- ***Candidates should be able to :***

  - *Define **POWER** as the rate of work done.*
  - *Define the **WATT**.*
  - *Calculate power when solving problems.*
  - *State that the **EFFICIENCY** of a device is always less than 100% because of heat losses.*
  - *Select and apply the relationship for % EFFICIENCY :*

$$\%\ \text{efficiency} = \frac{\text{useful output energy}}{\text{Total input energy}} \times 100\%$$

  - *Interpret and construct **SANKEY** diagrams.*

- ***POWER (P)***

- *Energy can be **transferred** from one object to another by :*
  - ***WORK DONE,***
  - ***HEATING,***
  - ***ELECTRICITY, or***
  - ***WAVES.***

- *The **POWER** of any energy transfer process depends on how quickly a given amount of energy can be transferred. All timed athletic events are a 'power' struggle between the competitors. In all such events, the athlete is required to do the work needed to carry their body over a measured distance and the winner is the person who can perform the task in the shortest time. Of course, since their weight is different the amount of work done by each person will differ, so it is not strictly the most powerful athlete that will emerge the winner. The gold medal belongs to the athlete with the greatest 'power to weight ratio'.*

- ***POWER (P)** is defined as the rate of work done or of energy transfer.*

- *The unit of power is the **WATT (W)**.*

***1 WATT (W)** is defined as a rate of work done or of energy transfer of **1 JOULE PER SECOND**.*

$$1\ W = 1\ J\ s^{-1}$$

We also use larger power units such as the KILOWATT (kW) and MEGAWATT (MW) and smaller units such as the MILLIWATT (mW).

$$1\ kW = 10^3\ W$$
$$1\ MW = 10^6\ W$$
$$1\ mW = 10^{-3}\ W$$

*If **ENERGY (E)** is transferred in **TIME (t)**, the **POWER (P)** is :*

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

(P in W, E in J, t in s)

From which :

$$E = P \times t$$

*If the energy is transferred by a force doing **WORK (W)** in **TIME (t)**, the **POWER (P)** is :*

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

(P in W, W in J, t in s)

- ***NOTE** : 'W' is used for both the **WATT** and **WORK DONE**. Take care not to confuse them !*

- **HUMAN BODY POWER**

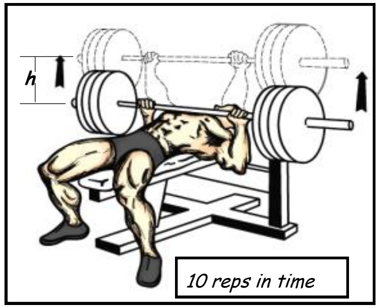
The average daily food intake for a typical human being would give about 12 MJ of energy. This energy is used by the body to keep warm, to move about etc.. We can use this to estimate the average power used by a person in the course of a single day.

$$\text{average power} = \frac{\text{energy transferred}}{\text{Time}} = \frac{12 \times 10^6}{24 \times 60 \times 60} \approx 140\ \text{W.}$$

So, the average human being dissipates energy at approximately the same rate as two 60 W light bulbs. Of course, this power value can be much greater when we are engaged in any kind of physical activity.

PRACTICAL ESTIMATION OF PERSONAL POWER

- *A weight-training exercise such as the **BENCH PRESS** is performed **10 times** using the maximum weight which the individual can comfortably manage. The **time (t)** taken to do all 10 repetitions is measured using a stopwatch.*



- *A steel tape measure is used to measure The **height (h)** through which the known **weight (W)** is moved for each repetition.*

- $\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \frac{10 \times mgh}{t} = \_\_\_\_\_\_\_\_\_\_ = \_\_\_\_\_\ \text{W}$

- *It should be noted that this is only a rough estimate. In order to simplify the determination, no account has been taken of :*
  - *The work done against friction.*
  - *The work done in the second half of each repetition as the weight is lowered to the starting position under gravity.*

- ***USEFUL POWER EQUATION - P = Fv***

*If a constant **FORCE (F)** is applied to an object and it does work by moving its point of application through a **DISTANCE (s)** in a **TIME (t)**, then the **POWER (P)** is given by :*

$$\text{Power} = \frac{\text{work done}}{\text{time}} = \frac{\text{force} \times \text{distance}}{\text{time}}$$

$$P = \frac{F \times s}{t} = F \times v$$

$$P = Fv$$

P (W), F (N), v ($m\ s^{-1}$)

- **PRACTICE QUESTIONS (1)**

1 (a) An athlete delivers ***24 kJ*** of energy as he goes through an exercise over a ***2 minute*** period. What is his ***average power ?***

(b) Calculate the ***energy*** used by a ***100 W*** light bulb if it is left on all day.

(c) A racing car engine does ***8500 kJ*** of work in ***55 s.*** What is its ***output power ?***

2 A cyclist uses a dynamo to generate electricity for the lights on his bike. If the lights are rated at ***4 W*** and he cycles for ***1 hour***, how much ***energy*** will he use up ? Assume that no work is done against friction.

3 Each time the heart beats, it pumps and accelerates about ***25 g*** of blood from ***0.20 m s***$^{-1}$ to ***0.35 m s***$^{-1}$. Calculate :

(a) The ***increase in kinetic energy*** of the blood produced by each beat.

(b) The ***power*** of the heart when it beats at ***80 beats per minute.***

4 At the famous ***Niagara Falls*** water drops through a height of ***60 m*** at the amazing rate of ***5.7 x 10***^{6} ***kg s***$^{-1}$.

Calculate the ***power*** of this energy transfer from gravitational potential energy to kinetic energy.

5 (a) Show that ***power*** may be expressed as ***force x velocity.***

(b) A car engine has a maximum power of ***150 kW.*** Calculate the ***maximum motive force*** which such an engine can provide at ***10 m s***$^{-1}$ and ***30 m s***$^{-1}$.

6 A girl of mass ***65 kg*** rides a mountain bike of mass ***15 kg*** at a constant speed of ***4 m s***$^{-1}$ up a hill which rises ***1.0 m*** for every ***10 m*** of its length.

If air and road resistance amount to ***25 N*** and the acceleration due to gravity, g = ***9.81 m s***$^{-2}$, calculate the ***power*** she is developing.

- ***EFFICIENCY AND SANKEY DIAGRAMS***

- *No energy transfer is 100% efficient. Only part of the input energy Is transformed into the energy form which is wanted. We say the Rest is wasted because it appears in an unwanted form (e.g. heat or Sound). Devices are always less than 100% efficient because even Though friction can be reduced, it can never be completely eliminated.*

- *The **% EFFICIENCY** of any device or system may be calculated using the following equations :*

$$\% \text{ Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

$$\% \text{ Efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100\%$$

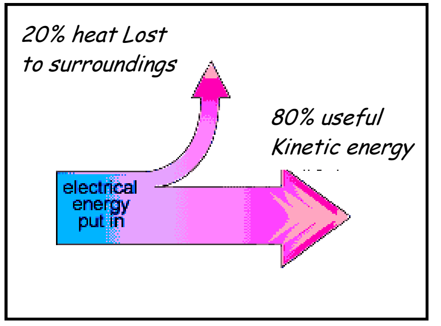
- *Efficiency may be represented pictorially using **SANKEY DIAGRAMS***
(previously discussed in 1.3.1 - Work and Energy Conservation).

__SANKEY DIAGRAMS__ are schematic representations of energy transfer situations in which the width of the arrows used shows the percentage of the total input energy that is transformed into each energy form.

- ***SANKEY DIAGRAM EXAMPLES***

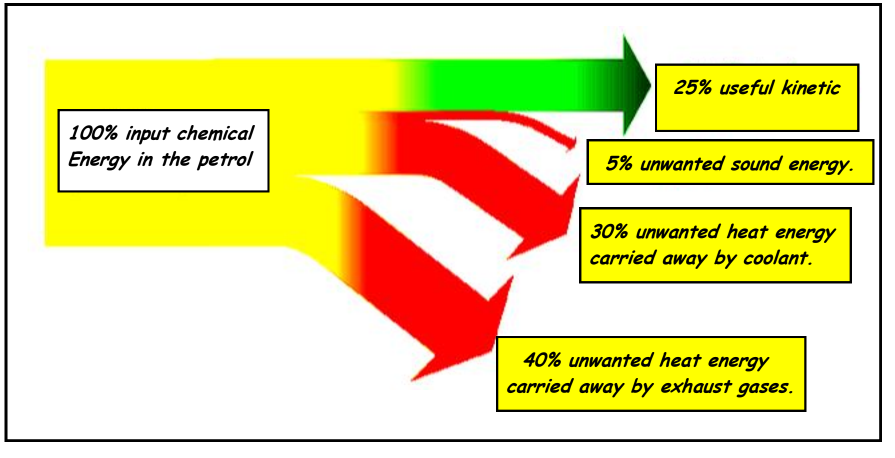
  - ***Electric Motor***

In this simple case, 80% of the electrical energy input which powers the motor is transformed into useful kinetic energy. The rest is transformed into unwanted heat which is lost to the surroundings. So this motor is 80% efficient.



  - ***Petrol Internal Combustion Engine***

The Sankey diagram below shows that in an internal combustion engine only 25% of the chemical input energy is transformed into useful output energy. The remaining 75% is transformed into unwanted heat and sound. So this engine is 25% efficient.



1 A ***40 kW*** electric motor powers a hotel lift. The lift and the people in it at a particular time has a total weight of ***20 kN.*** If the motor raises the lift and passengers through a height of ***24 m*** in ***18 s,*** calculate :

(a) The ***electrical energy supplied*** to the motor.

(b) The ***useful gravitational potential energy*** transferred by the motor.

(c) The ***percentage efficiency*** of the motor.

2 A Premiership footballer is being tested for muscle efficiency. He pedals an exercise bike whose speedometer registers a speed of ***12 m s^{-1}*** when the bike is generating a constant braking force of ***45 N.***

(a) Calculate the ***useful power*** supplied by the footballer's muscles.

(b) If percentage muscle efficiency is ***24%,*** calculate the ***total power*** supplied to the footballer's muscles.

3 A ship whose engine is developing a useful power output of ***500 kW*** is cruising at a constant velocity of ***6.0 m s^{-1}.*** Calculate :

(a) The ***thrust*** exerted by the propeller on the water.

(b) The size of the ***force*** resisting the ship's forward motion.

(c) The ***power input*** if the engine efficiency is ***30%.***

- **HOMEWORK QUESTIONS**

1 (a) Explain what is meant by the term ***POWER.***

(b) Water leaves a reservoir, falls through a vertical height of ***130 m*** and causes a water wheel to rotate. The rotating wheel is then used to produce ***110 kW*** of electrical power.

(i) Calculate the ***velocity of the water*** as it reaches the wheel, assuming that all the gravitational potential energy is converted to kinetic energy.

(ii) Calculate the ***mass of water*** flowing through the wheel per second, assuming that the production of electrical energy is 100% efficient.

(iii) ***State*** and ***explain*** two reasons why the mass of water flowing per second needs to be greater than the value in ***(ii)*** in order to produce this amount of electrical power

(OCR AS Physics – Module 2821 - June 2004)

2 A car of mass ***1000 kg*** is moving on a horizontal road at a ***steady*** speed of ***10 m s^{-1}*** against a constant frictional force of ***400 N.***

(a) Calculate the ***power output*** of the engine.

(b) The car now climbs up a hill inclined at ***8°*** to the horizontal. Assuming that the frictional force remains constant at ***400 N***, calculate the ***new engine power*** required to maintain the ***10 m s^{-1}*** speed.

3 A small dinghy has an outboard motor with a propeller which is ***20 cm*** in diameter. If the dinghy is tied to the quayside and the engine is started, the propeller forces back a stream of water at a speed of ***6.0 m s^{-1}.***

Calculate the ***input power*** to the engine if it is ***40%*** efficient and the density of sea water is ***1.1 x 10^3 kg m-3.***

4 (a) Explain the concept of ***work*** and relate it to ***power.***

(b) A cable car is used to carry people up a mountain. The mass of the car is ***2000 kg*** and it carries ***80*** people, of average mass ***60 kg.*** The vertical height travelled is ***900 m*** and the time taken is ***5 minutes.***

(i) Calculate the ***gain in gravitational potential energy*** of the 80 people in the car.

(ii) Calculate the ***minimum power*** required by a motor to lift the cable car and its passengers to the top of the mountain.

(OCR AS Physics - Module 2821 - June 2001)