Impulse and Work

How hard is it to stop a moving object?

To stop an object, we have to apply a force over a period of time.

This is called **Impulse**

$$\text{Impulse} = F\Delta t \quad \text{Units: } N\cdot s$$

$$\Delta t = \text{time elapsed (s)}$$

- Using Newton's 2nd Law we get

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

Which means

Impulse = change in momentum

Why does an egg break or not break?

- An egg dropped on a tile floor breaks, but an egg dropped on a pillow does not. Why?

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

In both cases, m and Δv are the same.

If Δt goes up, what happens to F, the force?

Right! Force goes down. When dropped on a pillow, the egg starts to slow down as soon as it touches it. A pillow increases the time the egg takes to stops.

Practice Problem

A 57 gram tennis ball falls on a tile floor. The ball changes velocity from -1.2 m/s to +1.2 m/s in 0.02 s. What is the average force on the ball?

Identify the variables:

Mass = 57 g = 0.057 kg

Δvelocity = +1.2 – (-1.2) = 2.4 m/s

Time = 0.02 s

using $$F\Delta t = m\Delta v$$

$$F \times (0.02\ s) = (0.057\ kg)(2.4\ m/s)$$

$$F = 6.8\ N$$

You're standing under the eaves of your house when a huge icicle breaks off and hits you, imparting a force of 300.0 N for 0.10 seconds. What was the impulse?

Car Crash

Would you rather be in a head on collision with an identical car, traveling at the same speed as you, or a brick wall?

Assume in both situations you come to a complete stop.

Take a guess

Car Crash (cont.)

Everyone should vote now

1- it is better to hit another car,

2- it's better to hit a wall

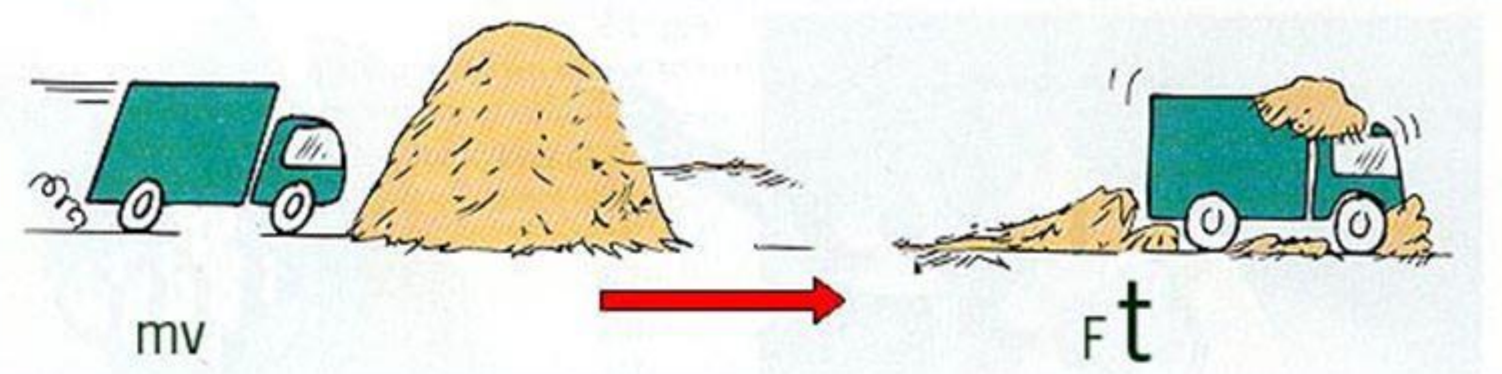
3- it doesn't matter.

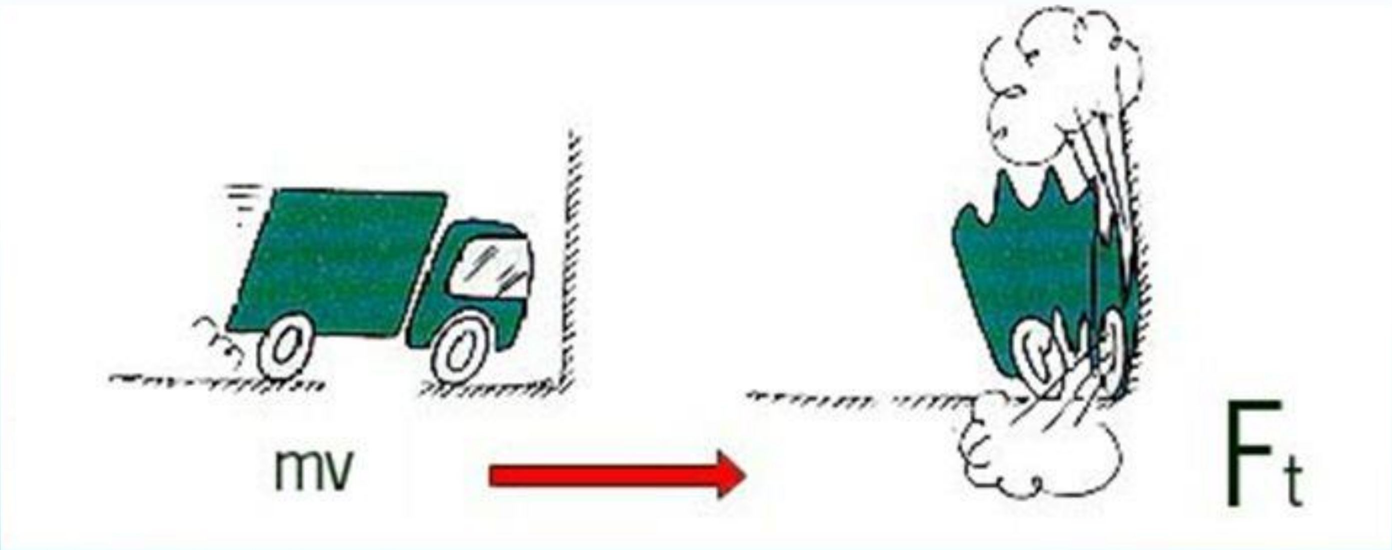
the answer is…..

It Does Not Matter!

Look at $F\Delta t = m\Delta v$

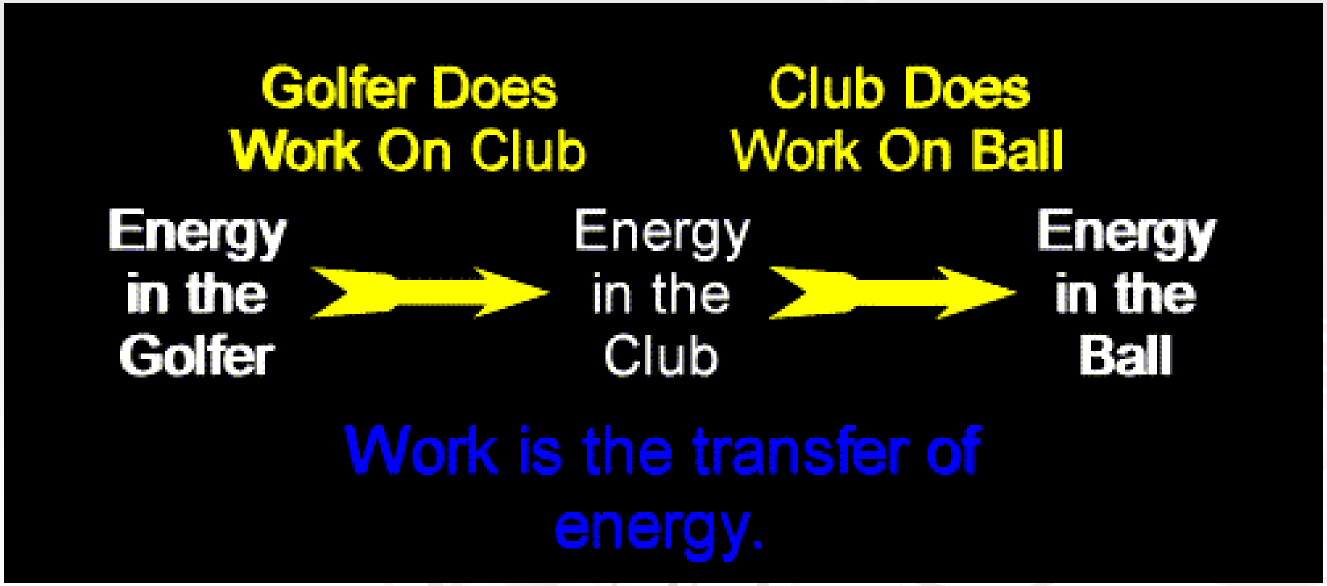
Impulse – Momentum Relationships





What is work?

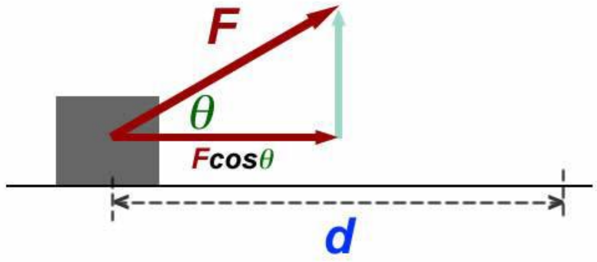
- In science, the word work has a different meaning than you may be familiar with.
- The scientific definition of work is: using a force to move an object a distance, or
- Work is the ***transfer*** of ***energy***.



Formula for work

Work = Force . Distance

$$W = Fd\cos\theta$$



Conditionally

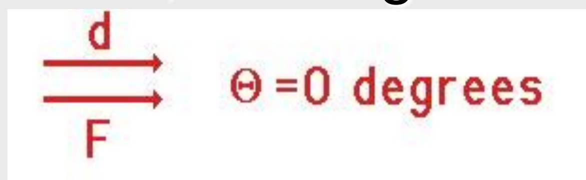
when both the force and the motion of the object are in the same direction.

The unit of work is a joule

To gather an idea of the meaning of theta angle, consider the following <u>three scenarios</u>:

Scenario A

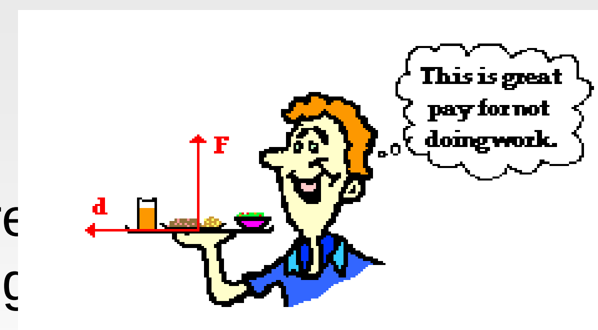
the force vector and the displacement vector are in the same direction. Thus, the angle is 0 degrees. (+W)



Scenario B

the force vector and displacement vector are in the opposite direction. thus, the angle is 180 degree (- W)

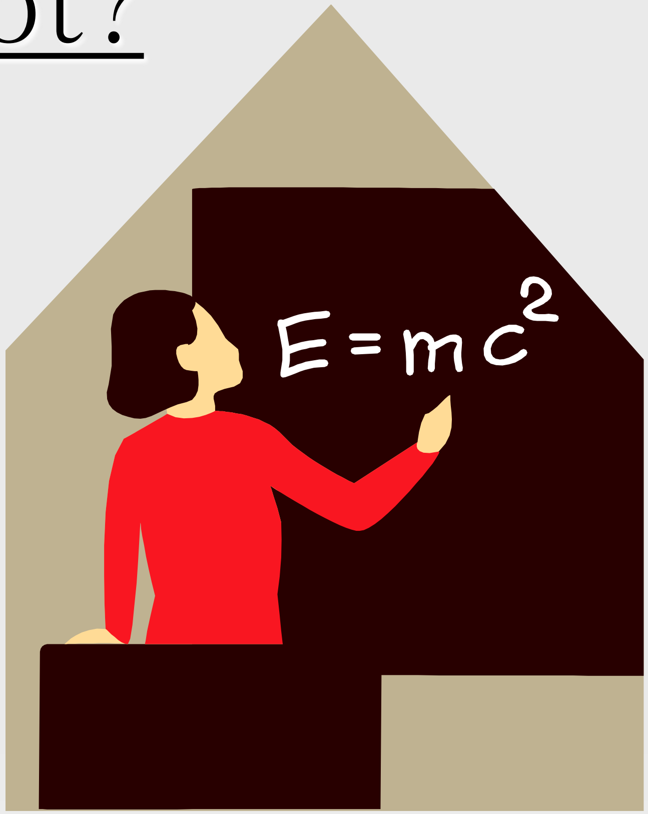
- ***Scenario C***
- the force vector and the displacement vector are other. Thus, the angle between F and d is 90 deg



To Do Work, Forces Must Cause Displacements.

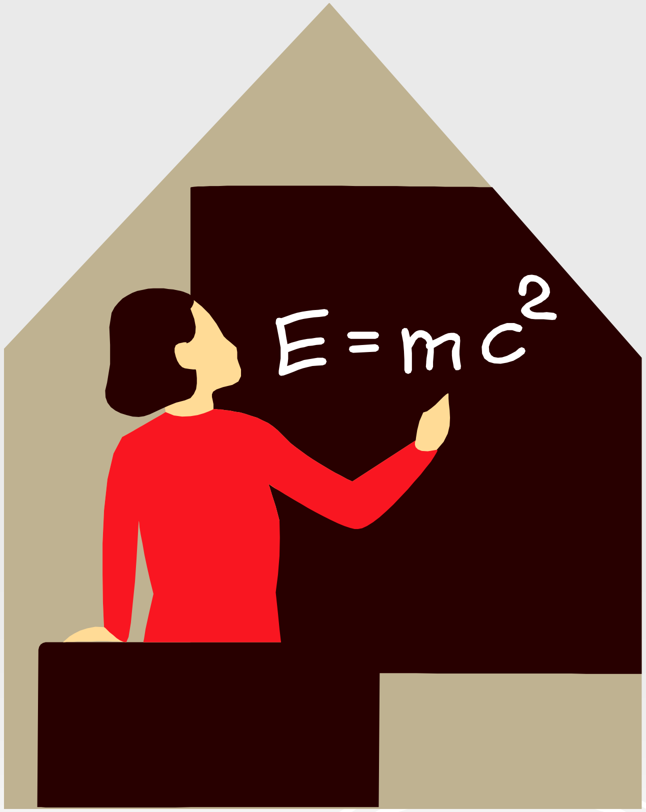
Work or Not?

- According to the scientific definition, what is work and what is not?
  1- a teacher lecturing to her class
  2- a mouse pushing a piece of cheese with its nose across the floor



Work or Not?

- a teacher lecturing to her class. No
- a mouse pushing a piece of cheese with its nose across the floor. Yes

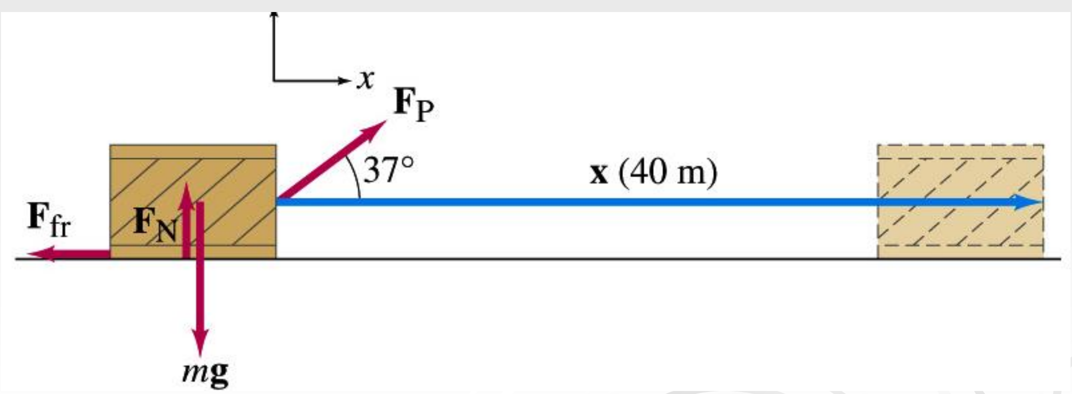


Work & Force

- □ Work done by a constant force
- (scalar product)
- □ Work done by a varying force
- (scalar product & integrals)

Work done by a constant force

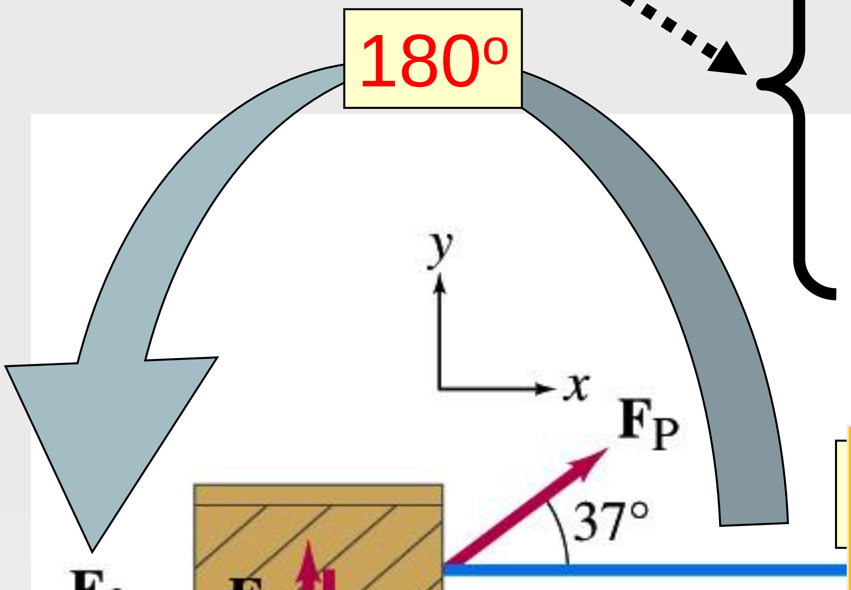
A 50.0-kg crate is pulled 40.0 m by a constant force exerted (F_P = 100 N and θ = 37.0°) by a person. A friction force F_f = 50.0 N is exerted to the crate. Determine the work done by each force acting on the crate.



Example 1A (cont'd)

F.B.D.

$$\begin{cases} W_P = F_P\, d \cos(37^o) \\ W_f = F_f\, d \cos(180^o) \\ W_g = m\, g\, d \cos(90^o) \\ W_N = F_N\, d \cos(90^o) \end{cases}$$



$W_P = 3195$ [J]

$W_f = -2000$ [J] (< 0)

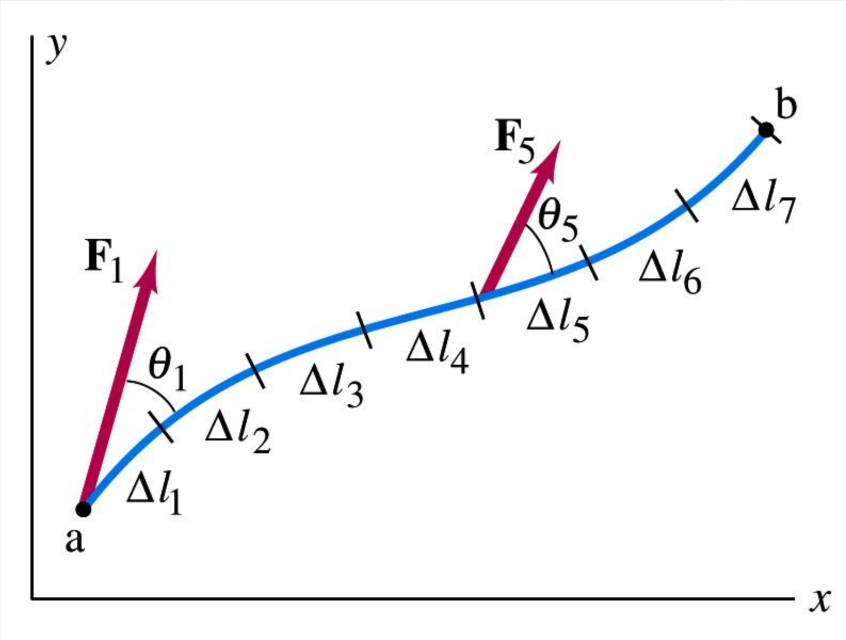
$W_g = 0$ [J]

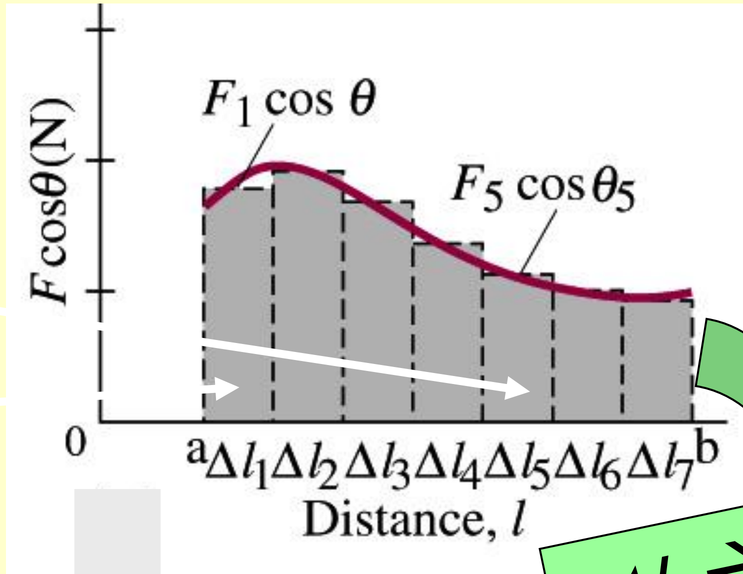
$W_N = 0$ [J]

$$W_{net} = \Sigma W_i$$

$$= 1195 \text{ [J]} \quad (> 0)$$

Work Done by a Varying Force



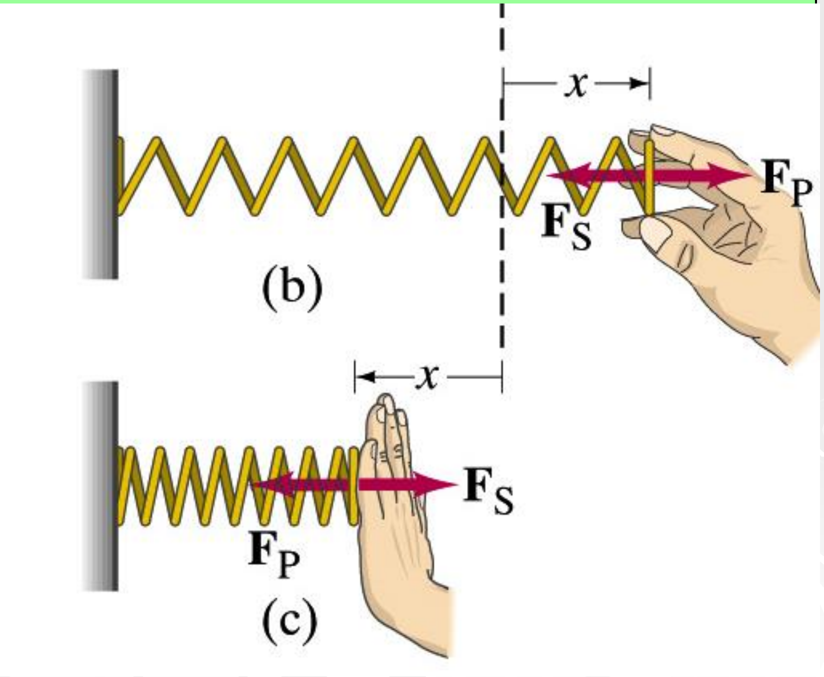


$\Delta l \rightarrow 0$

$$W = \int_{l_a}^{l_b} F_{\parallel}\, dl$$

Example 1A

A person pulls on the spring, stretching it 3.0 cm, which requires a maximum force of 75 N. How much work does the person do ? If, instead, the person compresses the spring 3.0 cm, how much work does the person do ?



Example 1A (cont'd)

(a) Find the spring constant *k*

$$k = F_{max} / x_{max}$$

$$= (75\ \mathrm{N}) / (0.030\ \mathrm{m}) = 2.5 \times 10^3\ \mathrm{N/m}$$

(b) Then, the work done by the person is

$$W_P = (1/2)\, k\, x_{max}^2 = 1.1\ \mathrm{J}$$

(c)

$$W_P = \int_{x_1 = 0}^{x_2 = 0.030\ \mathrm{m}} F_P(x)\ dx = 1.1\ \mathrm{J}$$

Kinetic and Potential Energy

What is Energy?

What does it mean if you have a lot of energy?

For students it means you can run around, lift weights and scream.

If you have energy you can do things.

What is Energy?

Energy is the ability to do work

This is similar to our every day definition of energy. **You** can't run up the stairs (work) without **energy!**

There are a lots of types of energy. Can you name a few?

Energy comes in many different forms

- Gravitational potential energy
- Thermal Energy (heat)
- Nuclear Energy (nuclear power, atomic bomb)
- Electrical Energy (electricity)
- Chemical Energy (food, fire, …)

All forms of energy can be in either of two states:

1- Kinetic Energy (used)

2- Potential Energy (stored)

2. *Kinetic Energy*

Kinetic energy is the energy of motion. An object which has motion - whether it be vertical or horizontal motion - has kinetic energy. The amount of translational kinetic energy (from here on, the phrase kinetic energy will refer to translational kinetic energy) which an object has depends upon two variables: the mass (m) of the object and the speed (v) of the object. The following equation is used to represent the kinetic energy (KE) of an object.

The following equation is used to represent the kinetic energy (KE) of an object.

$$KE = \frac{1}{2} * m * v^2$$

* Where **m** = mass of object

and **v** = speed of object

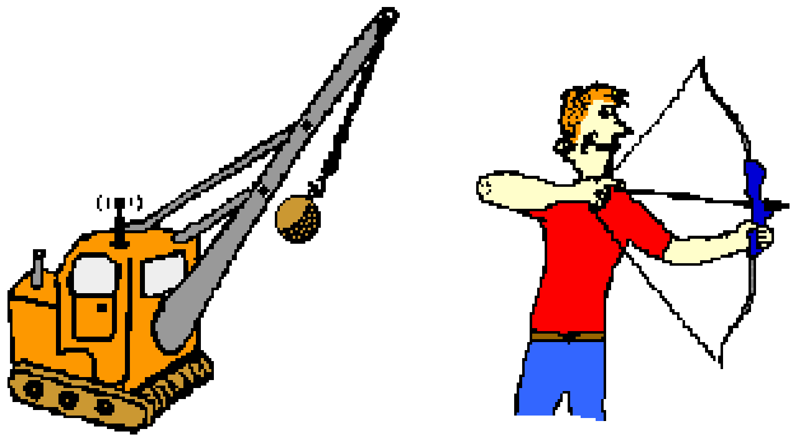
Kinetic Energy Examples

- Wind
- A flowing river
- An airplane in flight
- A bullet fired from a gun
- Planets orbiting the sun
- Someone jump-roping
- Someone running
- A fish swimming
- Fruit falling from the tree
- Your jaw when you are chewing
- Gas molecules moving around in a room

1. Potential Energy

An object can store energy as the result of its position

- potential energy is the energy which is stored in an object due to its position relative to some zero position
- Only conservative force has potential energy



The massive ball of a demolition machine and the stretched bow possesses stored energy of position - potential energy.

A. Gravitational Potential Energy

- Gravitational potential energy is the energy stored in an object as the result of its vertical position or height.
- There is a direct relation between gravitational potential energy and the mass of an object.
- More massive objects have greater gravitational potential energy.
- There is also a direct relation between gravitational potential energy and the height of an object.
- The higher that an object is elevated, the greater the gravitational potential energy.

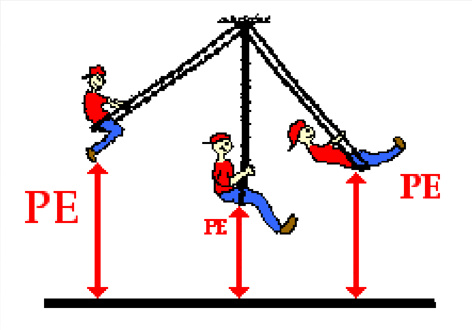
$$PE_{grav} = mass * g * height$$

$$PE_{grav} = m * g * h$$

Where, **m** represents the mass of the object.
h represents the height of the object.
g represents the acceleration of gravity.

Example

a pendulum bob swinging to and from above the table top has a potential energy which can be measured based on its height above the tabletop. By measuring the mass of the bob and the height of the bob above the tabletop, the potential energy of the bob can be determined.



B. *Elastic Potential Energy*

Elastic potential energy is the energy stored in elastic materials as the result of their stretching or compressing. Elastic potential energy can be stored in rubber bands, bungee chords, trampolines, springs, an arrow drawn into a bow, etc. The amount of elastic potential energy stored in such a device is related to the amount of stretch of the device - the more stretch, the more stored energy.

The compressed springs of a dart gun store elastic potential energy. When the trigger is pulled, the springs apply a force to do work on the dart.

Potential Energy in a Human Body

- Your jaw before you chew food
- The energy stored as fat in the body
- Your leg before you move it
- Digestive enzymes in your stomach before you eat
- The brain before you think (electrical energy)
- Your hands before you clap them together (sound energy)

Total Energy

TE = PE + KE

Where is, TE=Total Energy

PE=Potential Energy

KE=Kinetic Energy

Work and Energy

1. Work Energy
   → Work done by a constant force (scalar product)
   → Work done by a varying force (scalar product & integrals)
2. Kinetic Energy

Work-Energy Theorem

Conservation Laws and Symmetries

- • Energy conservation follows from translation symmetry in time.

(Experiments done yesterday and today give the same result.) •

- Momentum conservation is tied to translation symmetry in space.

(Experiments done in New York and Paris give the same result.)

Potential energy

- Potential energy is only for Conservative forces
- Your jaw before you chew food
- The energy stored as fat in the body
- Potential energy is energy that can be associated with the configuration (arrangement) of a system of objects that exert forces on one another.

$$\Delta U = -W.$$

- Some forms of potential energy:
- Gravitational potential energy,
- Elastic potential energy

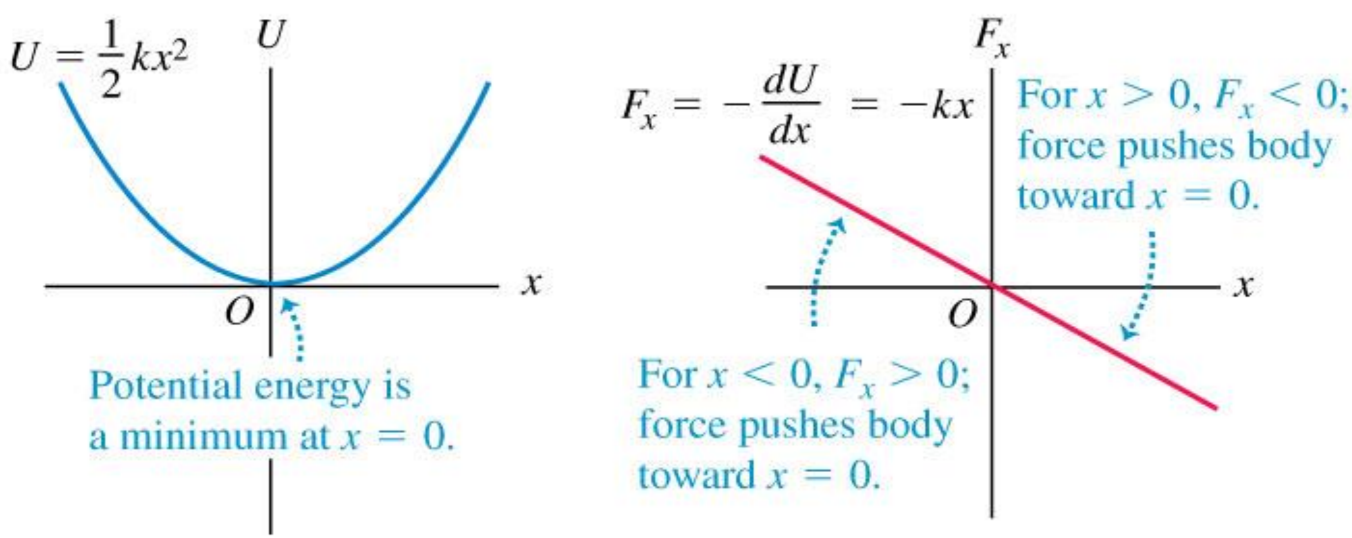
$$\Delta U = -\int_{x_i}^{x_f} F(x)\, dx.$$

Work-Energy Theorem

$$\Delta U = -\int_{x_i}^{x_f} F(x)\,dx.$$

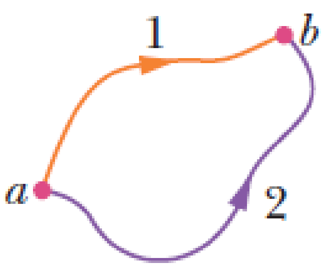
- $F_x(x) = -dU(x)/dx$

(a) Spring potential energy and force as functions of x



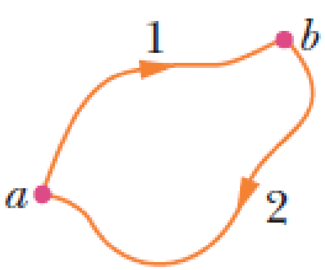
Conservative Forces

The work done by a **conservative force** is **path independent**. -- as the definition



(a)

The force is conservative. Any choice of path between the points gives the same amount of work.



(b)

And a round trip gives a total work of zero.

The net work done by a conservative force on a particle moving around any closed path is zero.

Power

- Power: The rate of energy usage

$$P = \frac{dU}{dt} \qquad P = \frac{W}{t} \qquad P = f.v$$

Measured in **Watt**

Bench Step

- Subject steps up and down at specified rate
- Example:
  - 70-kg subject, 0.5-m step, 30 steps•min^{-1} for 10 min
- Total work = force x distance
  - Force = 70 kg x 9.79 N•kg^{-1} = 685.3 N
  - Distance = 0.5 m•$step^{-1}$ x 30 steps•min^{-1} x 10 min = 150 m

685 N x 150 m = 102,795 J (or 102.8 kJ)

- Power = work ÷ time

102,795 J ÷ 600 s = 171.3 W

Examples

Example-1

A crate of mass 50kg is pushed along a floor with a force of 20N for a distance of 5m. Calculate the work done.

100 J

Example-2

How far must a 5N force pull a 50g toy car if 30J of energy are transferred?

6 m

Example-3

A man exerts a force of 2kN on a boulder but fails to move it. Calculate the work done.

Zero

Example-4

A football of mass 2.5kg is lifted up to the top of a cliff that is 180m high. How much potential energy does the football gain?

4500 J

HW

Example-5

A person of mass 70kg runs up a flight of stairs with a vertical height of 5m. If the trip takes 7s to complete, calculate the person’s power.

Example-6

How much kinetic energy has a 160g cricket ball when it is thrown at a speed of 22m/s?

Example-7

How fast is a trolley moving if it has 180.5J of kinetic energy?

Example-8

A lift motor has to move a fully laden lift 4m between floors in 1.5s.

The lift has a mass of 1850kg (ignore friction).

a) Calculate the weight of the fully laden lift.

b) What is the work done by the motor?