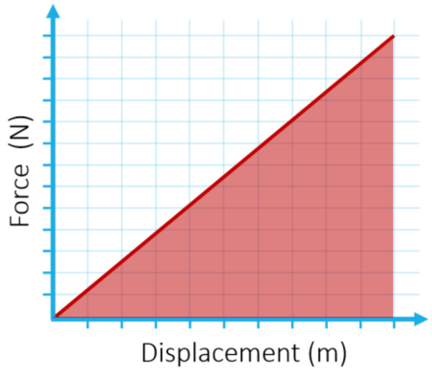


Area = (y-axis)(x-axis)

Impulse = (force)(time)

Impulse = Ft

Remember how we found work done by a varying force?

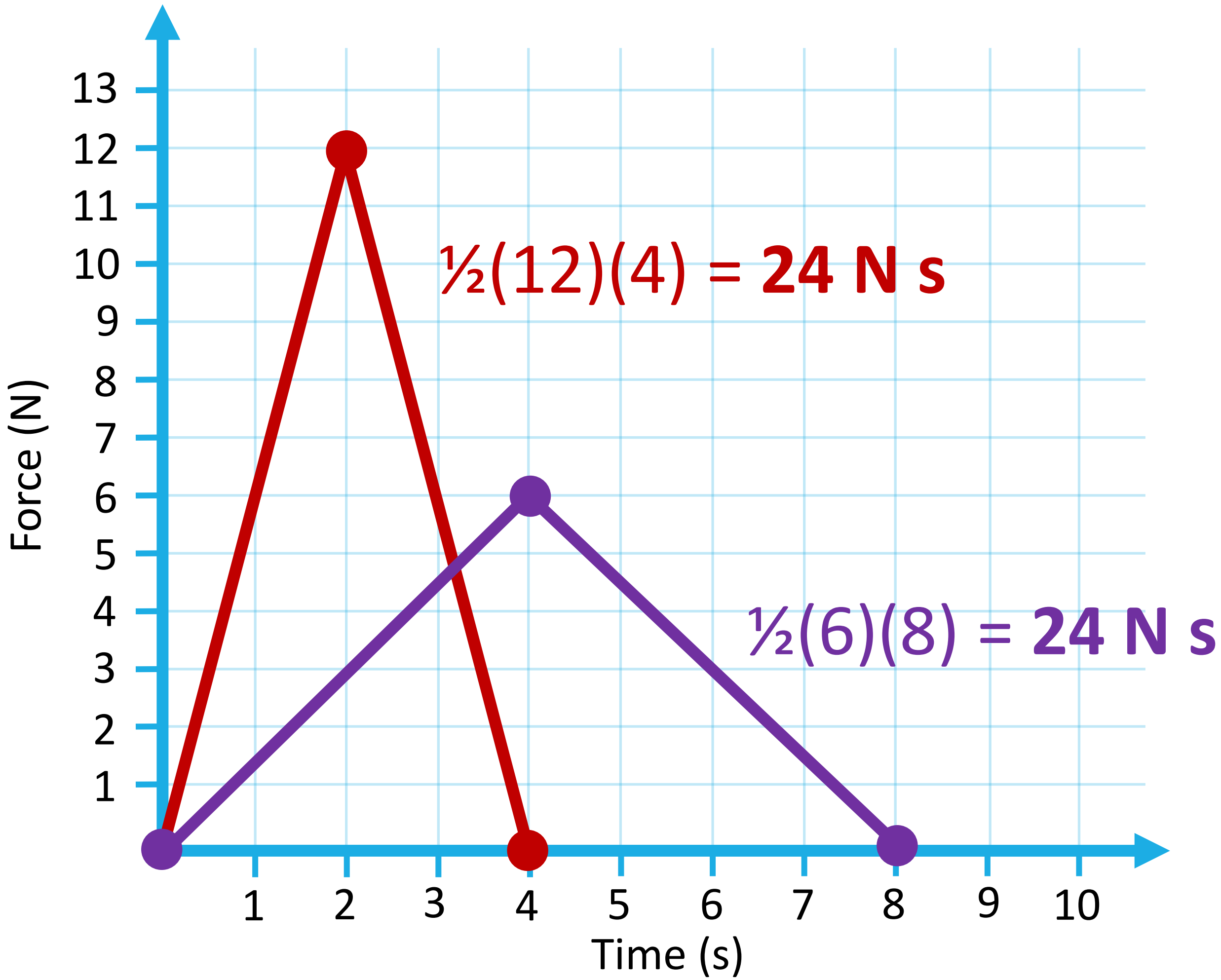


Area = (y-axis)(x-axis)

Work = (force)(displacement)

W = Fs

Which impulse is larger?

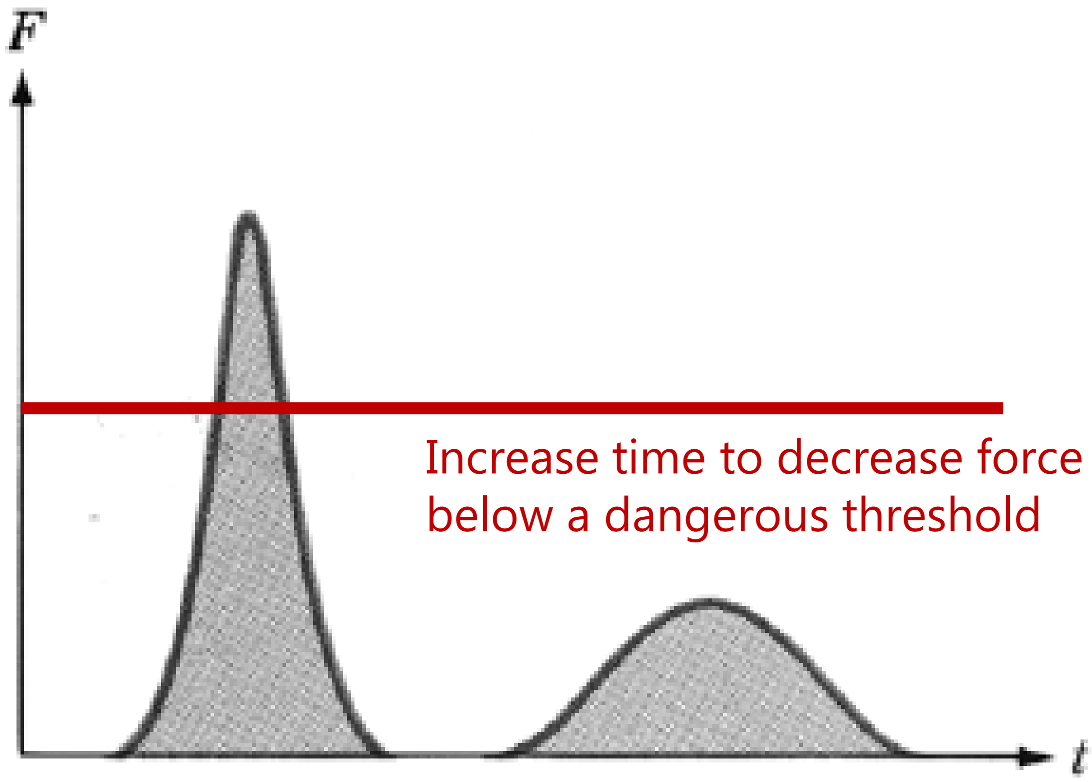


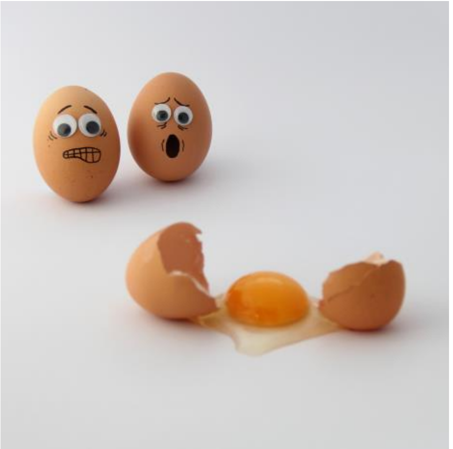
Same

Twice the time

Half the force

The force matters!





Lesson Takeaways

- ❑ I can describe the meaning of impulse and how it is related to momentum change
- ❑ I can conceptually describe how to decrease the force experienced in a collision
- ❑ I can determine the impulse of a collision from a force vs time graph

Impulse & Momentum Calculations

IB PHYSICS | ENERGY & MOMENTUM

Impulse Review

Work → Change in Energy

Impulse → Change in Momentum

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

Impulse Slowing Down

Short Time

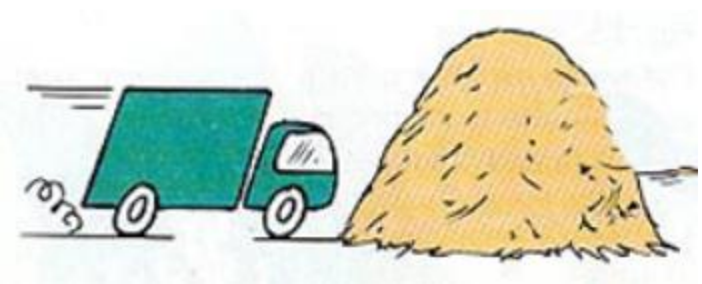
Large Force

$F \times \Delta t$

Same Mass

Same Momentum

Same Impulse



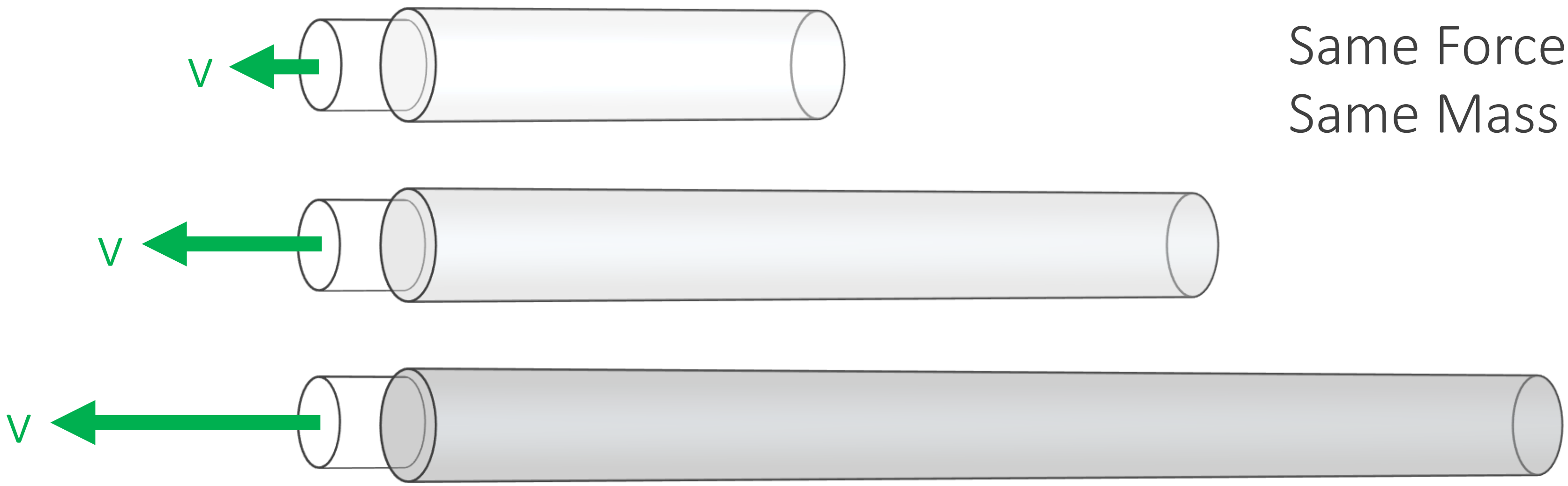
Long Time

Small Force

$F \times \Delta t$

Marshmallow Shooter

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



Same Force
Same Mass

More Time → More Velocity

Slapshot!

A hockey puck has a mass of 0.115 kg. A player takes a slap shot which exerts a force of 31.0 N for 0.15 sec. How fast will the puck be moving?

Initial Momentum → Impulse Added → Final Momentum

Initial Momentum = 0 kg m s^{-1}

Impulse = $F\Delta t = (31 \text{ N})(0.15 \text{ s}) = 4.65 \text{ kg m s}^{-1}$

Final Momentum = $4.65 \text{ kg m s}^{-1} = mv = (0.115 \text{ kg})v$

Final Velocity = v = **40.4 m s^{-1}**

Impulse and Momentum

The 440 newton Liquid Apogee Motor (LAM) of India's Mars Orbiter Spacecraft, was successfully fired for a duration of 3.968 seconds on September 22, 2014. This operation of the spacecraft's main liquid engine was also used for the spacecraft's trajectory correction and changed its velocity by 2.18 m s^{-1}. What was the mass of the spacecraft at the time of this engine firing?

$$\text{Initial Momentum} \xrightarrow{\text{Impulse Added}} \text{Final Momentum}$$

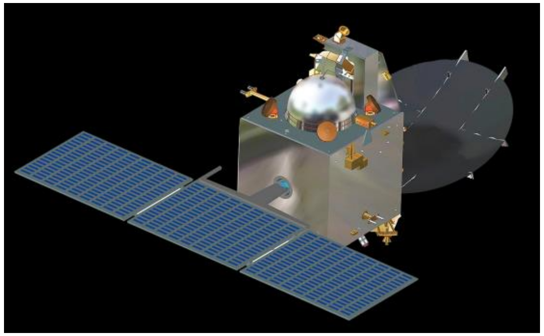
$\boxed{\text{Impulse} = F\Delta t = \Delta p}$

Impulse = $F\Delta t$ = (440 N)(3.968 s) = 1746 kg m s^{-1}

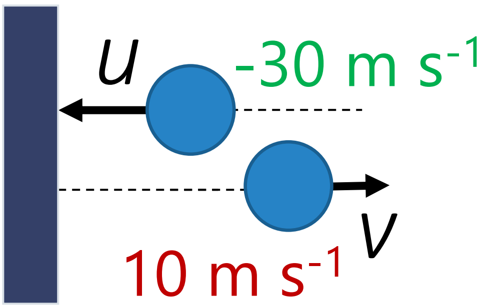
Change in Momentum = 1746 kg m s^{-1} = (m)(Δv)

1746 kg m s^{-1} = (m)(2.18)

m = 801 kg



Direction Matters

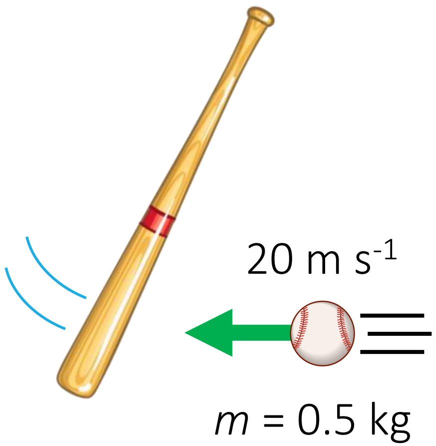


Assume *u* is 30 m s^{-1} to the left and *v* is 10 m s^{-1} to the right.
What is the change in velocity?

Change in Velocity = 40 m s^{-1}

Try This...

A **500 g** baseball moves to the left at **20 m s^{-1}** striking a bat. The bat is in contact with the ball for **0.002 s**, and it leaves in the opposite direction at **40 m s^{-1}**. What was average force on ball?



Initial Momentum

$p = (0.5)(-20)$

-10 kg m s^{-1}

Impulse Added

Δp

30 kg m s^{-1}

Final Momentum

$p = (0.5)(40)$

20 kg m s^{-1}

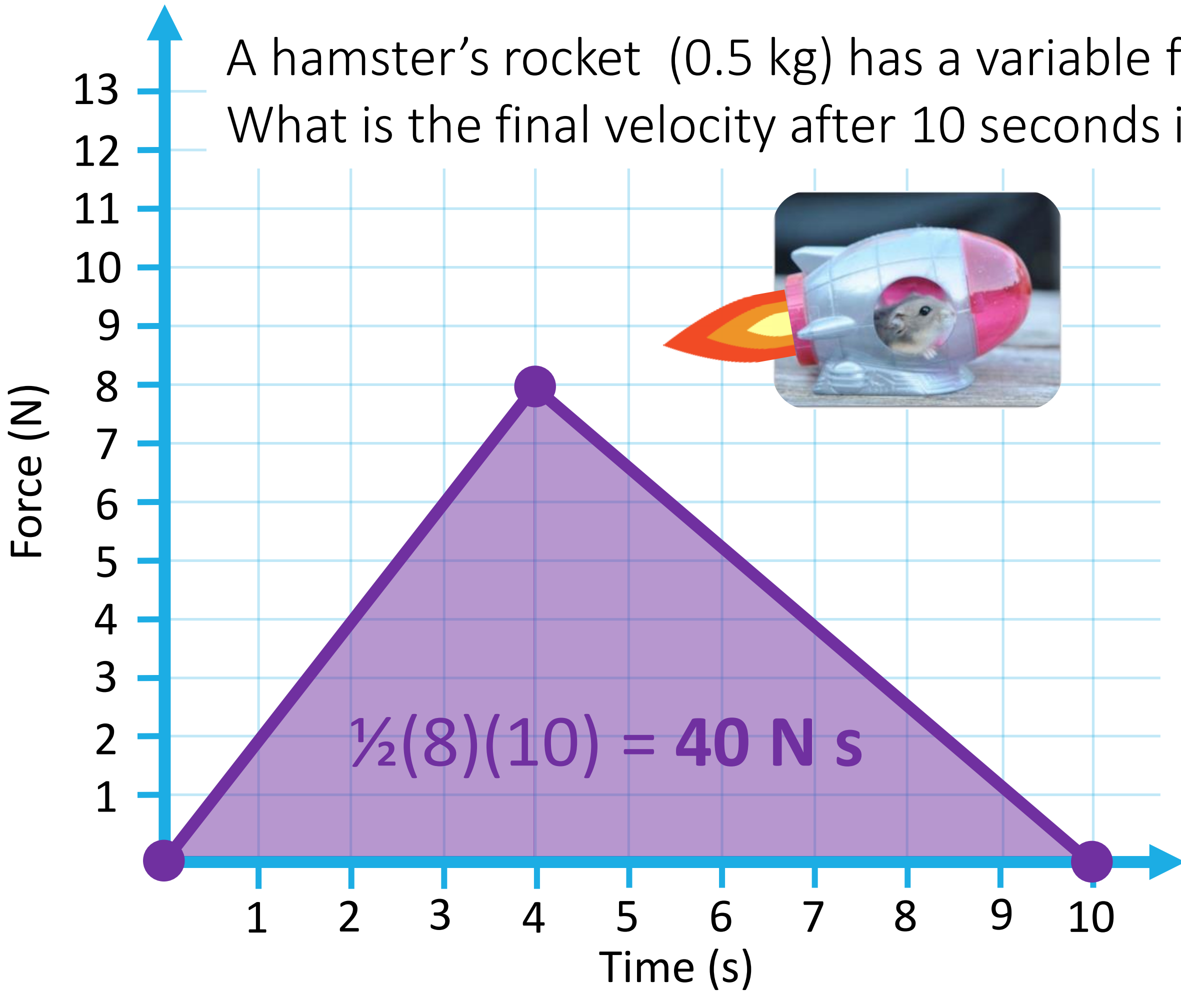
Impulse = $F\Delta t = \Delta p$

Impulse = $F(0.002\ s) = 30$ kg m s^{-1}

F = 15,000 N

Impulse from a Graph

A hamster’s rocket (0.5 kg) has a variable force as shown in the graph. What is the final velocity after 10 seconds if it starts from rest?



Initial Momentum → Impulse Added → Final Momentum

0 → **40** → **40**

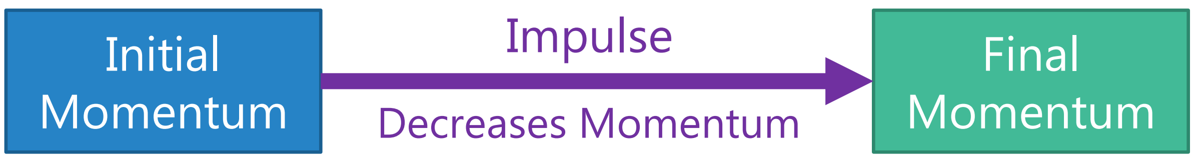
$$p = mv$$

$$40 = (0.5)v$$

$$v = 80 \text{ m/s}$$

Try This...

Kara Less was applying her makeup when she drove into South's busy parking lot last Friday morning. Unaware that Lisa Ford was stopped in her lane, Kara rear-ended Lisa's rental car. Kara's 1300-kg car was moving at 5 m s^{-1} and stopped in 0.4 seconds. What was the force?



Initial Momentum = mv = (1,300)(5) = 6,500 kg m s^{-1}

Final Momentum = 0 kg m s^{-1}

Impulse = 6,500 kg m s^{-1} = (F)(0.4 s)

Force = F = **16,250 N**

Lesson Takeaways

- ❑ I can use impulse and momentum to solve for an unknown **force**
- ❑ I can use impulse and momentum to solve for an unknown **velocity**
- ❑ I can calculate the change in velocity when there is a direction change
- ❑ I can calculate change in momentum from a Force vs Time graph