- When a force causes an object to move through a distance, **work** is done.

- Work done, force and distance are related by the equation : $W = F \times d$

  W is the **work done** in **joule (J)**.
  F is the **force applied** in **newton (N)**.
  d is the **distance moved in the direction of the force** in **metre (m)**.

- **Energy is transferred** when work is done. Candidates should be able to discuss the transfer of kinetic energy in particular situations (e.g. shuttle re-entry or meteorites burning up in the atmosphere).

- Work done against **frictional forces**.

- **Power** is the work done or energy transferred in a given time. $P = E/t$

  P is the **power** in **watt (W)**.
  E is the **energy transferred** in **joule (J)**.
  t is the **time taken** in **second (s)**.

- **Gravitational potential energy** is the energy that an object has by virtue of its position in a gravitational field. When an object is raised vertically, **work is done** against gravitational force and the object gains **gravitational potential energy**.

$$E_p = m \times g \times h$$

  E_p is the **change in gravitational potential energy** in **joule (J)**.
  m is the **mass** in **kilogram (kg)**.
  g is the **gravitational field strength** in **newton per kilogram (N/kg)**.
  h is the **change in height** in **metre (m)**.

- The **kinetic energy** of an object depends on its **mass** and **speed**.

$$E_k = \frac{1}{2} m \times v^2$$

  E_k is the **kinetic energy** in **joule (J)**.
  m is the **mass** in **kilogram (kg)**.
  v is the **speed** in **metre per second (m/s)**.

WORK

- When a **force** is applied to an object and cause it to **move in the force direction, work is done** on the object.

- **Energy** is then transferred to the object being moved.

- For the purpose of calculations involving work done and energy transferred it is assumed that :

WORK DONE (J) = ENERGY TRANSFERRED (J)

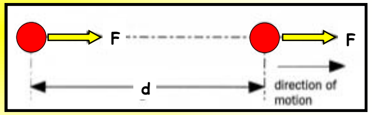
It should be noted however, that some of the work done is converted into into **non-useful energy forms** (e.g. heat, sound ..), so in practice the useful energy transferred to an object is always **less** than the work done on it.

- The relationship between **work done, force applied** and **distance moved** is expressed in the following equation :

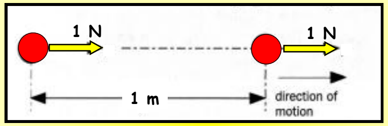
WORK DONE = FORCE × DISTANCE MOVED IN THE FORCE DIRECTION

$$W = F \times d$$

(J) (N) (m)



1 JOULE (J) is the work done when a force of **1 NEWTON (N)** moves its point of application a distance of **1 METRE (m)** in the force direction.



1 joule = 1 newton x 1 metre

1 J = 1 N x 1 m

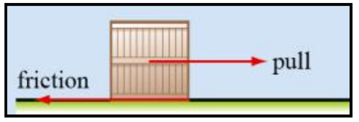
1 J = 1 Nm

Work Done and Energy Transferred

In the solution of many problems we make the assumption that **all** the work done on an object is transferred as kinetic or potential energy of the object (i.e. that none of the work done is wasted as heat or sound). In practice, some of the work done is always transferred as unwanted heat and sound energy.

1. A Crate Pulled Along the Ground

- If a crate is pulled along the ground as shown opposite, some of the work done will be used to overcome the frictional force which opposes the motion. The crate and the ground will heat up and some sound will also be produced.



So, although in simple calculations we may assume that the work done on the crate is totally transferred to kinetic energy, the reality is that :

work done on crate = kinetic energy gained by crate + (heat energy + sound energy)

The Space Shuttle Re-entering Earth's Atmosphere

When a space shuttle returns to Earth it has a great deal of kinetic energy, since it has a large mass and speed.

On re-entry into the atmosphere the shuttle encounters enormous frictional forces which cause it to decelerate. Some of the initial kinetic energy is converted into heat and this means that the shuttle is subjected to extremely high temperature with the subsequent risk of fire and explosion. NASA scientists have developed special heat shields which protect the body of the shuttle, as well as the astronauts inside, from the intense heat generated on re-entry.

Meteorites Entering Earth's Atmosphere

Even if they are **not massive**, meteorites have **enormous kinetic energy** because of the **very high speed (≈ 40 km/s)** at which they are travelling when they enter the atmosphere.

As it travels into the atmosphere a meteorite encounters tremendous air resistance and This causes it to **decelerate, lose kinetic energy and heat up.** As its outer layers get hotter and hotter, the meteorite loses energy to the surrounding air in the form of **heat and light** (this makes it visible on Earth, especially at night).

As the meteorite continues its journey through the atmosphere, its surface layers become so hot that vaporization begins. Continued heating causes more and more of the surface mass to be lost and in most cases the meteorite is completely vaporized before reaching the planet's surface.

Work Done Against Frictional Forces

As we have seen in the cases discussed on page 30, **work done against frictional forces** is mainly transformed into **heat energy**.

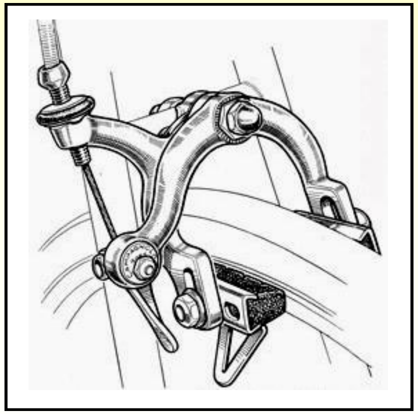
In the film **"Castaway"**, Tom Hanks continuously rubs a dry stick against a split branch as he attempts to make fire.

The **work done** in moving the stick back and forth is transformed into **heat energy** and eventually enough heat is generated to ignite some coconut hairs he has placed in the branch. The split in the branch allowed air to flow through the hairs and so ensure ignition.

When the brakes on a bike are applied, **work is done** against the **frictional force** between the rubber pads and the wheel rims.

This opposes the motion of the wheels and both the pads and the rims **heat up**.

The **kinetic energy** of the moving bike is transformed into **heat energy** (plus some **sound energy** if the brakes 'squeal').



Power

Power is the **work done** or **energy transferred** in a **given time**.

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'.

If **energy (E)** is transferred in **time (t)**, the **power (P)** is given by :

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

P (W), E (J), t (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 given by :

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

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

From which : $W = P \times t$

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

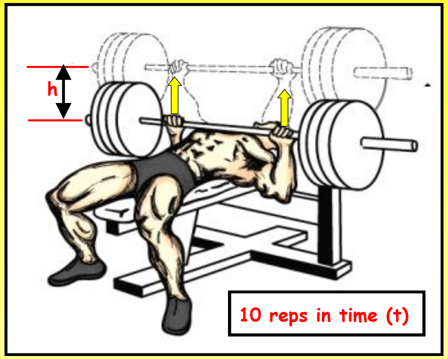
1 watt (W) is a rate of working or energy transfer of **1 joule per second (J/s).**

$$1\ W = 1\ J/s$$

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

PRACTICAL WORK : 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.

- $$\text{power} = \frac{\text{work done}}{\text{time taken}}$$

  $$= \frac{10 \times m \times g \times h}{t}$$

  $$= 10 \times \_\_\_\_ \times \_\_\_\_ \times \_\_\_\_$$

  $$= \_\_\_\_ \text{ W}$$

- 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*.

Gravitational Potential Energy (E_p)

Gravitational Potential Energy (E_p) is the energy possessed by an object by virtue of **its position in a gravitational field.**

- When an object is raised vertically, **work is done** against gravitational force and the object gains **gravitational potential energy**.

- The **gain or change** in an object's **gravitational potential energy** may be calculated using the equation shown below :

$$E_p = m \times g \times h$$

E_p is the **change in gravitational potential energy** in **joule (J).**
m is the **mass** in **kilogram (kg).**
g is the **gravitational field strength** in **newton per kilogram (N/kg).**
h is the **change in height** in **metre (m).**

Kinetic Energy (E_k)

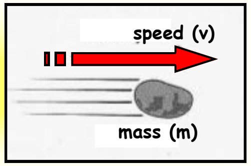
Kinetic Energy (E_p) is the energy possessed by an object by virtue of **its motion** and it depends on both the **mass** and **speed** of the object.

- The **kinetic energy** of a moving object may be calculated using the equation shown below :

kinetic energy = ½ x mass x speed ²

$$E_k = \tfrac{1}{2} m v^2$$

(J) (kg) (m/s)



- **PRACTICE QUESTIONS**

1 Work is said to be done when a force moves an object in the direction of the force.

In each of the following examples, **state** and **explain** whether or not any work is done by the force mentioned.

(a) Pulling a child in a pushchair along the sand on a beach.

(b) Pushing a very heavy off-road vehicle, but being unable to get it to move.

(c) A boulder falls off a cliff under the force of gravity.

(d) A weight-lifter lifts a heavily laden barbell from the ground to a point above his head.

(e) The same weight-lifter holds the weights at the same height above the ground.

2 **(a)** Write down a **word equation** relating **force applied**, **work done** and **distance moved.**

(b) State **two equivalent SI units** for **work done**.

(c) Calculate the **work done** when a force of **25 N** moves an object over a distance of **6.5 m** in the direction of the force.

(d) When an object is moved over a distance of **12 m** over a frictionless surface, **960 J** of work is done. What is the size of the **applied force**?

3 In the solution of many problems we make the assumption that **all** the work done on an object is transferred as kinetic or potential energy of the object.

Explain why this is **not true** in practice and **describe** an example which illustrates this fact.

4 The **Burj Khalifa** in Dubai is the world's tallest building. It rises to an amazing **828 m** above the ground and if you were get to the top using the stairs, you would climb a total of **3234 steps**!

(a) If each of these steps has a depth of **20 cm**, calculate the **total work done** by a man of weight **800 N** who climbs to the top using the stairs.

(b) How much **gravitational potential energy** does the man have when he gets to the top of the building?

(c) If the man achieves his rather foolhardy mission in a total time of **1 hour and 50 mins**, calculate his **average power**.

5 A boulder of mass **1450 kg** is dislodged and falls from the top of a **120 m** high cliff.

(a) Calculate the **work done by the force of gravity** in bringing the boulder to the base of the cliff (Take **g = 10 N/kg**).

(b) How much **kinetic energy** is theoretically transferred to the boulder by its fall ? Why is the kinetic energy transferred to the boulder **less than this** in practice ?

(c) Given that the boulder has the amount of kinetic energy you have calculated in **(b)** when it hits the ground, calculate the **impact speed** of the boulder.

6 Calculate the **increase in kinetic energy** of a vehicle of mass **1200 kg** when it accelerates from **10 m/s** to **25 m/s**.

7 A bullet of mass **8.0 g** is given **160 J** of kinetic energy when it is fired from a gun.

Calculate the **speed** of the bullet as it exits the gun barrel.

- HOMEWORK QUESTIONS

1 **(a)** A catapult is used to fire an object into the air.
Describe the energy transformations when the catapult is :

(i) **Stretched** **(ii)** **Released**

(b) An object of weight **2.0 N** fired vertically upwards from a catapult reaches a maximum height of **5.0 m**. Calculate :

(i) The gain in **gravitational potential energy**.

(ii) The **kinetic energy** of the object when it left the catapult.

2 *A man uses a bow to fire an arrow up into the air. He draws back the bowstring and releases the arrow, which then flies into the air, reaches a maximum height, and then falls back to the ground.*

Complete the following passage which describes the main energy changes involved :

When the bowstring is drawn back, it stores ……………………………… …………………………………… energy. This is transferred to ………………………………………………… energy as the arrow is released and flies into the air. As the arrow rises, it gains ……………………………………………… ………………………………………… energy and loses ………………………………………………… energy. As the arrow falls, it gains ……………………………… energy and loses …………………………………………… ……………………………………………… energy. When the arrow hits the ground, this energy is transferred to …………………… energy and ……………………………… energy.

3 **(a)** A man having a mass of **95 kg** steps onto a box of height **24 cm**. Assuming that the gravitational field strength, **g = 10 N/kg**, calculate :

(i) The **gain of gravitational potential energy** of the man when he does this.

(ii) The **total work done** by the man if he repeats the exercise **40 times**.

(b) The same man climbs to the top of a ladder and gains **1710 J** of gravitational potential energy. **How far off the ground** is his centre of gravity when he is at the top of the ladder?

4 A car moving at a constant speed has **360 000 J** of kinetic energy. When the driver applies the brakes, the car is brought to rest in a distance of **95 m**.

(a) Calculate the **average decelerating force** that stops the car in this distance.

(b) **What happens** to the car's kinetic energy?

(c) The speed of the car was **30 m/s** when its kinetic energy was **360 000 J**. Calculate its **mass**.

5 A steel ball bearing of mass **0.06 kg** at a height of **1.5 m** above a steel table is released from rest and it is found to rebound to a height of **1.3 m**. Calculate :

(a) The **gravitational potential energy** lost during the fall.

(b) The **kinetic energy** of the ball bearing just before impact.

(c) The **speed** of the ball bearing just before impact.

(d) The **gravitational potential energy** gained by the ball bearing when it rebounds to a height of **1.3 m**.

Assume that the gravitational field strength, **g = 10 N/kg**.