Work and Energy

What does **Work** mean to you?

What does Energy mean to you?

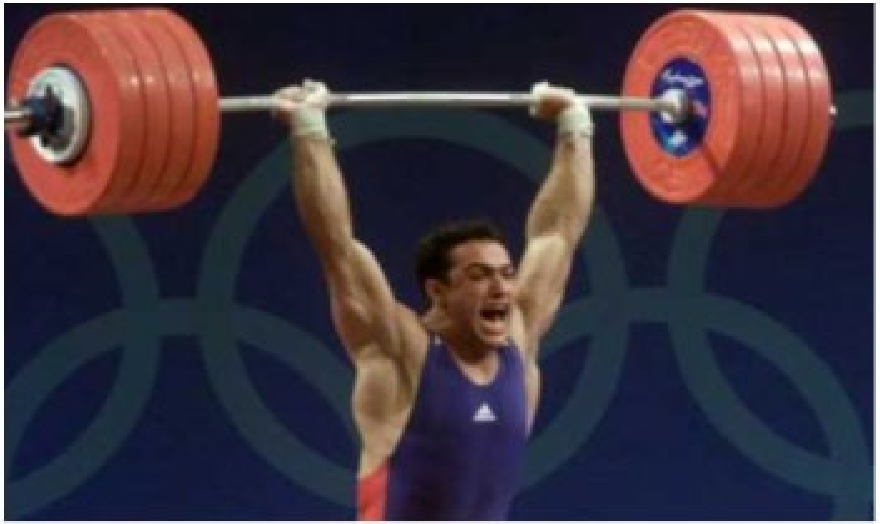
What takes more work?

Lifting a goat or a boat?

***We deduce that ________________________________**

What takes more work?

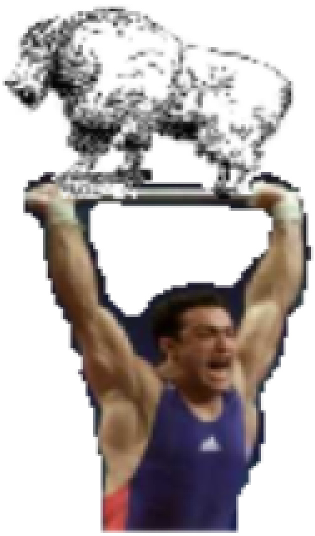
Lifting a mass up to your knees, or above your head?



*We deduce that ________________________________

What takes more work?

Lifting a goat on Earth or on the moon?



Earth

Moon

*We deduce that ________________________________

What is work?

Work takes place anytime energy is transferred. Mathematically, we can write this as

$$W = \Delta E$$

where:

W = work E = energy

This is a huge statement.

We can go further and actually derive a formula for work:

We know that work is directly proportional to mass:

$$W \alpha m$$

and that work is directly proportional to displacement moved:

$$W \alpha \vec{d}$$

and that work is directly proportional to the field strength (an acceleration):

$$W \alpha \vec{a}$$

If we put these three proportionalities together, we get

$$W = m\vec{a}\vec{d}$$

or

$$W = \vec{F}\vec{d}$$

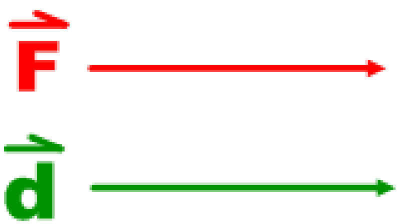
where:

$\vec{F}$ = force

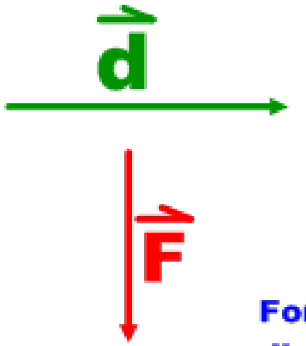
$\vec{d}$ = displacement

Work is a scalar, meaning it only has magnitude. However, the direction of the force and displacement are important.

The force must be in the same direction as the displacement in order for work to be done.



Force and displacement in same direction = work done.



Force and displacement in different direction = no work done.

What are the units of work?

The units of force is the newton, the unit of distance is the metre, so it would follow that work is measured in Nm, otherwise called a joule (J).

James Prescott Joule

$$W = \vec{F}\vec{d}$$

where:

$\vec{F}$ = force $\vec{d}$ = displacement

Ex 1) How much work is done in lifting a 25 kg _______ to a height of 15 m?

Ex 2) How much work is needed, after lifting the _______, to carry it horizontally 250 m?

Applications: Work in 2 dimensions

We know that work is only done when an object is moved in the same direction as the force which is acting on it. Therefore, if we have movement in a direction perpendicular to the force, no work is done.

However, what if the direction of movement was at an angle, θ, to the force? Then there would still be a component of the movement in the direction of the force, thus there would be some work done.

Ex 3) _____ is shoveling the walk. A force of 150 N is applied down the shovel handle, which makes an angle of 35.0° with the horizontal. ________ pushes the shovel 10.0 m. How much work is being done on the shovel?

Note that we can find the work by using the expression

$$W = Fd\cos\theta$$

where θ is the angle between the force and the direction of motion.

Ex 4) Adele pushes a crate of mass 7.00 kg up a hill of incline 11.0° for a distance of 3.00 m up the hill. Adele pushes on the crate with a force of 90 N horizontally, parallel to the ground. The coefficient due to friction is 0.200.

a) How much work does Adele do?

b) How much work is done by gravity against the crate?

c) How much work is done by friction against the crate?

Energy Review

*Energy is the capacity to do work on an object or the environment, to change either in some way.

*Energy can be converted from one form to another.

*A change in energy is called work

Kinds of Energy

There are many different forms of energy, but none of them are distinct. We simply have different ways of determining how much energy is present in different situations.

$$W = \Delta E$$

***Types of energy:**

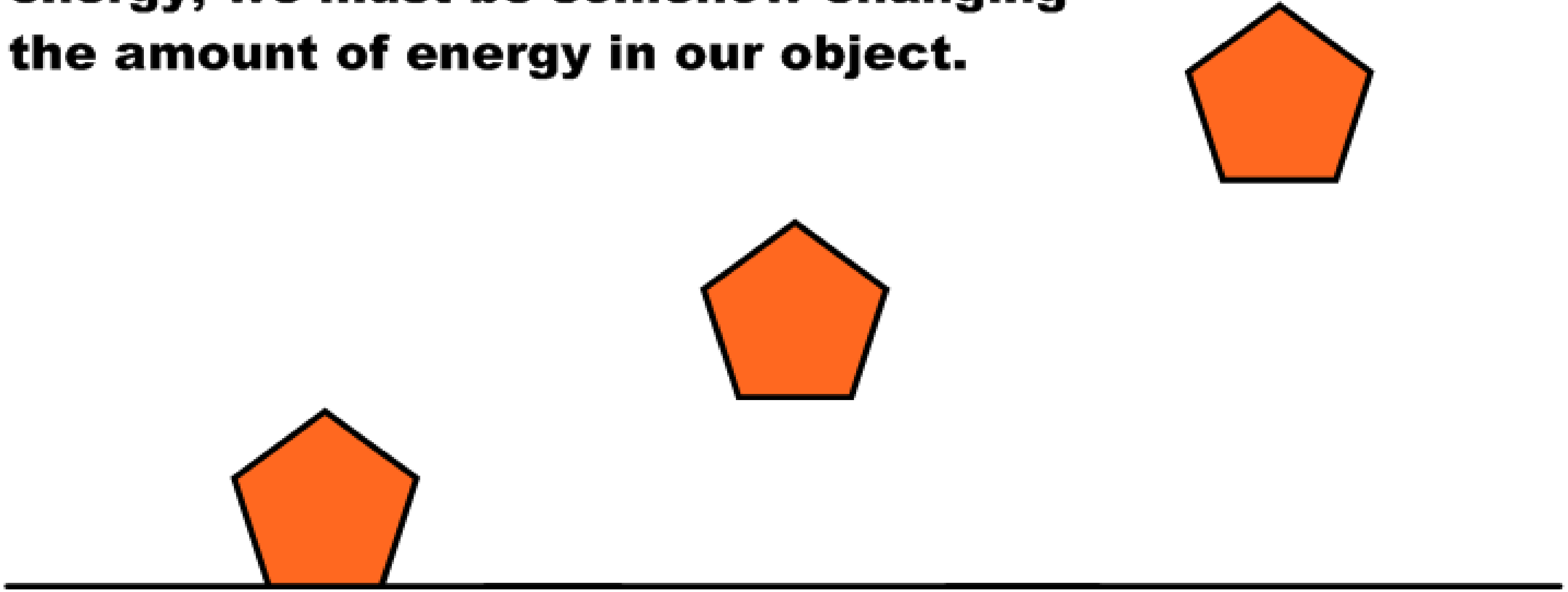
- **Mechanical Energy (kinetic and potential)**
- **Nuclear Energy**
- **Energy stored in chemical bonds**
- **Energy produced by electricity**
- **Thermal Energy**

Gravitational Potential Energy

Imagine raising an object to some height *h* above a reference level (say, the ground) which we will call zero.

The force of gravity will be resisting this move (there is a force in the same direction as the distance moved), which means it must take work to elevate this object.

The higher we move an object, the more work it takes. As work is a change in energy, we must be somehow changing the amount of energy in our object.



h = 0
W = 0

It would also follow that this energy is directly proportional to height.

If there is work done on an object, we say the object has gained some amount of energy. Work means there was a change in energy. The energy gained by raising an object against the gravitational field of the earth is called <u>potential energy</u> (E_p or PE).

Lets derive an equation for E_p:

Hydroelectric Dam in Baie-Comeau, Quebec

$$W = \Delta E$$

$$\vec{F}\vec{d} = \Delta E$$

$$m\vec{g}\vec{d} = \Delta E$$

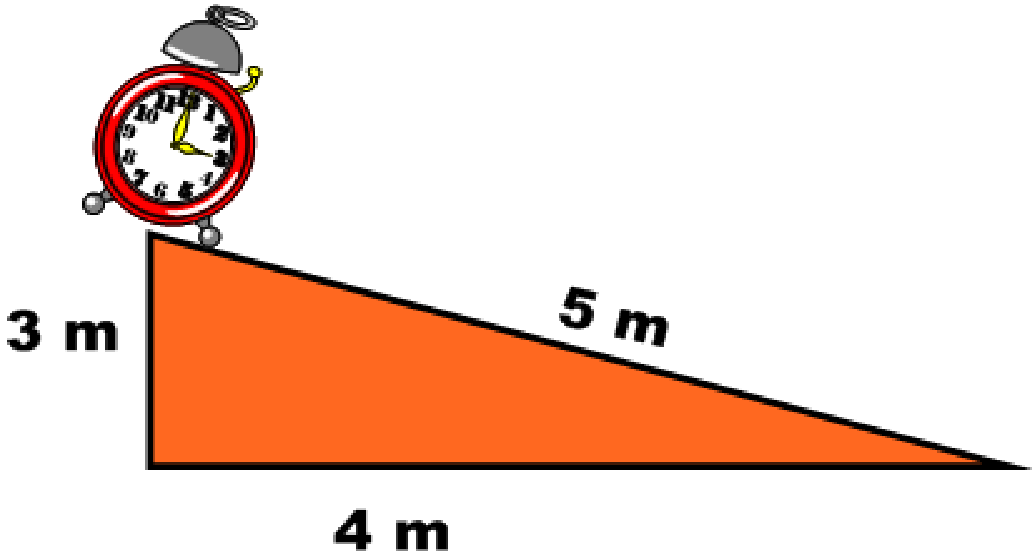
$$m\vec{g}\vec{h} = E_p$$

As we call the distance moved the height, h, in metres.

Where E_p = potential energy, measured in joules (J).

Remember:

The height we consider here is the vertical height above the ground the object is raised through. This displacement must be parallel to the force of gravity in order for work to be done.

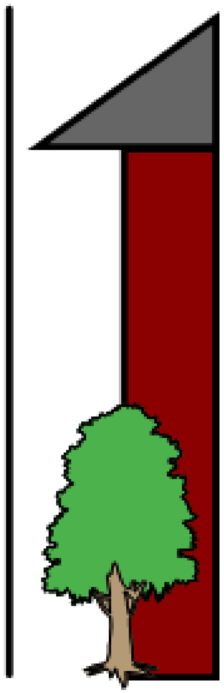


Reference Levels

The height you measure is always with respect to some reference level. The reference may be the floor, the table, or some other point in space.

Where we measure from is not terribly important as we are just calculating the change in energy from one point to another.

ex) Young Mr.P (m = 70 kg) climbed ladders for a living. Mr.P climbed a 12 m ladder on one particular job. Calculate Mr.P's PE with respect to:



a) The ground.

b) The roof (11 m above the ground)

c) A tree, 7.0 m below the top of the ladder.

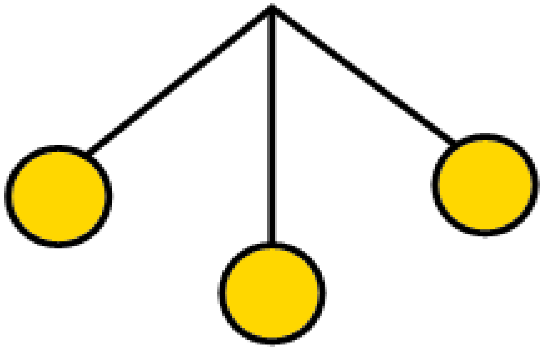
ex) A 10 kg cat climbs a tree to a height of 20 m. What is the potential energy of the cat?

ex) To what height does 1.00 kg of water need to be raised to give it 1.0 MJ of energy?

ex) A 1500 g bag of potatoes is dropped from 1.5 km. What is the potential energy of the bag?

ex) A 50 g golf ball has a potential energy of 500 J. To what height was it hit?

ex) A pendulum bob of mass 2.00 kg is fixed from the ceiling by a string of length 1.00 m. If the bob is pulled 0.750 m to one side, what is its potential energy with respect to its equilibrium position?



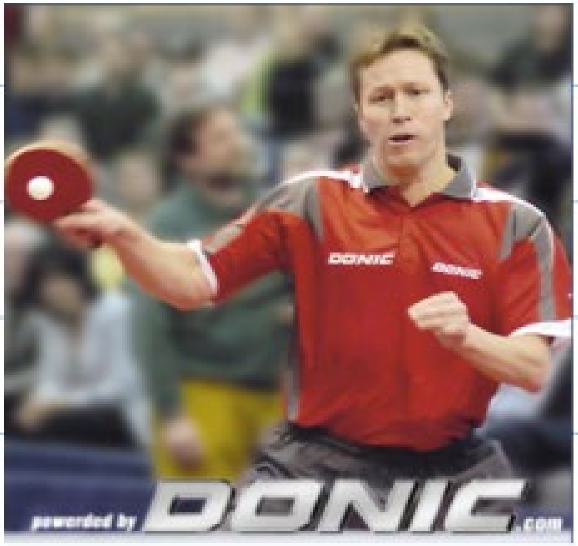
Kinetic Energy

Energy of Motion (kinetic is Greek for "motion")

Kinetic energy is the energy produced by accelerating an object. In P20, we only deal with constant acceleration, and we assume that the object starts at rest ($\vec{v}_I = 0$ m/s).

What has more

energy:



A ping-pong ball...

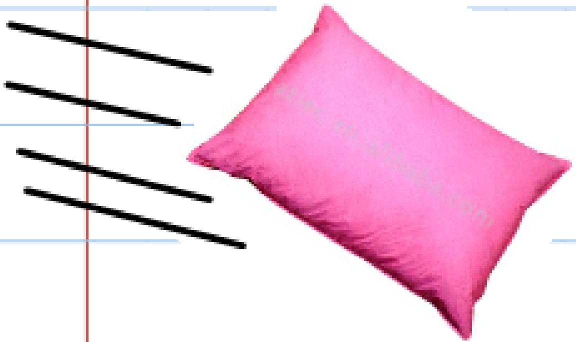
or a cannon ball

moving at the same velocity?

*We deduce that ________________________________

What has more

energy:



A slow moving pillow… **or a fast moving pillow**

of equal mass?

***We deduce that ______________________________________**

From these experiments, we can conclude that:

a) KE must be proportional to mass.

$$KE \propto m$$

b) KE must be proportional to velocity.

$$KE \propto \vec{v}$$

We can now derive an equation for the E_k:

Kinetic Energy

- energy by virtue of speed/motion
- notice the squared term!

$$KE = 1/2m\vec{v}^2$$

Don't forget to square the velocity! (Or square root if solving for velocity.)

Sometimes an object does not start at rest. In these cases, the object already has some kinetic energy, E_{ki}, and then gains some more energy (by having work done upon it) to go to a final kinetic energy, E_{kf}.

The work done on the object causes a change in energy.

This statement is the basic premises of the Work-Energy theorem, which we study in more detail later.

ex) A 10.0 N melon is accelerated uniformly from rest at a rate of 2.50 m/s^2. What is the kinetic energy of this object after it has accelerated a distance of 15.0 m?

ex) An 8.0 kg rock is dropped from a height of 7.0 m. What is the kinetic energy of this rock as it hits the ground?

ex) By what factor must the KE of an object be increased to cause the speed to triple?