


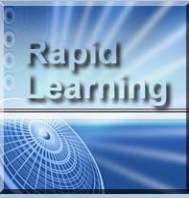
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 **Work, Power and Energy**

**Physics Rapid Learning Series**

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## Learning Objectives

By completing this core tutorial, you will:

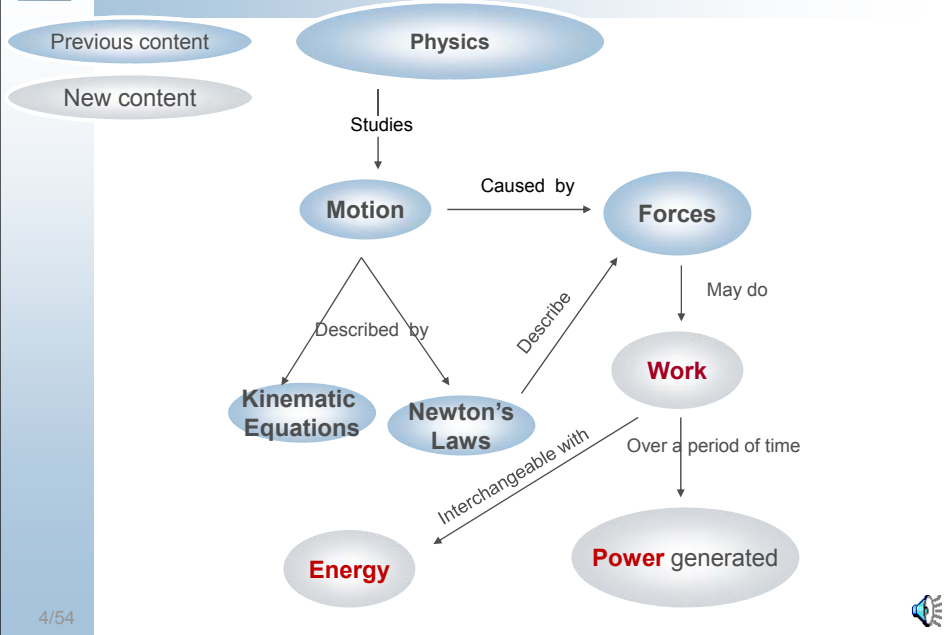


- Utilize the correct force component, and calculate the work done on an object .
- Calculate the power generated.
- Calculate kinetic and potential energy
- Utilize the concept of conservation of energy

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## Concept Map




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## Basic Concepts



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## Work


In physics, commonly used terms may have slightly different definitions from normal usage.

The quantity work is a perfect example of this.

Thus, the physics definition of work may not be in complete agreement with the everyday definition.



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## Definition - Work

**Work** - The work ,  $W$ , done by a constant force on an object is defined as the product of the component of the force along the direction of displacement and the magnitude of the displacement.



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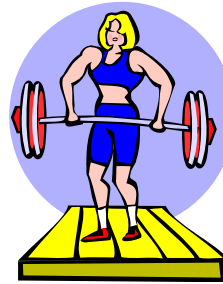
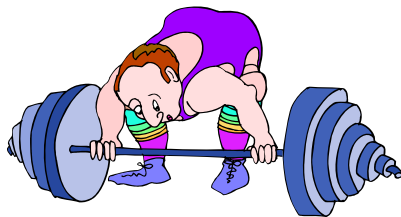


## Work Formula

Work = Force x Distance

$$W = Fd$$

Thus, work depends on force applied in the direction of movement, and distance moved in that direction.



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## Formula Hint

$$W = Fd$$

However, since  $F = ma$        $W = mad$

**Mass, kg**

**acceleration,  
m/s<sup>2</sup>**

Also, since  $a = \frac{\Delta v}{\Delta t}$        $W = m \left( \frac{\Delta v}{\Delta t} \right) d$

**Change in  
velocity, m/s**

**Change in  
time, s**

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## Work Units

Since  $W = Fd$

Work is  
measured in  
 $N \cdot m$



James Joule

One  $N \cdot m$  is also  
called 1 Joule.

This is  
equivalent to  
 $kg \cdot m^2/s^2$

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## Work or No Work?

How much work is our mighty weight lifter doing if he steadily holds the 1000 N barbell 2m above his feet?



The weightlifter holding the bar in a stationary position does **NO** work since distance equals zero. The force exerted is irrelevant since the distance moved equals 0.

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## Vectors Involved With Work



Although work is a scalar quantity (magnitude only), the quantities that are used to calculate it are vectors (magnitude and direction).

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 **Consider the Direction**


When calculating work, only the force that is applied in the direction of motion is considered.

If a force acts at an angle, only the component of that force in the direction of motion should be used to calculate the work done.

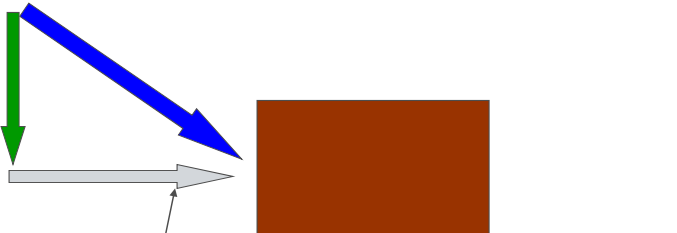
Thus, the work formula is often given as

$$W = Fd \cos \theta$$


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 **Component Diagram**

The **applied force** pushes both **vertically** and **horizontally**. Since the box is moving horizontally, only that component is used in the calculation of work done.



**Component of force used in work calculation since this is the direction of motion.**

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## Work Example Calculation

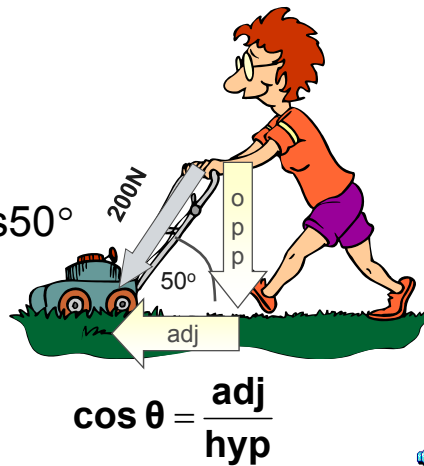
If a person pushes a lawnmower handle that is inclined with the ground at 50.0 degrees, with a force of 200N, for a total distance of 100m, how much work was done?

$$W = Fd$$

$$W = Fd \cos\theta$$

$$W = 200\text{N} (100\text{m}) \cos 50^\circ$$

$$W = 12,900 \text{ Nm or J}$$



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## Work Formula and Vector Product

You may have noticed that the work formula actually represents a scalar, or dot product of **force** and **displacement**.

Thus, the work formula could also be written as:

$$\mathbf{W} = \mathbf{F} \cdot \mathbf{d}$$

This is exactly equivalent to our algebraic form of:

$$W = Fd \cos\theta$$

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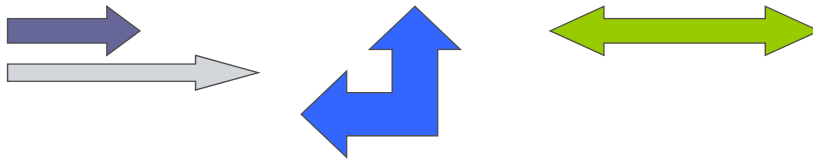


## ? Sign Convention Question

Can the quantity work be positive or negative?

**Hint:** Consider the definition/formula  $W = Fd \cos\theta$

**Hint:** Consider possible values that  $\cos\theta$  may have.

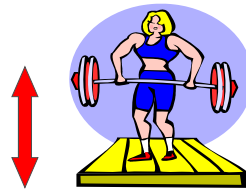


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## > Positive Work

If the force and displacement are in the same direction, that would be considered positive work:



**She does (+)  
work**

The lifting force and the direction of movement are in line with each other.  $\cos(0^\circ) = 1$

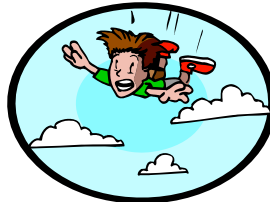
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## Negative Work

If the force and distance are in opposite directions, that would be considered negative work:



**Air resistance:  
negative ( - ) work**

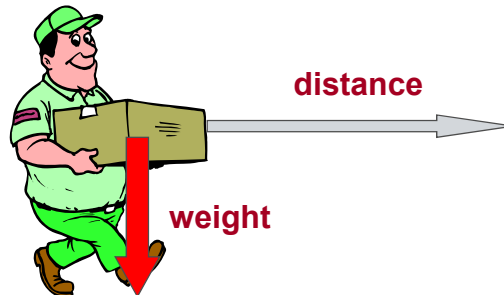
Force due to air resistance and the distance moved are  $180^\circ$  apart.  $\text{Cos}(180^\circ) = -1$

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## No Work

If the force and distance are in perpendicular directions, that would be considered zero work:



Force due to gravity and the distance moved are  $90^\circ$  apart.  $\text{Cos}(90^\circ) = 0$

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## Calculus Connection

Work can also be found through calculus:

$$W = \int_{x_1}^{x_2} F(x) dx$$

This means you can find the work done on something by integrating the force function with respect to position.

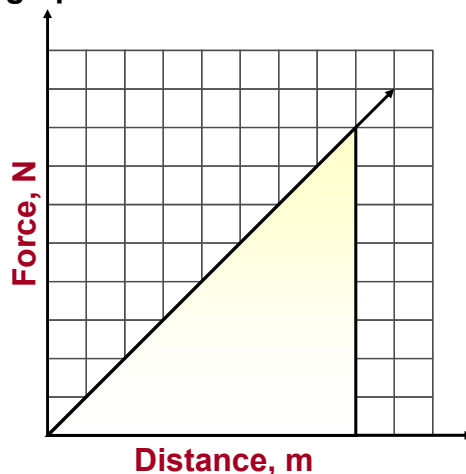
$x_1$  and  $x_2$  simply refer to an initial and final location.

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## Graphical Connection

Sometimes it may be difficult or impossible to integrate a particular function to find work. You can also use a graph of data:



The area under the curve would give the work done. For this example triangle, it could be found by:

$$\text{Area} = \frac{1}{2} \text{ base} \times \text{height}$$

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## The Speed of Work?

If one person lifts a 100 kg mass a distance of 1m up in 3 seconds, and another person does the same task in only 1 second, who does more work?

**Hint:** consider the variables that go into calculating work.



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## Work and Time

**Neither!** Since work is entirely independent of time, *both* do the same amount of work.

Common sense might say that the faster person did more work, but that idea is actually referring to **power**, a different quantity.

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## Power



Although work and power are very similar, they are not exactly the same.

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## Power Definition

**Power = Work / time**

$$P = W / t = Fd / t$$

**Power is a measure of how quickly work is done.**



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## Power Units

Since  $P = W / t$

Power is measured in J/s

Named after James Watt who invented the steam engine

1 J/s = 1 Watt, W

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## Power Calculation

A 50 kg boy wants to escape the monster beneath his steps. He climbs the 5m high steps in 2.0 seconds. How much power did he generate during his run? Assume he climbs the steps at a constant rate.

5m high

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## Example Solution

$$P = W / t$$

$$= Fd / t$$

**(notice the force needed is the boy's weight)**

$$= mad / t$$

$$= (50\text{kg}) ( 9.8 \text{ m/s}^2) ( 5.0 \text{ m}) / (2.0\text{s})$$

$$= 1225 \text{ J/s}$$

$$= 1200 \text{ Watts}$$

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## Energy



The various forms of energy and work are closely related.

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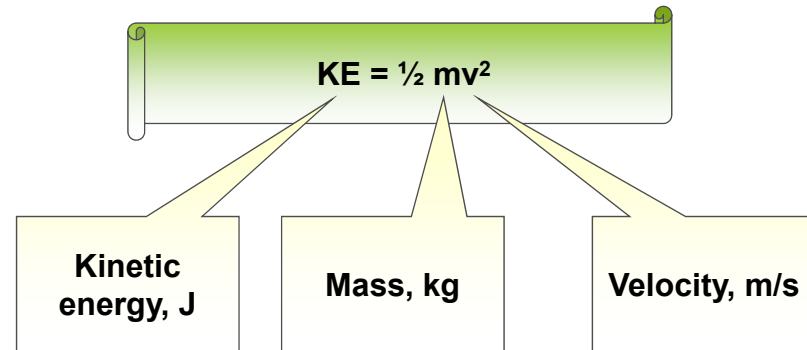




## Kinetic Energy

**Kinetic energy is energy of motion.**

All moving objects possess kinetic energy.



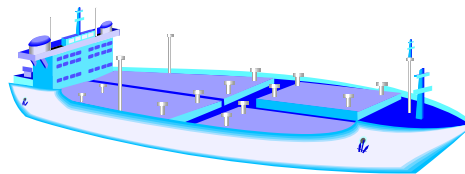
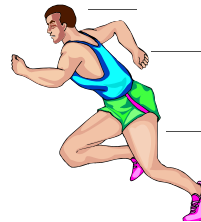
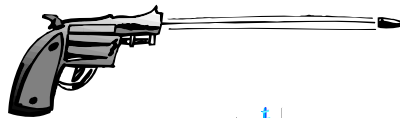
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## Kinetic Energy Requires Motion

An object may possess substantial kinetic energy by being:

- very fast
- very large
- or a combination of both!



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## Kinetic Energy Calculation

An 80 kg sprinter may average about 10 m/s during a 100m dash. What would his KE be?

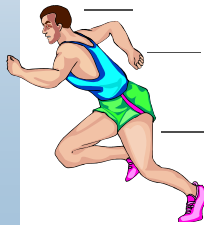
Unnecessary information

$$KE = 1/2 mv^2$$

$$KE = 1/2 (80\text{kg}) (10\text{m/s})^2$$

$$KE = 4000 \text{ kgm}^2/\text{s}^2$$

$$KE = 4000 \text{ J}$$



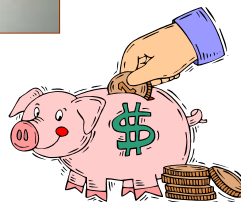
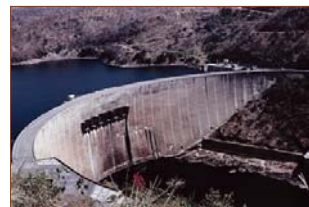
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## Potential Energy

There are many ways that energy can be stored and then released:

It's a lot like saving money in the bank so that it can be used later.



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## A Spring's Potential Energy

When a spring is stretched or compressed, it can store energy.

$$PE_{\text{spring}} = \frac{1}{2} kx^2$$

Potential energy, J

A spring constant that describes the stretchiness of a spring, N/m

Distance the spring is stretched, m

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## Hooke's Law

The previous spring potential energy formula is also related to Hooke's law:

$$F = -kx$$

Force exerted by spring, N

A spring constant that describes the stretchiness of a spring, N/m

Distance the spring is stretched, m

Again, the spring constant,  $k$ , relates how much a spring is stretched or compressed for a given amount of push or pull.

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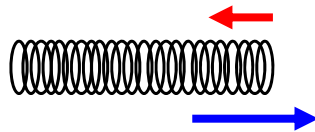


## Odd Negative Sign

$$F = -kx$$

You may have noticed the unusual negative sign in the formula.

This only signifies that the spring force has one sign (**negative**), while the direction the spring is moved is the opposite sign (**positive**).



The spring **pulls** inward here, but it is **stretched/lengthened** outward.

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## Gravitational Potential Energy

In this discussion, the energy from the Earth's gravitational field will be the main type of potential energy, PE, used.

You increase an object's PE when you move an object against the pull of gravity.



Moving an object horizontally doesn't change its gravitational PE.

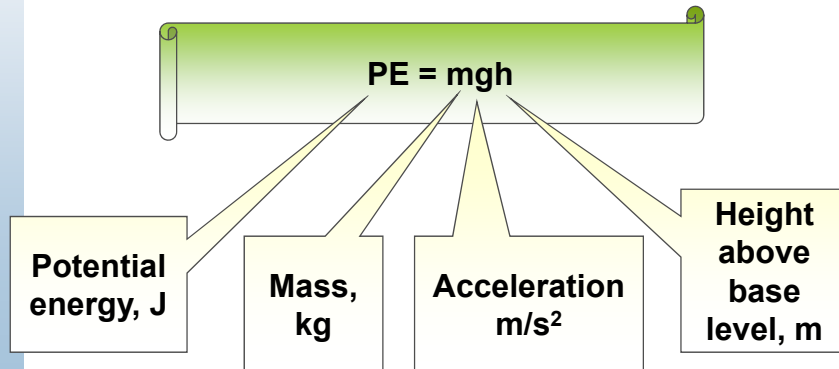
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## Gravitational PE Formula

Gravitational Potential energy is the energy an object possesses due to its position.



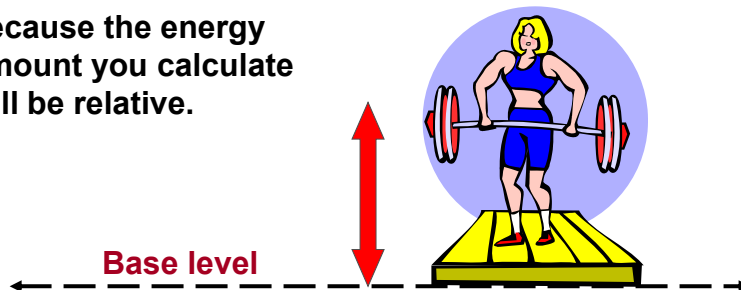
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## Base Level

When measuring an “h” to calculate PE, its important to know where you are measuring from.

Any position can be used as a base level because the energy amount you calculate will be relative.



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## Potential Energy Calculation

How much would you increase your potential energy if you climbed from sea level to the top of mount Everest , 8,850 m high? Assume your mass to be 80 kg.

$$PE = mgh$$

$$PE = (80 \text{ kg}) (9.8 \text{ m/s}^2) (8,850\text{m})$$

$$PE = 6.9 \times 10^6 \text{ kgm}^2/\text{s}^2$$

$$PE = 6.9 \times 10^6 \text{ J}$$



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## Work Energy Theorem

Work is equivalent to the change in energy.

$$\text{Work} = \Delta E$$

**Work Energy Theorem**

Work and change in energy are identical.

Work and energy have the same units, Joules, J.

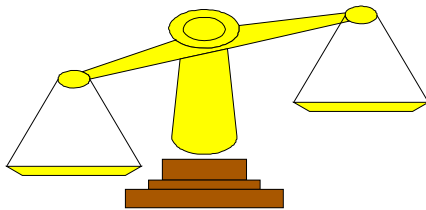
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## Conservation of Energy

Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.



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## Total Energy Is Conserved

Often, it may seem like energy is lost, but it merely is transformed into another type of KE or PE.

Just look closely and consider where energy may be transferred.

**total energy before = total energy  
after**





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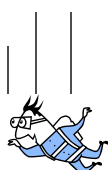
## ? Energy Conservation Situation

- Imagine a skydiver jumps from an airplane above the ocean. Assume they accelerate all the way down. How will their PE and KE vary?






## ? Energy Transfer

<div style="background-color: #90c040; color: white; padding: 5px; width: 60px; margin: 0 auto;">1000J PE</div>	<div style="background-color: #c00000; color: white; padding: 5px; width: 60px; margin: 0 auto;">0J KE</div>		<p><b>When the skydiver jumps, initially all their energy is PE.</b></p>
<div style="background-color: #90c040; color: white; padding: 5px; width: 60px; margin: 0 auto;">500J PE</div>	<div style="background-color: #c00000; color: white; padding: 5px; width: 60px; margin: 0 auto;">500J KE</div>		<p><b>PE transforms into KE, but the total is still constant.</b></p>
<div style="background-color: #90c040; color: white; padding: 5px; width: 60px; margin: 0 auto;">0J PE</div>	<div style="background-color: #c00000; color: white; padding: 5px; width: 60px; margin: 0 auto;">1000J KE</div>		<p><b>Just before they hit, all their E has turned into KE.</b></p>

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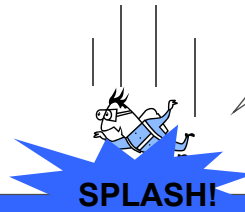


## Energy Still Conserved

When the skydiver safely lands in the water, all of their accumulated KE will be transferred into:

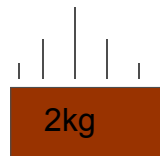
- the motion of the water
- sound
- heat, etc.

**Energy still conserved!**



## Conservation of Energy Example

If a 2.0 kg brick were to fall from a building 20m high, how fast would it be traveling just before it hits the ground?



$$PE_{\text{top}} = KE_{\text{bottom}}$$

$$mgh = \frac{1}{2} m v^2$$

$$2mgh = mv^2$$

$$v = \sqrt{\frac{2mgh}{m}}$$

$$v = \sqrt{\frac{2(2.0\text{kg})9.8\text{ m/s}^2(20\text{m})}{2.0\text{ kg}}}$$

$$v = 20\text{m/s}$$

**Notice that the mass cancels out, so it isn't really needed.**

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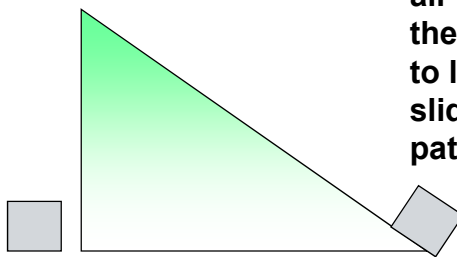


## Conservative Forces

A force is classified as a “conservative” force if:

**#1 the work it does on a moving object is independent of the path between the initial and final position.**

**Same work!**



If we neglect friction and air resistance, you need the same amount of work to lift the box as you do to slide it up the incline. The path is irrelevant.

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## More Conservative Forces

A force is also classified as a “conservative” force if:

**#2 it does no net work on an object moving around a closed path, starting and finishing at the same point.**



On the way up the loop, gravity does negative work.

On the way down, gravity does positive work.

Overall, no net work is done!

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## Non Conservative Forces

Not all forces fit the previous two definitions.  
Consider friction or air resistance as an example.

If the block is moved a bit and returned,  
some work is done due to friction.

If it is then moved much more, and returned to  
the same spot, more work is done.

Friction is **non conservative**.

mass

Rough surface

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## Learning Summary

Power =  
work/time

$$P=W/t$$

Work = force x  
distance

$$W = Fd$$

Use correct  
component!

Work = Joules  
Energy = Joules  
Power = Watts

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

$$PE = mgh$$

Total energy is  
conserved.

$$E_{\text{before}} = E_{\text{after}}$$

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**Congratulations**

You have successfully completed  
the tutorial

**Work, Power and Energy**

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**What's Next ...**

Step 1: Concepts – Core Tutorial (Just Completed)

→ Step 2: Practice – Interactive Problem Drill

Step 3: Recap – Super Review Cheat Sheet

**Go for it!**

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