ACTIVITY 15 WORK and ENERGY

AIM: To have a clear understanding of what scientists mean by WORK and ENERGY.

BACKGROUND: In science some words such as WORK have very specific meanings which are different to everyday use.

Work is done when a force moves something in the direction of the force.

$W = F \times s$ where **W** represents the Work done in joules (J)
F represents the Force in newtons (N)
s represents the displacement in metres (m)

Note: F and s must be in the same direction.

Work is a measure of the amount of energy that is transferred from one place to another.

e.g. lifting a weight vertically.

When an object like the weight bar has work done on it, then the weight bar gains energy.

If an object (like a weightlifter) does work she "loses" some of her energy.

OR

Work is a measure of the amount of energy that is transformed from one form to another.

e.g. Work is done when chemical energy in a battery is transformed into electrical energy.

EXAMPLE:* *Consider the work done when the weightlifter lifts a 200 kg mass above their head (a total distance of 2 m). Then she holds it there for a short time and then carries it above her head a horizontal distance of 1.5 m.

WORK DONE LIFTING THE MASS

$W = F\ s$ Because the force being applied is equal to the weight of the bar then $F = mg$

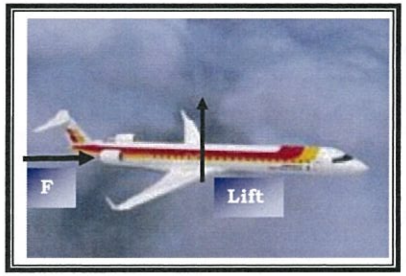
Therefore $W = m\ g\ s = 200 \times 9.8 \times 2 = 3920$ J

WORK DONE IN HOLDING THE MASS ALOFT

While holding the mass aloft the force is still acting but there is NO CHANGE in the masses displacement.
Therefore $W = m\ g\ s = 200 \times 9.8 \times 0 = 0$ J

WORK DONE IN TRANSFERRING THE MASS 1.5 m HORIZONTALLY

The displacement of the masses is 1.5 m horizontally.
The force is upwards.
Because there is NO DISPLACEMENT IN THE DIRECTION OF THE FORCE there is NO WORK DONE. (assuming no frictional force)



For scientists, work is the product of a force acting through a distance. In the example shown in the photo, an aircraft which is acted on by a force (F) from time (t) equals zero to some later time moves some distance (s). The work done on the aircraft during this time is F times s.

In our simple example, the force is a constant value aligned with the displacement of the aircraft. It is important to note that work is only done on (or by) the component of the force along the path.

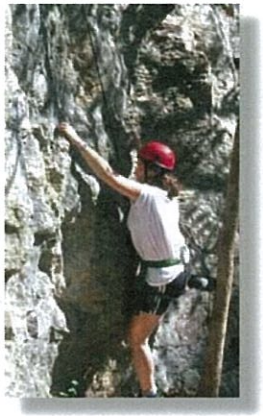
Using a cruising aircraft as another example, the **lift** is defined to be the force perpendicular to the flight path. **Lift does no work** on a cruising aircraft because the displacement is perpendicular to the force.

Similarly, if an aircraft was stopped at the end of the runway with the brakes on and the engines at full throttle, the engines do no work on the aircraft because the displacement distance is **zero**.

ENERGY:

Energy is best defined as the ability to do work.

Energy cannot be directly observed, it can only be measured or observed when it is transferred from one place to another OR transformed from one form to another.



The higher the climber goes the greater their potential energy

Nuclear energy is being transformed into heat and blast energy

Energy may exist in many different forms such as heat, light, sound, electrical, chemical or motion of an object. All of these forms of energy can be broadly categorised as either **kinetic energy OR potential energy**

KINETIC ENERGY:
Kinetic Energy (E_K) is the energy possessed by any **moving** object.
e.g. A car has kinetic energy when it moves.

POTENTIAL ENERGY:
Potential Energy (E_P) is the energy possessed by an object due to its position or condition. It appears as stored energy.
e.g.
1. A brick raised above the ground has the ability to do work when it is dropped. It has **gravitational potential energy**. Commonly called potential energy.
2. The petrol in a car has the ability to release heat when it is burnt. It has **chemical potential energy.** Commonly called chemical energy.
3. A stretched rubber band has **potential energy**.

METHOD: Using the following important energy and work formulae answer the questions below. *See the sheets on Calculations in Physics if you want assistance with calculations.*

POTENTIAL ENERGY	KINETIC ENERGY
$E_P = m\,g\,h$	$E_K = \frac{1}{2} m v^2$
where: E_P is potential energy in joules (J) m is mass in kg g is acceleration due to gravity = 9.8 ms^{-2} h is vertical height in metres	where: E_K is kinetic energy in joules (J) m is mass in kg v is velocity in metres per second (ms^{-1})

WORK

$W = F\,s$ Use when work is done against *friction* or when a *force* acts over a certain distance. Both force and displacement must be in the same direction.

$W = \Delta\, m\,g\,h$ Use when work is done in lifting an object vertically against *gravity.*

$W = \Delta E_K = \frac{1}{2} m v^2 - \frac{1}{2} m u^2$ Use when work is done in changing the *velocity* of an object.

$W = m\,a\,s$ Use when work is done in *accelerating* an object

where:

W is work in joules (J)	h is height in metres (m)
F is force in newtons (N)	v is velocity in metres per second (ms^{-1})
s is displacement in metres (m)	u is initial velocity in metres per second (ms^{-1})
g = 9.8 ms^{-2}	a is acceleration in metres per second squared (ms^{-2})

1. What is energy?
2. What is kinetic energy?
3. What is potential energy?
4. What is work?
5. What are some energy changes occurring on a slide and on a swing?
6. A 204 kg oil drum is rolled onto the back of a utility 1.0 m above the ground. Calculate the potential energy acquired by the drum.
7. The gain in potential energy of an aircraft after take-off is 5 x 10^8 J. What is its height above the ground if its mass is 10 000 kg?
8. Calculate the kinetic energy of a mass of 20 kg moving at 4 ms^{-1}.

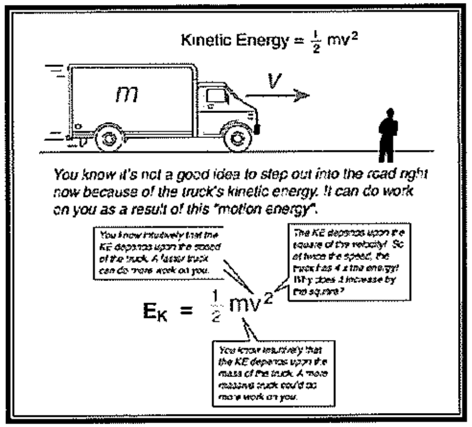
9. A body accelerates at 5 ms^{-2} for 20 seconds from rest. If the increase in kinetic energy is 2 500 J find the mass of the body.
   [Hint: First find v by rearranging the formula $a = \frac{v-u}{t}$]
10. An object of mass 10 kg is moving at 20 ms^{-1}.
    (a) What is its kinetic energy?
    (b) If it is now accelerated by a force so it reaches a velocity of 50 ms^{-1}, what will be the increase in kinetic energy?
11. Find the work done when a box is pushed 10 m across a floor with a constant speed against a frictional resistance of 24 N.
12. How much work is done in changing the velocity of a vehicle of mass 2000 kg from 10 ms^{-1} to 40 ms^{-1} if the change occurs over 200 m. [Hint: kinetic energy is changing]
13. 100 J of energy are used to move a stationary box of mass 10 kg through a distance of 15 m in 5 seconds. Find the force used.
14. How much work does a 60 kg man do against gravity when he climbs a 700 m high hill?

CHALLENGE:

15. A body of mass 50 kg moving at 10 ms^{-1} is brought to rest by a constant force in a distance of 5.0 m. Calculate the work done by the force. [Hint: First find a by rearranging the formula $v^2 = u^2 + 2as$]

ANSWERS TO NUMERICAL PROBLEMS:

6.	1999 J
7.	5102 m
8.	160 J
9.	0.5 kg
10.	(a) 2000 J (b) 10 500 J
11.	240 J
12.	900 000 J
13.	6.67 N
14.	411 600 J
15.	2500 J



Work and energy

Science understanding

Logical/Mathematical

1 **Calculate** the work done in the following situations. Show your working.

(a) A weightlifter applies a force of 784 N in order to lift a heavy barbell 2.1 m above the ground.

(b) Tayla lifts a sports bag with a force of 280 N to raise it 1.3 m from the ground into the boot of her car.

2 **Calculate** the kinetic energy of the following moving objects.

(a) Diego is moving in a dodgem car at a speed of 8 m/s; the combined mass of Diego and the dodgem car is 325 kg.

(b) A seagull of mass 0.5 kg is flying at a speed of 12 m/s.

3 **Calculate** the gravitational potential energy in each of the following situations.

(a) Sophie of mass 18 kg is sitting at the top of a 20 m climbing structure made from steel cables.

(b) A paint tin of mass 200 g is resting on a 1.5 m high shelf in a garage.

4 A car of mass 12 100 kg is travelling at 15 m/s. The driver sees that the traffic light ahead has changed to red and applies the brakes, bringing the car to a stop.

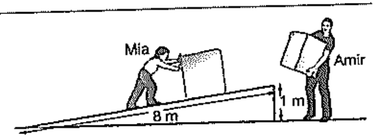
(a) **Calculate** the initial and final kinetic energy of the car.

(b) **State** the change in kinetic energy as the car comes to a stop: ____________ J

(c) The change in kinetic energy is equal to the work done by the brakes in stopping the car. **State** the work done by the brakes in stopping the car: ____________ J

(d) Given that a force of 18 150 N was supplied by the brakes of the car, **calculate** the distance over which the car slowed to a stop.

5 Mia and Amir need to lift 5 kg packing boxes by 1 m into a truck. Amir lifts his box vertically, while Mia pushes her box up a ramp.

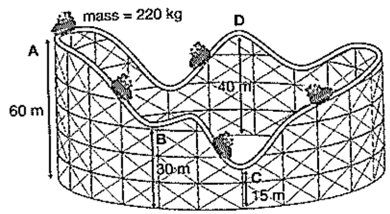


(a) **Calculate** the increase in gravitational potential energy of each box, assuming the acceleration due to gravity is $9.8\ m/s^2$.

(b) **State** whether Mia or Amir did more work in shifting or lifting the packing box.

(c) **Justify** your answer to part (b).

6 This diagram shows the rollercoaster that Tina and Rebecca rode on at a fun park.



(a) **Calculate** their gravitational potential energy at point A at the top of the first hill.

(b) **Describe** how the gravitational and potential energy of the cart has changed as the girls ride through point B on the track.

(c) **Calculate** the gravitational potential energy at point C.

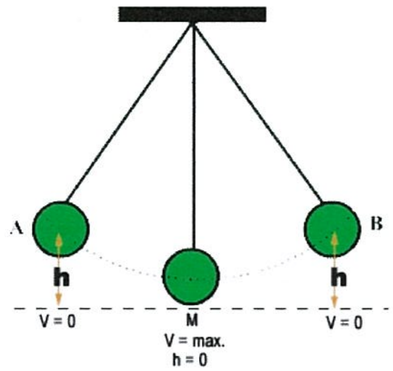
(d) Ignoring energy losses due to friction, **calculate** the girls' speed at point C, rounding off your answer to one decimal place.

ACTIVITY 16 CONSERVATION OF ENERGY

AIM: To have a clear understanding of the LAW OF CONSERVATION OF ENERGY.

BACKGROUND:
According to the **LAW OF CONSERVATION OF ENERGY:**

> **"Energy can neither be created nor destroyed, however energy can be converted from one form of energy to another form of energy."**



THE MOTION OF A SIMPLE PENDULUM ILLUSTRATES THE LAW OF CONSERVATION OF ENERGY.

PROOF:
Consider a simple pendulum as shown in the diagram above.

Energy Conservation at Point A:
At point **A** the velocity of the bob of the pendulum is zero.
Therefore, kinetic energy (E_K) at point **A** = 0.
Since the bob is at a height (**h**), the potential energy (E_P) will be a maximum. i.e. E_P = m g **h**
Energy Total = E_K + E_P
Energy Total = 0 + m g h
Energy Total = m g h
This shows that at point A the total energy = potential energy

Energy Conservation at Point M:
If we release the bob of the pendulum from point **A**, the velocity of the bob gradually increases, but the vertical height of the bob will decrease from point **A** to point **M**. At point **M** the velocity will be at a maximum and the height will be zero.

Therefore, kinetic energy (E_K) at point **M** = maximum = ½ mv^2 but E_P = 0.
Energy Total = E_K + E_P
Energy Total = ½ mv^2 + 0
Energy Total = ½ mv^2
This shows that the E_P at point A is completely converted into E_K at point M.
That is, E_P at point A = E_K at point M

Energy Conservation at Point B:
At point **M** the bob of the pendulum will not stop, but due to inertia, the bob will move towards point **B**. As the bob moves from point **M** to **B**, its velocity gradually decreases but the vertical height increases. At point **B** the velocity of the bob is zero and the vertical height is **h**.

Therefore, kinetic energy (E_K) at point **B** = 0 but E_P = maximum.
Energy Total = E_K + E_P
Energy Total = 0 + m g h
Energy Total = m g h
This shows that at point B the total energy is again potential energy.

This LOSS IN POTENTIAL ENERGY = GAIN IN KINETIC ENERGY idea can be used to solve many motion problems.

TYPE EXAMPLE:
A stone is thrown vertically upwards at 10 ms^{-1}. How high will it go?

v = 10 ms^{-1}
g = 9.8 ms^{-2}
h = ?

<u>*From the Law of Conservation of Energy*</u>
E_K at bottom = E_P at top
½ mv^2 = m g h

Rearranging equation gives: $h = \frac{0.5mv^2}{mg} = \frac{0.5v^2}{g} = \frac{0.5 \times 10 \times 10}{9.8} = 5.1$ m

METHOD: Using the conservation of energy concept to answer the questions below. *See the sheets on Calculations in Physics if you want assistance with calculations.*

1. Find the kinetic energy gain of a 10 kg object falling through 8 metres.
2. A stone is dropped down a vertical shaft and has 200 J of energy just before impact with the bottom. If the mass of the stone is 0.5 kg find the depth of the shaft.
3. What is the maximum height that a 0.5 kg ball will reach when thrown vertically upwards with a kinetic energy of 200 J.
4. A rogue satellite strikes the sea with a velocity of 500 ms^{-1}. If it has a mass of 1500 kg calculate from what height it fell. (Neglect friction and assume g is constant)
5. What must the initial velocity of a 7 kg rock projected vertically upwards if it is to reach a height of 15 m?
6. A 9 kg object is dropped 7 m from rest. Find (a) its gain in E_K (b) its loss in E_P (c) its velocity just before it hits the ground.

CHALLENGE QUESTIONS:

7. A metal spring is compressed and tied with some acid resistant ribbon. The spring is then added to a beaker containing some acid solution. The acid will dissolve the metal. What has happened to the potential energy that was stored in the spring?

8. When we speak in a sound proof room we do not hear a noise indefinitely. What has happened to the energy that the sound wave had?

9. A rubber ball is dropped from a height of 1.0 m and bounces to a height of 0.8 m. Where has the "lost" potential energy of the ball gone?

10. Sketch 3 graphs on the same axes of energy versus time that show the variation of kinetic, potential and total energy with time that occurs when an object is dropped.

11. Re-sketch the graphs of question 10 above to show what they would look like if there was a significant amount of wind resistance as the object fell.

12. A pendulum bob is pulled back so the string makes an angle of 60° with the vertical. What is the maximum speed achieved by the pendulum if the string is 2 m long? [Hint: some trigonometry is required].

ANSWERS TO NUMERICAL PROBLEMS:

1. 784 J
2. 40.8 m
3. 40.8 m
4. 12755 m
5. 17.15 ms^{-1}
6. (a) 617 J (b) 617 J (c) 11.7 ms^{-1}

"WITH WHAT VELOCITY WILL I HIT THE GROUND WHEN THEY CUT ME DOWN?"