Physics 2AB Notes - 2012

Heating and Cooling

Kinetic Theory

- All matter is made up of tiny, minute particles.
- These particles are in constant motion.
- The kinetic energy of a substance defines its temperature.
- Forces of attraction are stronger in liquid and solid phases than those in gas phase.
- Particles in gas phase are widely spread out from each other.
- Particles in all phases are repulsive.

- Solid

  Exerts strong forces of attraction which gives matter a fixed shape.

  Particles are in motion in a lattice arrangement

  Forces are therefore sometimes predominantly attractive and repulsive.

- Liquid

  Have less freedom to move around. (takes up a greater volume)

  Particles collide but remain attracted to each other.

  Liquid remains in fixed volume but not fixed shape and therefore takes shape of container.

- Gases

  Constant random motion

  Particles collide with each other (no force of attraction)

  Repulsion causes particles to move off in new directions

When a substance is heated particles within the material gain kinetic energy (as they move faster) and potential energy (as they move away from their equilibrium positions). However they are still held in place by strong intermolecular forces.

Heat: Transfer of energy from a hot object to a cold object during temperature change or change of state.
Internal energy: The kinetic and potential energy of the molecules within a substance. An increase in the internal energy will result in a gain in temperature, only if there is a net gain in energy.

If heat is added to an object, that object may

1. Change temperature
2. Expand or
3. Undergo a change of state.

As energy is transferred to a material, the average kinetic energy of particles increase and this is a rise in temperature.

Difference between heat and temperature

Temperature is defined as the **measurement of the average kinetic energy of particles within a body/substance.** Objects of low temperatures are cold, while objects with higher temperature are warm/hot.
Heating can be described as the transfer of heat from an object at a higher temperature to an object at a lower temperature. **The transfer of energy to an object of lower kinetic energy.** No heat energy can be exchanged to bodies of the same temperature.
Never from cold to hot! Unless supplied by external forces.

Absolute zero

- Lowest temperature attainable by a substance
- Particles/atoms of substance transmit no thermal energy! No motion whatsoever!
- Value=-273.15*C (Triple point of water)
- K=C+273.15
- C=273-K

Thermal expansion

When a solid body is heated particles gain kinetic energy and vibrate more rapidly and occupy more space. Neighbouring particles are pushed further away and there is an increase in potential energy. Similar situation occurs when a liquid or uncontained gas is heated. Particles expand when heated and contract when cooled.

Air in a thermometer is removed so that changes in air pressure have no effect on air the tube.

Thermal expansion of water

Water's smallest volume and maximum density is at about 4*C. When cooled below this temperature it expands. When it freezes it continues to expand further. (e.g. a water bottle in the freezer)

Specific Heat Capacity

- The amount of heat required to raise the temperature of 1 kg of a substance to 1*C.

  In order to increase the temperature of a substance we need to apply heat. Some substances are more difficult to heat up than others, and therefore they have a greater heat capacity. Materials with **large heat capacities can absorb and store more internal energy and when cooled, cool more slowly.**

The amount of heat required to produce a temperature rise in a substance depends on:

- Mass (*m)*: the greater the mass, the greater the heat required to increase the kinetic energy of all particles.
- Specific heat capacity ©: Substances with low specific heat capacities, such as copper and steel, require little heat to produce a temperature rise.

- Temperature rise: the greater the temperature rise, the greater the amount of heat required.

$$Q = mc\Delta T$$

  The specific heat of a substance changes as its temperature increases and its molecular structure changes.

  Thermal equilibrium

  In order for a substance to reach thermal equilibrium:

- Heat lost = Heat gained
- The final average kinetic energy of the particles of both substances is the same.

For example if a hot rod is placed in a bath of cold water, heat from the metal is transferred from the metal to the water. The temperature of the water will increase and the temperature of the metal rod will decrease until thermal equilibrium is reached.
This does not mean that both materials have the same internal energy. That would only occur of both materials have the same specific heat capacity and mass.
Assuming that there are no energy losses or gains from the surrounding environment, the total energy will remain the same. This is referred to as conservation of energy.

Thermal equilibrium depends on:

- The mass of the object and the specific heat capacities of the materials.

Heat Transfer: Conduction & Convection

Conduction: Process in which thermal energy (heat energy) is transferred from one vibrating particle to another particle nearby. There is no net movement of particles. Occurs mostly in solids. Particles with high kinetic energy share the energy with neighbouring particles. This way heat is transferred throughout material.

- Some materials are good conductors of heat. Some are referred to as insulators as they conduct heat poorly.
- A material's ability to conduct heat depends on how conduction occurs within the material. Which can happen in two ways:

1. **Energy transfer through molecular or atomic collisions.**
   If one part of the material is heated, then particles in that region will vibrate more rapidly than surrounding particles. This vibrational system will pass through the bonds between the particles. This process can be quite slow since the mass of particles is relatively large and vibrational velocities are low. Low vibration velocities= slow to pass on energy.
2. **Energy transfer by electrons.**
   Not only will molecules gain energy but so will free electrons. As electrons have tiny masses compared to atoms, even a small energy gain will result in a very large amount of velocity. These fast moving electrons transfer heat energy throughout the material very quickly.

Factors affecting thermal conduction:

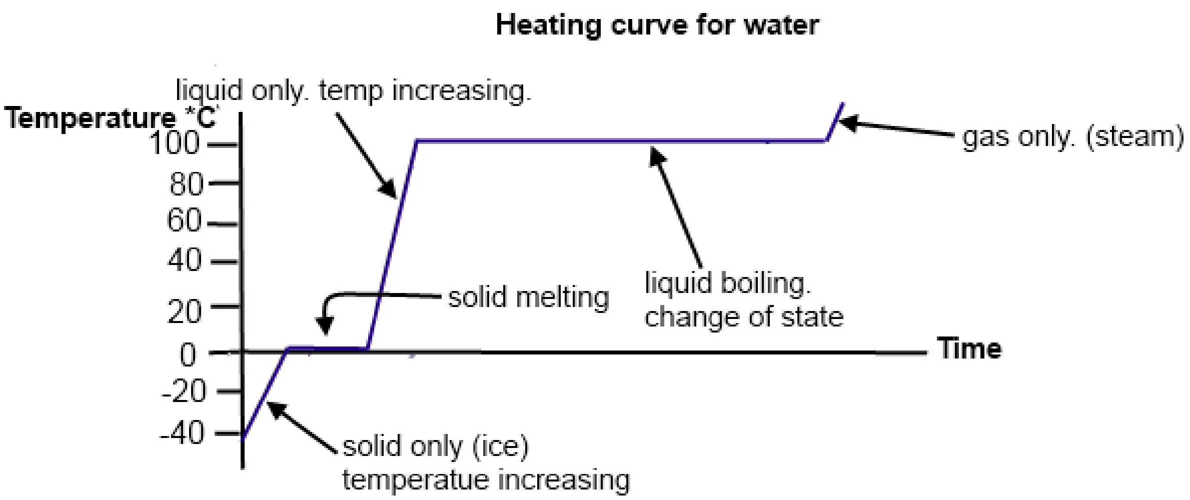
- Thickness of material
  Thicker material requires greater number of molecular collisions to transfer energy
- Temperature difference across material
  Greater temperature difference will result in a faster rate of heat energy transfer
- Surface area
  Increased surface area=increased number of particles involved in process=increased rate of conduction
- Nature of material
  Larger a material's thermal conductivity more rapidly it will conduct heat energy.

Convection: The transfer of energy within a fluid (gas or liquid) where a hot parcel of fluid will move from one place to another. When a fluid is heated it becomes less dense and therefore rises. **Convection currents** result as the cold and more dense fluid moves downwards to take its place. Convection involves mass movement of particles over a distance.

Change of State

Substances exist as solids, liquids or gases. If heat is applied to a substance then there is an increase in temperature which is an increase in the average kinetic energy of its particles.

At particular temperatures, the applied heat can cause a change of state. The applied heat is absorbed by the particles as potential energy as they move further apart from each other.



Latent Heat

Amount of heat required to cause a change of state **without change in temperature**. Referred to as 'hidden' heat.

Specific latent heat of fusion

Amount of heat required to change 1 kg of a substance from a **solid to liquid (or vice versa)** without any change in temperature. Water's latent heat of fusion is 3.34×10^5 J kg^{-1}

Specific heat of vaporisation

Amount of heat required to change 1 kg of a substance from a liquid to gas (or vice versa) without any change in temperature. Water latent heat of vaporisation is 2.26×10^6 J kg^{-}

$$Q = mL$$

Motion

Motion can be described as the change in position of an object/body in respect to time.

- Displacement (position): distance moved from one origin to current position directly; change in position e.g. 10.2m south east, 4.21 km due North

- Distance: actual distance covered when position changes during motion. e.g. a swimmer completes 2 lengths of a pool, distance covered would be 10 + 10=20m

- Speed: Distance an object has travelled over time. e.g. a car travelling at 50 km h.

- Velocity: distance an object has travelled in a particular direction. e.g. a car travelling at 65km h South East

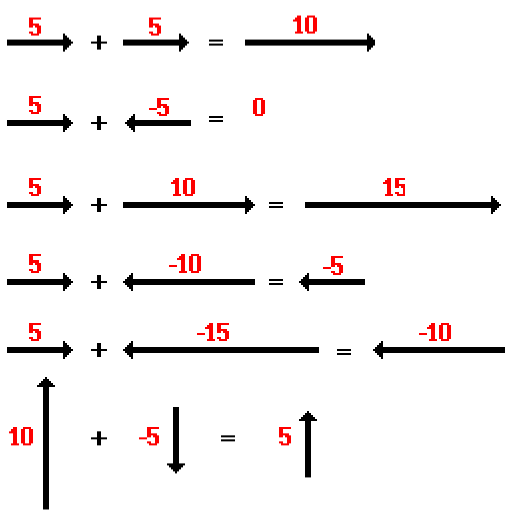
- Acceleration: rate of change of velocity in a particular direction. e.g. a falling body accelerates at 9.8 m s towards

Scalar Quantities: a magnitude on its own **without direction**.

Vector quantities: a magnitude with size and direction.

Vector Addition and Subtraction

Vector quantities can be represented as an arrow.



Speed = distance travelled over time

= scalar quantity (no direction)

= symbol *v*

units ms^{-1}

Velocity

Velocity = displacement over time

= vector quantity (includes direction)

= symbol $\bar{v}\ or\ v$

units ms^{-1} $\boldsymbol{v_{av}} = \frac{\bar{s}(\boldsymbol{displacement})}{\boldsymbol{time}\ (\boldsymbol{seconds})}$

Speed or velocity can be determined from the gradient of a position vs. time graph.

Acceleration

The rate of change of velocity. This may be due to the body going faster, slower or changing it's direction of motion.

- $\frac{\text{change in velocity}}{\text{change in time}}$ $\frac{ms^{-1}}{s}$
- Vector quantity (direction, $\pm$)
- Symbol $\bar{a}$

  Units ms^{-2}

Acceleration can be determined from the gradient of a velocity vs. time graph.

Equations of motion

$$v = u + at$$
$$s = ut + \frac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

- Falling bodies

If a body is to fall freely under the influence of gravity it will accelerate at a speed of $9.8m/s^{-2}$

The equations of motions can be applied to a falling body.

Forces

A force can be a push or a pull acting on a body. Forces acting on a body are known as contact forces and forces acting on a body at a distance are known as non-contact forces.

- Contact forces include the simple push or pull that are experienced in everyday situations. Example of these include the forces colliding between billiard ball, the force on a bouncing ball and so on. Other contact forces include:
- Adhesion: force of attraction between different materials (e.g. Sellotape and paper)
- Cohesion: Force of attraction between particles of the same material (e.g. attraction between water molecules that become rain droplets)
- Surface tension: A force of attraction between molecules across the surface of a liquid, which can be strong enough in water to support the weight of some insects.
- Any force that occurs when two or more bodies actually touch each other.

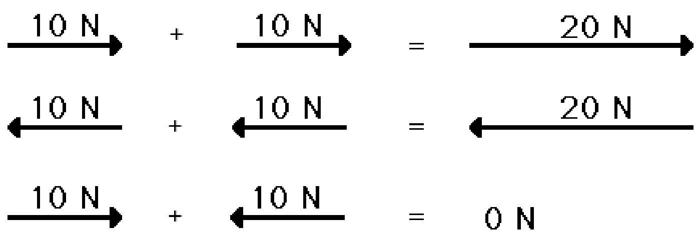
Non-contact forces occur when the object causing the push or pull is physically separated from the object that experiences the force. These forces are said to act at a distance. Gravitation, magnetic and electric forces are non-contact forces.

A force may change an objects shape, speed or the direction of its motion. The amount of force is measured in newtons (N). 1 N is the force exerted when holding a 100g mass against gravity.

<u>Representing force as a vector</u>

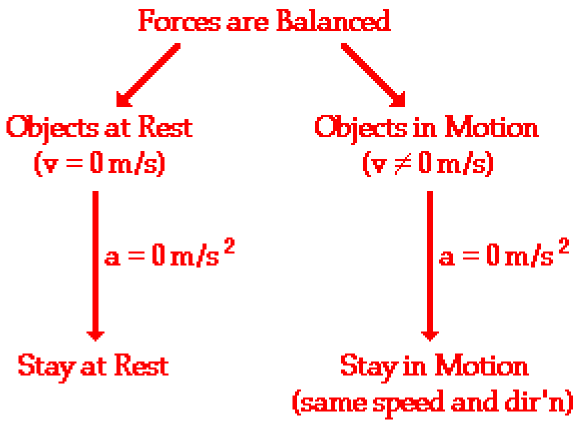
Force is a vector quantity. The direction which a force acts is also needed if the effect of the force is to be determined.

Vector quantities can be represented using arrows. Using vectors determines the overall effect of two or more forces acting on a body.



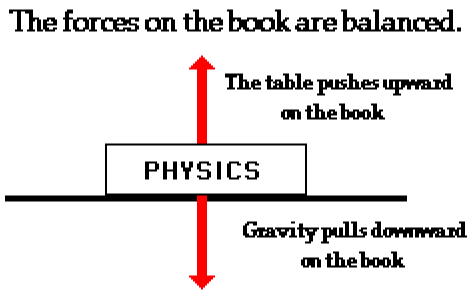
Newton's First Law of Motion

- The state of which bodies will only change if a net force (external) is applied to them. "Everybody continues at a state of rest, or of uniform motion in a straight line, unless acted upon by an external force unbalanced force"
- This is often referred to as the Law of Inertia. The larger the mass, the larger the inertia. Inertia ids the ability of an object to remain at rest (or in uniform straight line motion) unless acted upon by an external unbalanced force.



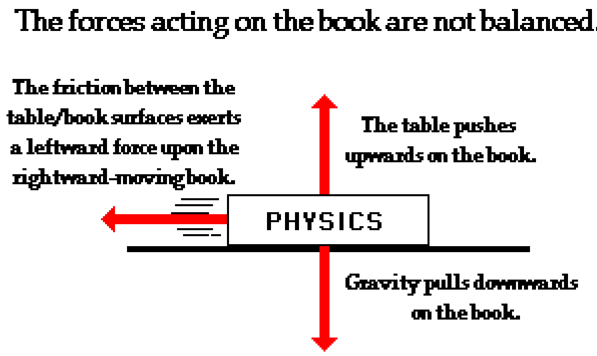
Forces in equilibrium

When the net force is zero, the forces are said to be in equilibrium or the forces are balanced.



The two forces are of equal magnitude and in opposite directions, they balance each other. The book is said to be at **equilibrium**. There is no unbalanced force acting upon the book and thus the book maintains its state of motion.

When all the forces acting upon an object balance each other, the object will be at equilibrium; it will not accelerate.



The force of gravity pulling downward and the force of the table pushing upwards on the book are of equal magnitude and opposite directions. These two forces balance each other. Yet there is no force present to balance the force of friction. The frictional force opposes the motion of the book in the horizontal direction.

Momentum

The tendency of an object to continue moving at the same speed in the same direction. It depends on the mass and velocity of the object. Any **moving** object has acquired momentum. This momentum is the product of mass times velocity and it is a vector quantity which has the same direction as the velocity.

For example, it is more difficult to stop a heavy truck than a light car travelling at the same speed. A cricket ball travelling at high velocity is also harder to stop than one moving slowly.

Whenever an unbalanced force is applied to a body it's velocity will change and so will its momentum.

$$p = mv$$

Newton's Second Law of Motion

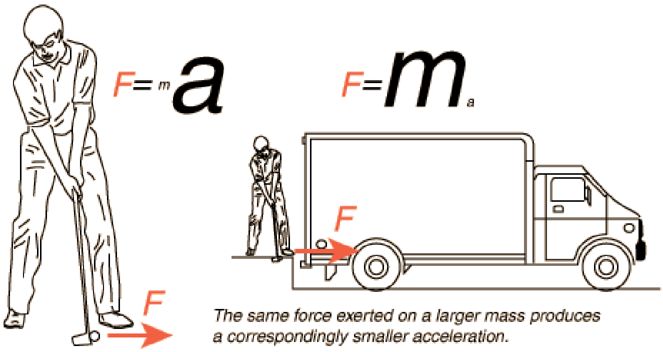
Newton's Second Law of motion describes the effect of an external force applied to a body.

- The acceleration of a body is directly proportional to the external force applied to it and inversely proportional to its mass.

In other words the greater the force applied to the object, the less difficult it is accelerate. The heavier an object, the more difficult it is to accelerate.

1 Newton is the force needed to accelerate a mass of 1kg.

$$Fnet = ma$$



REMEMBER FORCE CAUSES ACCELERATION NOT MOTION!!!

Mass

A body's ability to resist acceleration when the body is acted on by a net force.

Weight

Force of attraction in a body due to gravity.

$$\boldsymbol{W = mg}$$

Impulse (Change in momentum)

- An external force acting on a body can change its velocity and hence its momentum. The longer the force acts on the body, the greater the change in momentum.

The effect of force on a force on the momentum of a body is called the impulse of a force. Impulse is a vector quantity having the same direction as the change in momentum.

An unbalanced force is required to change the momentum of the object, increase its momentum, decrease its momentum or change its direction.
This force might be a result from a collision or interaction with another object.

$$\Delta p = p_f - p_i$$
$$= mv_f - mv_i$$

If the force acts opposite the object's motion, it slows the object down. If a force acts in the same direction as the object's motion, then the force speeds the object up. Either way, a force will change the velocity of an object. And if the velocity of the object is changed, then the momentum of the object is changed.

In a collision, an object experiences a force for a specific amount of time that results in a change in momentum. The result of the force acting for the given amount of time is that the object's mass either speeds up or slows down (or changes direction). The impulse experienced by the object equals the change in momentum of the object. In equation form, F • t = m • Δ v.

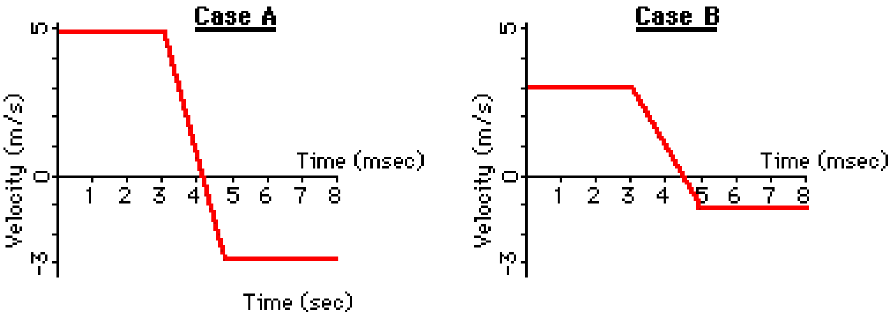
$$I = Ft = mv - mu = m(v - u)$$

Measured in N s

Change In momentum= change in impulse!

Impulse can be given to a body over a very short time period, as in a collision, or over a much longer period, such as the steady acceleration of a car.

The change in momentum (impulse) can be determined from the area under a force vs. time graph.



Decreasing the amount of force caused by a collision can be achieved by increasing the impact time.

An increase in time taken to lose our momentum causes corresponding decrease in the average impact force.

Newton's Third Law of Motion

- *For every action there is an equal and opposite reaction.*

Whenever one body exerts a force (an action) on a second body, the second body exerts an equal and opposite force (a reaction force) on the first.

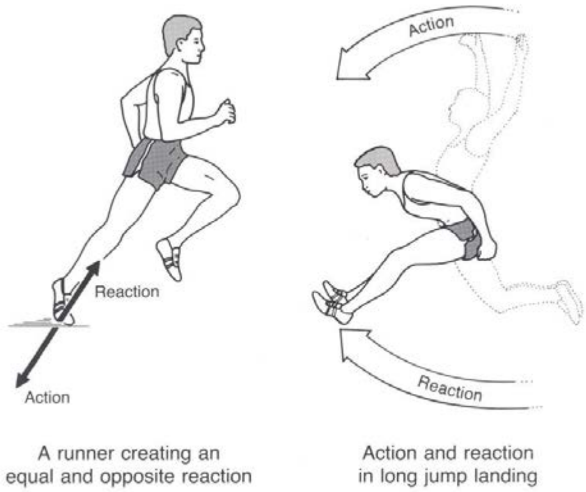
This means that in every interaction between objects there is a pair of forces.

The size of the forces on the first object equals the size of the force on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. Forces always come in pairs - equal and opposite action-reaction force pairs.

Action-reaction force pairs make it possible for fish to swim.

$$F(A\ on\ B) = -F(B\ on\ A)$$

Walking relies on an action-reaction pair in which the foot will push down and backwards with an action force. In response, the ground will push upwards and forwards. The forward component is responsible for the body moving forward as a whole, while the back foot remains at rest.



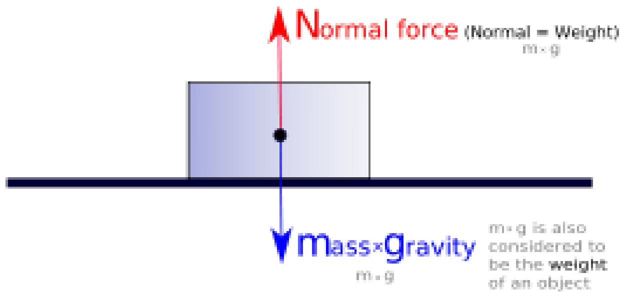
Normal Force

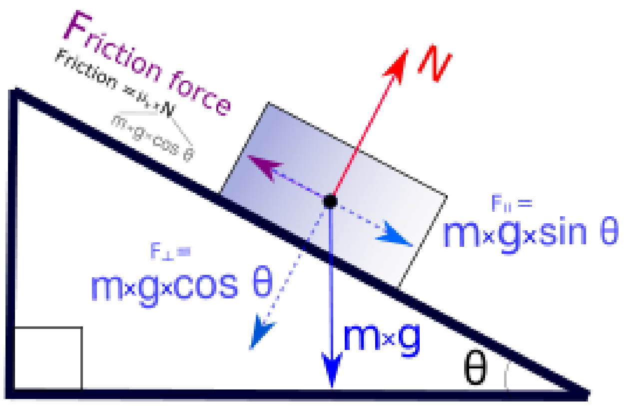
When an object is allowed to fall under the influence of gravity, the effect of the force of gravity can be seen. The net force acting is the weight, which therefore accelerates at *g (9.8).*

When a body is at rest on a table the force of gravity still acts on the body. Since the object does not move there is obviously another force acting on the body, in order to balance the weight force. This force is provided by the table. Because of the weight of the object the table is deformed a little, and being elastic, it will push upwards. The elastic force is perpendicular to its surface and is called the normal reaction force.

$$\sum F = W + N = 0$$

Forces are balanced and must equal to zero as the object does not move.





The inclined plane

Where the surface is perpendicular to the weight force, the normal force will act directly upwards and cancel the weight force. On an inclined plane however, N is at an angle. This force will change in magnitude, getting smaller as the angle increases. If there is no friction, the body will slide down the incline.

From the vector diagram above we can conclude that:

$$\sum F = W + N = w \sin\theta = mg \sin\theta$$

From Newton's second law, the net force is:

$$\sum F = ma$$

So:

$$ma = mg \sin\theta$$

Or:

$$a = g \sin\theta$$

This means that acceleration down the incline is due to the angle of the incline alone and not the mass of the body.

Weight and Apparent Weight

Apparent weight: *normal reaction force acting on an object*

Tension: Stretching force is called tension. This occurs between ropes and objects e.g. a rope pulling on a block the stretching force acts on both directions along the length of the wire.

$$T = \sum F - W$$

Conservation of momentum

Law of Conservation of Momentum: If no external force acts upon a system its total momentum remains unchanged.

In any collision or interaction between two or more objects in an isolated system, the total momentum of the system will remain constant; that is, the total initial momentum will equal the total final momentum:

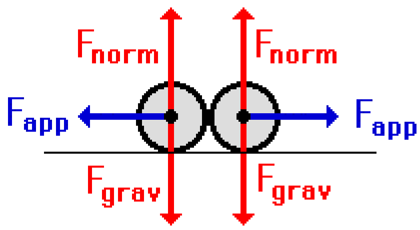
$$\Sigma p_i = \Sigma p_f$$

Or:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

For a collision occurring between object 1 and object 2 in an isolated system, the total momentum of the two objects before the collision is equal to the total momentum of the two objects after the collision. That is, the momentum lost by object 1 is equal to the momentum gained by object 2.

Total system momentum is conserved for collisions occurring in isolated systems



The collision between two billiard balls on a friction-free surface occurs in an isolated system; the only unbalanced forces occur from within the system.

Consider the collision of two balls on the billiards table. The collision occurs in an isolated system as long as friction is small enough that its influence upon the momentum of the billiard balls can be neglected. If so, then the only unbalanced forces acting upon the two balls are the contact forces that they apply to one another. These two forces are considered internal forces since they result from a source within the system - that source being the contact of the two balls. For such a collision, total system momentum is conserved.

A system is a collection of two or more objects. An isolated system is a system that is free from the influence of a net external force that alters the momentum of the system. There are two criteria for the presence of a net external force; it must be...

- a force that originates from a source other than the two objects of the system
- a force that is not balanced by other forces.

Work: *Involves a force acting on an object to cause displacement.*

- The product of the applied net force and its displacement in the direction of the force.
- When work is done on a body, the energy of the body changes. (measure of energy used to carry out the work).
- Measured in joules.

In all instances in which work is done, there is an object that supplies the force in order to do the work. If a World Civilization book is lifted to the top shelf of a student locker, then the student supplies the force to do the work on the book

$$W = Fs$$

Work is the area under a force vs. displacement graph.

- Whenever the net force is perpendicular to the direction of motion, no work is done due to the fact that there is no change in displacement.
- E.g a person carrying an armload of books. There is no work done on the books since the direction of the applied force is at right angles to the displacement.

The work achieved by a force acting at an angle, will be less than that when the force is acting in the direction of the displacement.

$$W = Fs\cos\theta$$

Where θ *is the angle between the applied force and the direction of the motion.*

Mechanical Energy

- Energy that is possessed by an object due to its motion or due to its position.
- An object's ability to do work.

Two types of mechanical energy include:

1. *Kinetic Energy*

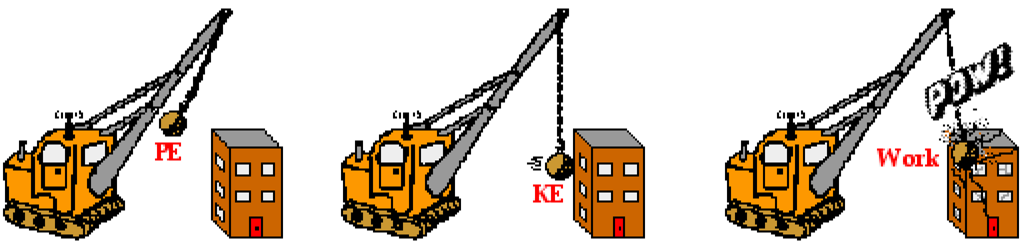
- An object in motion, possess kinetic energy.

$$E_k = {}^{1}/{}_{2}\,mv^2$$

2. *Gravitational potential energy*

Stored energy giving the body potential to do work or create a force creating motion. The work done by a body in changing position with or against a gravitational field can be quantified by considering the force acting on it.

$$E_P = mgh$$



The massive ball of a demolition machine possesses mechanical energy - the ability to do work. When held at a height, it possesses mechanical energy in the form of potential energy. As it falls, it exhibits mechanical energy in the form of kinetic energy. As it strikes the structure to be demolished, it applies a force to displace the structure - i.e., it does work upon the structure.

The total amount of mechanical energy is merely the sum of the potential energy and the kinetic energy. This sum is simply referred to as the total mechanical energy (abbreviated TME).

TME = PE + KE

Energy Transformations

Energy is never lost in the real sense as it is only converted from one form to another. An example is the conversion of potential energy to kinetic energy as a body is allowed to fall freely from some given height.

Internal & External Forces

Internal forces

- Capable of changing the form of energy without changing the total amount of mechanical energy.
- For example an object 'forced' from a high elevation to a lower elevation by the force of gravity. Its Ep is transformed into Ek, yet the total mechanical energy remains constant.

External Forces

- Capable of changing the total mechanical energy of an object.
- If the object gains energy, the work being done is positive. If the object loses energy, the work done is negative.
- The work that is being done will be equal to the change in TME.

Energy efficiency: is the percentage of energy which is transformed. All practical energy loses some energy as heat; and this energy efficiency can be expressed as:

$$efficiency\ (\%) = \frac{useful\ enrgy\ transferred\ \times\ 100}{total\ energy\ supplied}$$

$$= \frac{useful\ output\ \times 100}{total\ input}$$

Power

The rate at which energy is transformed or the rate at which work is done.

$$Power = \frac{work\ done}{time\ taken} = \frac{energy\ transformed}{time\ taken}$$

$$P = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t}$$

When finding the power required producing a constant speed against frictional or gravitational force, we can:

$$P = F_{av} v_{av}$$

For example when a person is pushing a lawnmower at a constant speed. There is no increase in Ek but the energy is being transformed to overcome the frictional forces acting against the lawnmower.

Elastic & Inelastic collisions

- **Elastic collisions:** Collisions in which both momentum and kinetic energy is conserved.
  The total system kinetic energy before the collision equals the total system kinetic energy after the collision.

- **Inelastic collisions:** Collisions in which momentum is conserved **but** kinetic energy is transformed into other forms of energy. Almost elastic collisions are collisions in which little friction acts e.g. between billiard balls, between air track gliders. Perfectly inelastic collisions are those in which colliding bodies stick together after impact e.g. a car crash, collision between the Moon and a meteorite would be perfectly inelastic. In these types of collisions much and sometimes all of the Ek in the system is lost.

Energy changes

In elastic collisions the energy is conserved meaning that the final kinetic energy of the system is equal to the initial energy of the system. It doesn't mean however that the Ek has remained constant at all times.

The efficiency in a collision can be given by:

$$efficiency\,\% = \frac{final\ kinetic\ energy}{initial\ kinetic\ energy} \times 100$$