

## Sub Topic 2: FORCES

At the end of this lesson, students should be able to:

- Calculate acceleration using  $a = v/t$
- Define force
- Use the equation  $F = ma$  to calculate force, mass or acceleration given the other variables
- Use a spring balance to measure a force in Newton
- State that the weight of an object is the force of gravity working on it
- Calculate weight,  $F = mg$  where  $g = 10\text{m/s}^2$
- Calculate the weight of various masses
- Explain that friction works against motion

### 1. Forces – pushes or pulls

- It can change the motion of the object
- Change in motion means that either the *speed* of the object changes or the *direction* in which it is moving changes.
- Change in speed means the object accelerates, i.e, it gets faster or slower
- Sometimes forces change both the speed and the direction of an object.
- Forces has a size and a direction
- The size of a force is measured in Newton (N), while arrow is used to show the direction of a force.
- Balanced forces – when the action and reaction forces are equal in size and opposite in direction they are said to be unbalanced.
- Balanced forces on a body can be recognised when an object is :
  - i. Stationary
  - ii. Moving at a constant speed.
- When the action force is different in size or direction from the reaction force then the forces are said to be unbalanced. The resultant unbalanced force always accelerates an object in the direction of the net force. This means that an accelerating object is always acted on by unbalanced forces.

$m$  = mass in kg  
 $a$  = acceleration in  $\text{ms}^{-2}$

$$F = ma$$

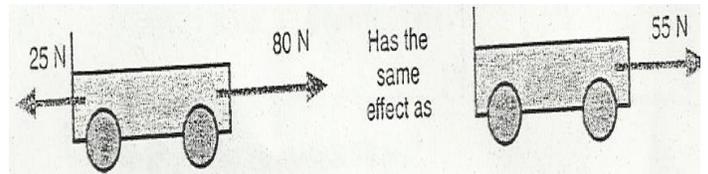
Unit = N

### Example A

The 80N and 25N forces acting in the same direction on the trolley give a single force of 105N.

### Example B

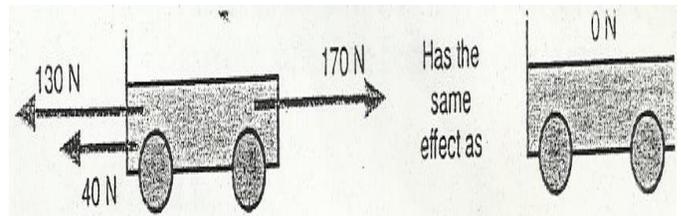
The 80N and 25N forces acting in opposite direction on the trolley give a single force of 55N toward the right.



In Example A and B, forces acting on the trolley are described as unbalanced because their combining effect is not zero.

### Example C

The 170N, 130 N and 40N forces acting on the trolley shown below combine to give a force of zero. The three forces acting on this trolley are balanced because they combine to give zero force.



### FORCE , MASS and ACCELERATION

- When the force acting on an object is unbalanced, the object will accelerate.

### Example 1.

A toy car of mass 1.5kg is pulled by a string and accelerates at  $2\text{ms}^{-2}$ . The size of the force which accelerated the car is  $F = ma$

$$= 1.5 \times 2 = 3\text{N}$$

- To calculate the mass,  $m = F/a$  and acceleration,  $a = F/m$

### Example 2

A force of 500N is used to accelerate a 2kg object. What is the acceleration of the object?

$$A = F/m$$

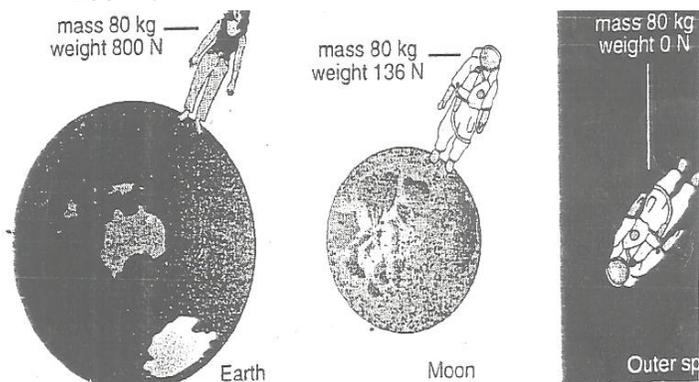
$$= 500/2$$

$$= 250 \text{ ms}^{-2}$$

mass 80 kg  
weight 800 N

mass 80 kg  
weight 136 N

mass 80 kg  
weight 0 N



An object accelerates at  $7.5\text{ms}^{-2}$  when a force of  $15000\text{N}$  is used to accelerate it. What is the mass of the object?

$$M = F/a$$

$$= 15000/75$$

$$= 2000\text{kg}$$

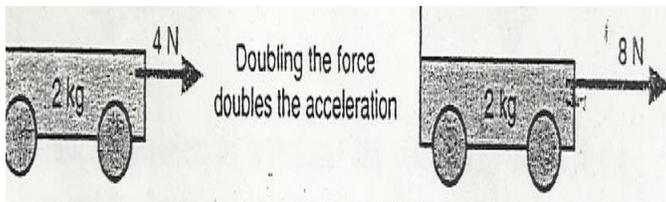
**Force and Acceleration**

- When different forces are applied to objects of the same mass, a greater force produces greater acceleration.

*Example -* Two trolleys with the same mass  $2\text{kg}$  are pulled by different sized forces. The trolley which had the greater force applied to it had the greater acceleration.

**Mass and Acceleration**

- When the same force is used to accelerate two different masses, the smaller mass has the greater acceleration.
- Example -* A trolley is pulled with a force of  $8\text{N}$ . Two trolleys are then pulled with the same sized force ( $8\text{N}$ ). The object with the larger mass has the smaller acceleration.



**Mass and Weight**

- Mass is the amount of material in an object. The amount of material making up an object is always the same wherever the object is.
- Mass is measured in kilograms (kg) or grams (g).
- Weight is the force on the object caused by gravity.
- Sometimes called gravity force and like all forces has the unit Newton.

Formula

Weight = mass  $\times$  gravity

$W = mg$

- The value of  $g$  is  $10\text{ms}^{-2}$  on earth.
- Gravity on the moon is  $1.7\text{ms}^{-2}$ . In outer space it can vary from much larger values to nearly zero.
- A baby of mass  $7\text{kg}$  has a weight

$$W = mg$$

$$= 7 \times 10$$

$$70\text{N}$$

**Gravity** – is the attractive force between different objects one of which is usually large, such as the earth (or moon) and the other is a small object, such as a person. The size of this attractive force varies depending on the mass of the objects and the distance between them.

The following example compares a person’s mass and weight on the earth, moon and in space.

*Example -* An astronaut has a mass of  $80\text{kg}$ . On earth her weight is given by Weight =  $m \times 10$  ( $80 \times 10 = 800\text{N}$ ).

On the moon her weight is  $136\text{N}$  (about  $1/6$  than on earth). In outer space she is weightless (weight =  $0$ ). Her mass is the same everywhere,  $80\text{kg}$ .

**FRICTION**

- Is a force which opposes the movement of one object past another.
- Examples -* rubbing your hand, shoe and floor, car running on the road receives friction, parachute falling.
- Without friction, an object will continue to move nonstop once given a small push. It slows down objects e.g. – a wooden block that has been pushed across a table slows and stops moving. This is due to friction force opposing the motion of the block.
  - Friction force is always opposite to the direction of motion. Heat is produced due to friction.
  - Friction can be useful and can also be a problem.

Advantage of Friction	Disadvantages of friction
Cars and bicycle tyre have treaded to grip the road	Cause surfaces in machinery to heat and wear out.
Brakes on cars and bicycle use friction to slow down and stop the vehicle	Air resistance and friction waste energy in machine
Parachute work because of friction with the air.	Slows down moving object unwanted by racing cars, boats

### AIR RESISTANCE

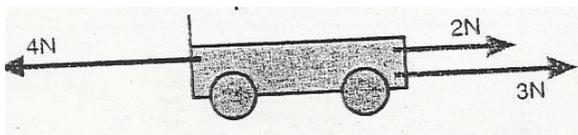
- Is the friction which results when one surface is air and an object is moving through air.
- Air resistance will always act to slow a car or to resist an object moving and in this way it is nuisance.
- If an object falls through the air, air resistance acts upon the object slowing its movement down. The larger the surface area of an object, the more friction (air resistance acting slowing down the object).
- Example – a flattened piece of paper and a crushed piece of paper were both dropped from the top of a building. The crushed paper reached the ground first before the flattened paper because air resistance act on a larger surface area slowing down the flattened paper.

### Ways of reducing friction.

- Lubricating oil and grease between surfaces. The reduces friction between two forces, avoiding wear and tears in parts of the machines.
- Wheels or ball bearings to roll the surface past each other. Round surfaces reduce friction
- Cushion of air. Eg in hovercraft a land or water vehicle that travels supported on a cushion of air.

### Self Check # 1.

1. The diagram shows three horizontal forces acting on a cart.

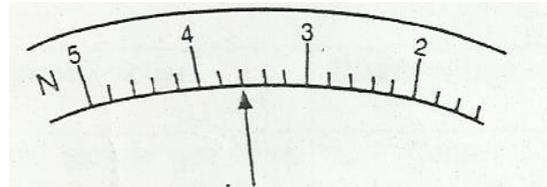


The three forces have the same effect as a single force of?

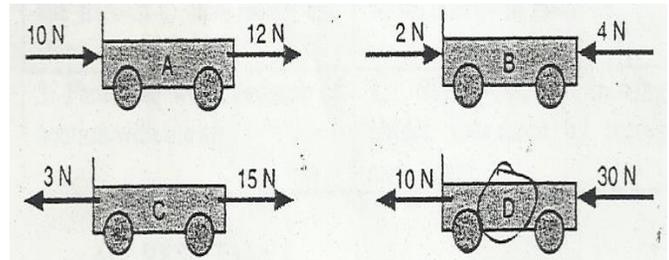
2. Completer the following table by calculating a to h.

Force	Mass	Acceleration
a.	2	8
b.	50	0.05
c.	25000	800
10	20	d.
15000	0.6	e.
60	1500	f.
800	g.	2.5
1000	h.	0.05

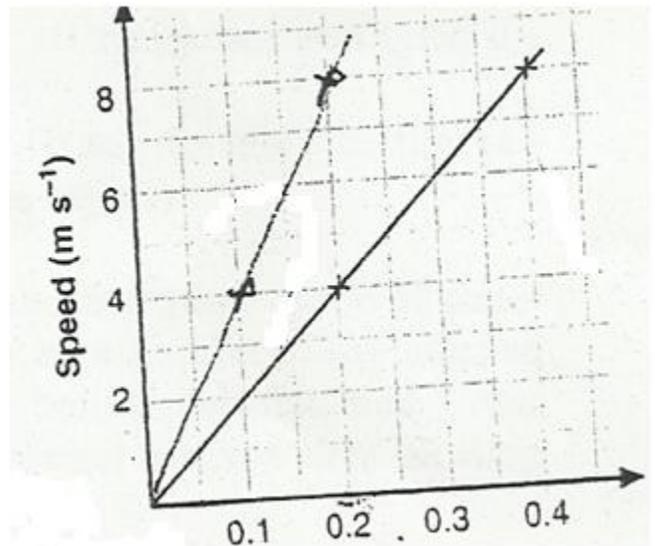
3. This is the scale of a force meter. What is the reading?



4. Which of the trolleys below will have the greatest acceleration?



5. In an experiment to investigate the relationship between the force and acceleration of a trolley the graph shown was obtained.



- a. What is the acceleration of the trolley?
  - b. If the mass of the trolley was 4kg what is the size of the force accelerating the trolley?
  - c. If the force is now doubled, what will the new acceleration be?
  - d. Sketch the speed time graph shown and on it sketch the new speed time graph which you would expect.
6. The speed time graph shown was drawn from the results of an experiment. Two trolleys of different

masses were each accelerated by a force of size 400N.

- Which trolley had the greatest mass?
- Calculate the acceleration of trolley A.
- Find the mass of trolley A using your result from b.

7. Which combination of force and mass produces the greatest acceleration?

	Force	Mass
A	Large	Large
B	Small	Large
C	Small	Small
D	large	Small

8. A force of 4N acts on a mass of 8kg. What is the acceleration of the mass in  $\text{ms}^{-2}$ ?

9. Explaining the meaning of:

- Mass –
- Weight –

10. What is the weight of?

- 105 kg rugby player
- 50kg sack of potatoes
- 500g container of margarine

11. A moon rock is brought to earth. How does its mass and weight on earth compare with its mass and weight on the moon?

	Mass on earth	Weight on earth
A	More than on the moon	Same as on the moon
B	More than on the moon	More than on the moon
C	Same as on the moon	Same as on the moon
D	Same as on the moon	More than on the moon.

12. What factors determine the gravitational force on a body near the earth?

- Mass only
- Mass and volume
- Distance from the centre of the earth only
- Both mass and distance from the centre of the earth.

13. There is no gravitational force acting on an astronaut.

- On the moon

- At a point between the earth and the moon
- In orbit around the earth
- In outer space far away from any star, planet or other object.

14. The largest acceleration is produced by as:

- Large force acting on a small mass
- Large force acting on a large mass.
- Small force acting on a large mass
- Small force acting on a small mass.

#### Self Check # 2

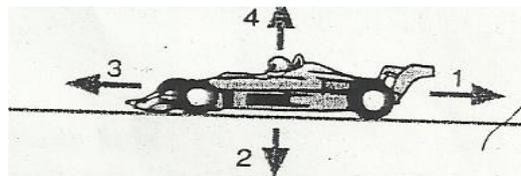
1. Give 3 examples of friction being a problem.

2. Give 3 examples where friction is useful.

3. Explain the effects of friction forces in each example below.

- A match is struck
- A meteor burns up when it enters the atmosphere
- An electric drill bit gets hot as it is used
- Soap is rubbed on a screw before it is used
- Car accidents are more frequent on wet or icy roads.

4. The diagram shows the four main forces acting on a car as travels to the left at a steady speed.



- Which force is the
  - Driving force of the engine (E)
  - Friction force (F)
  - Weight of the car (W)
  - Reaction force of the road on the car.

5. The wind pushes a sand yacht along dry sand. When the accelerating force on the yacht is 280N its acceleration is  $2\text{ms}^{-2}$ .

- Calculate the mass of the loaded yacht. Give units
- The yacht moves onto wet sand where the friction force has the same size as the wind force. What happens to the speed of the yacht?

## Sub Topic – WORK, POWER AND ENERGY.

= 100 J

*At the end of this lesson, students should be able to:*

- Define work done on an object.
- Derive  $W = mgh$  from  $F = ma$  and  $W = fd$ ,
- Identify that work done equals energy gained
- Identify the Joule as the unit of energy
- Calculate the gravitational energy and kinetic energy ( $E_k = \frac{1}{2} mv^2$ )
- Relate speed to accidents on roads and the  $E_k$  of cars and know how the value of  $E_k$  changes when speed is doubled, tripled or quadrupled.
- Calculate power ( $P = W/t$ )

### 1. WORK

- Is defined as the product of the force and the distance moved in the direction of the force.

$$\text{Work} = \text{Force} \times \text{distance}$$

- Unit used for work is Joules.
- If work is done to an object the object gains energy. The gain in energy is equal to the work done, so both work and energy are measured in the same unit the Joule (J)
- The amount of work done depends on the size of the force and the distance the object moves. The greater the force used or the greater the distance moved the greater the work done.

#### EXAMPLE

A car is pushed 3m across the ground by a force of 2000N the work done is

$$\begin{aligned} W &= Fd \\ &= 2000 \times 3 \\ &= 6000 \text{ J} \end{aligned}$$

- This work done equals the energy gained by the car. The car will gain 6000Joules of kinetic energy. (Assuming no energy is lost to friction.)
- Work is done to lift an object. The size of the force needed to lift the object is equal to the weight of the object.

- An object of mass 5kg lifted 2m off the floor. The weight of the object is:

$$\begin{aligned} W &= mg \\ &= 5 \times 10 \\ &= 50 \text{ N} \end{aligned}$$

So the force needed to lift the object is 50N. The work done to lift the object is :

$$\begin{aligned} W &= Fd \\ &= 50 \times 2 \end{aligned}$$

The work done equals the gain in energy of the mass. The mass has gained 100 J of gravitational potential energy.

### 2. GRAVITATIONAL POTENTIAL ENERGY. ( $E_p$ )

- This is the energy a body possesses because of a body's height above the earth.
- The symbol is  $E_p$  OR P.E

$$E_p = m g h$$

m- mass of body

g – gravitational acceleration

h – height above earths surfaces.

- Unit is in Joules

#### Example 1

How much energy does a mass of 2kg have if it is 5m above the earth?

$$\begin{aligned} E_p &= m g h \\ &= 2 \times 10 \times 5 \\ &= 100 \text{ Joules.} \end{aligned}$$

- The higher an object is lifted the greater its gravitational potential energy. The increase in gravitational potential energy is equal to the work done to lift the object.
- When an objects height decreases, the object loses gravitational potential energy. The same formula

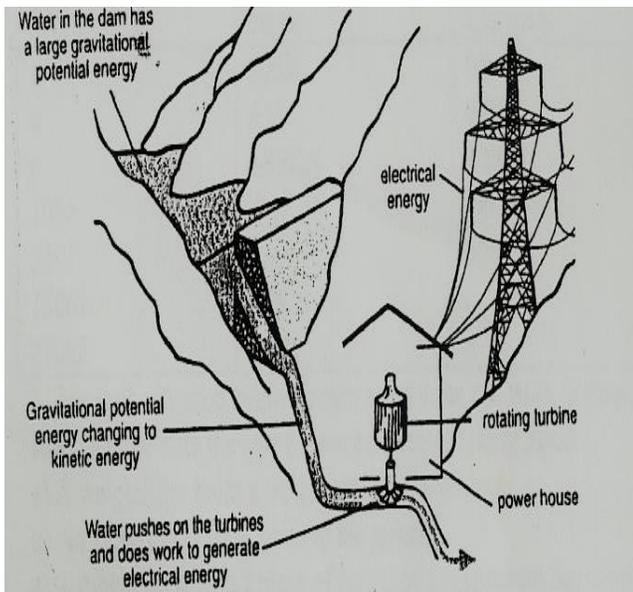
( $P. E = Fd$ ) is used to calculate the loss in gravitational potential energy.

#### Example 2

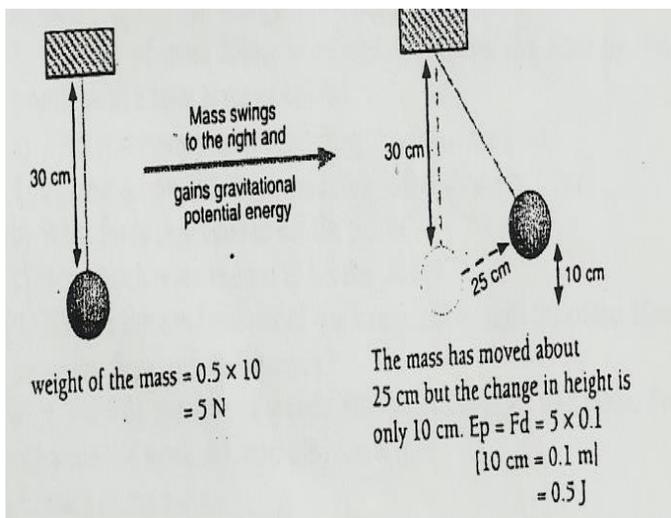
In a hydro – electric power station, water stored behind the dam has gravitational potential energy. As the water loses height passing through the dam, the potential energy of the water is changed into kinetic energy and then electrical energy in the turbines of the power station.

When calculating a change in gravitational potential energy, it is the vertical change in height rather than the distance moved which is used in the calculation.

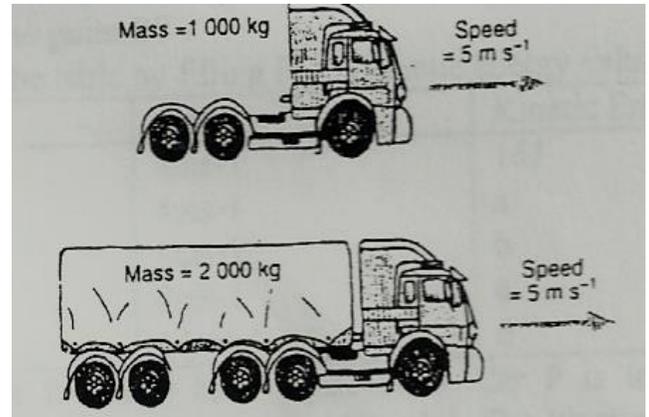
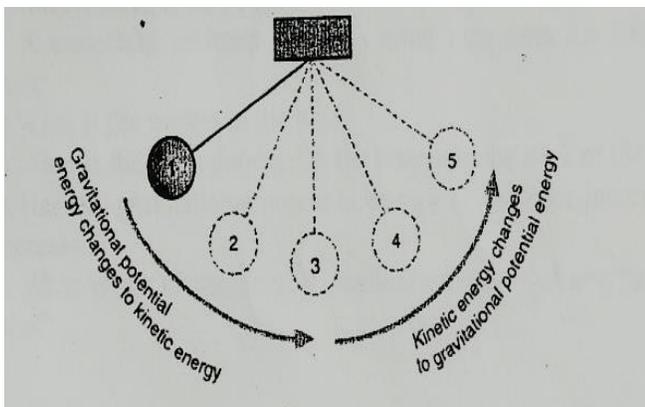
**EXAMPLE 3**



A pendulum is made from a mass of 0.5kg on the end of a piece of string which is 30 cm long.



**Note – when a pendulum swings the energy of the mass alternates between kinetic energy and gravitational potential energy.**



**KINETIC ENERGY ( $E_K$ )**

- Is the energy that an object has because it is moving.
- Unit for kinetic energy is Joule (J)
- The greater the mass of a moving object, the greater the kinetic energy of the object. If the mass of the object doubles and the speed remains the same, the kinetic energy will double.

$$E_K = \frac{1}{2} mv^2$$

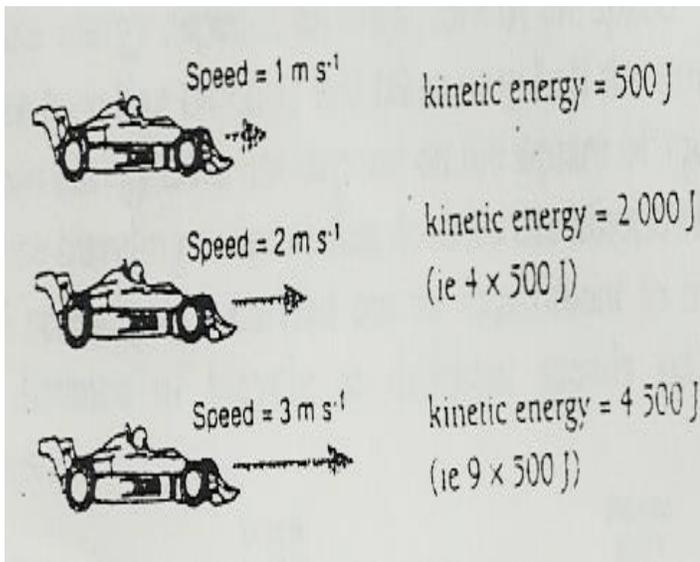
m – mass  
v – speed of object

**EXAMPLE 1**

- The faster an object moves the greater its kinetic energy. When the speed of an object doubles and the mass remains the same, the kinetic energy increased by factor of four. This is because the amount of kinetic energy is related to the square of the speed. This means that :  
If the speed doubles, the kinetic energy increased by ( $2^2 = 4$ )  
If the speed increases by 3 times the kinetic energy increase by ( $3^2 = 9$ )
- The relationship between speed and kinetic energy has important consequences for road safety

**EXAMPLE 2**

- If a car doubles its speed, there is four times the amount of kinetic energy to lose before the car becomes stationary. With the same brakes used in the same way, it will take a car travelling twice as fast about four times the distance to stop.
- When a moving car has an accident such as hitting a power pole, large amounts of kinetic energy are lost suddenly. Doubling the speed of a car increased the risk of injury and damage by a factor of four.



### POWER

- Is the rate at which work is done.
- A powerful machine is able to do a large amount of work in a short period of time. A less powerful machine will take longer to do the same amount of work.
- The unit for power is the Watt ( W).
- A watt is one joule per second and is written  $1W = 1 J/s^{-1}$
- 80 watts means  $80 Js^{-1}$ . A power rating of 80 W means 80 Joules of work is done each second. In two seconds  $80 \times 2 = 160J$  of work is done.
- Power is calculated using the work done and time taken.

$$P = W / t$$

W – work done in Joules

### Example

A woman walks along the road. She does 19800 J of work in one minute. The power the woman develops is :

$$P = W / t$$

$$= 19800 / 60$$

$$= 330 W \text{ (or } 0.33 kW \text{)}$$

$$1kW = 1000W, 1MW = 10^6W \text{ (1000, 000W)}$$

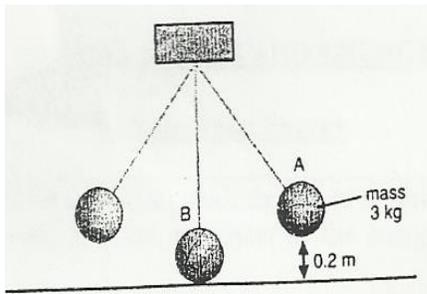
### SELF CHECK # 3

1. Calculate the following table by calculating a to g.

Work	Force	Distance
a.	200N	9m
b.	6.5N	0.05m
c.	10000N	1.5m
100J	d.	1m
350J	e.	50cm
1500J	50N	f.
280J	700N	g.

2. For each situation below decide whether or not work is done. If work is done state the type of energy changes taking place.
- A weightlifter holds a weight still above her head
  - An apple drops from a tree to the ground
  - A rubber band fires a piece of rolled up paper across the room.
  - In a tug of war, two equally matched teams pull against each other but the rope remains still.
3. Sarah used a spring exerciser. When she pulls on the exerciser with an average force of 400N, the springs stretched by 0.5m.
- How much work does Sarah do to the exerciser with an average force of 400N, the springs stretched by 0.5m?
  - How much energy does the exerciser gain? what type of energy is gained?
4. Which one for the following is not measured in joules?
- Heat. B. energy. C. force D. work
5. A piano of mass 250kg is moved 10m along the floor by two people with a total force of 4000N.
- What is the work done in shifting the piano the 10m?
  - The piano is now lifted up some steps of total height 1.5m. What force is needed to lift the piano?
  - How much work is done to lift the piano?
  - What is the total amount of work required to shift the piano 10m along the floor and up the stairs?
6. A girl lifts a carton of weight 80N from the floor to a table. To calculate the work she must also know the:
- Mass of the carton
  - Height of the table
  - Acceleration due to gravity
  - Time it takes to make the lift.

7. A motorbike of mass 150kg is lifted 21m onto the back of a truck.
- What is the weight of the bike?
  - What is the work done to lift the bike onto the back of the truck?
  - Has the gravitational potential energy of the bike increased or decreased?
  - What is the change in the gravitational potential energy of the bike?
8. Answer the questions below using the following diagram.



- a. The diagram shows a ball mass 3kg suspended on a string. The ball is held at point A. 0.2m higher than point B. it is released and allowed to swing back and forth. What is the weight of the ball?
- How much more gravitational potential energy has the ball at point A then it has at point B?
  - What is the major energy change occurring as the ball swings from point A to point B?
9. Two cars P and Q have equal mass. Car P is travelling at  $50\text{kmh}^{-1}$  and car Q is travelling at  $100\text{kmh}^{-1}$ . The kinetic energy of Q is:
- Twice that of P
  - One half that of P
  - Four times that of P
  - One quarter that of P
10. When brakes are used to stop a car, kinetic energy is changed mainly to:
- Heat energy
  - Sound energy
  - Potential energy
  - Electrical energy.
11. Calculate the kinetic energy of a 3g bullet moving at  $400\text{ms}^{-1}$ .
12. A steel ball bearing of mass 0.1kg falls from a height of 2m onto the ground.
- What is the loss of gravitational potential energy when the ball reaches the ground?
  - What will be its kinetic energy when it reached the ground?

- Use the formula  $E_k = \frac{1}{2} mv^2$  to find the speed of the ball bearing when it reaches the ground.
13. A bicycle and rider of total mass 100kg are travelling at  $10\text{ms}^{-1}$ . The rider then speed up to  $20\text{ms}^{-1}$ .
- What is the kinetic energy of the bike and the rider when they were travelling at  $10\text{ms}^{-1}$ ?
  - What is the kinetic energy of the bike and rider when they are travelling at  $20\text{ms}^{-1}$ ?
  - What is the increase in kinetic energy? How does this compare to the increase in speed of the rider?
  - What work did the rider do to increase their speed from  $10\text{ms}^{-1}$  to  $20\text{ms}^{-1}$ ?

#### SELF CHECK # 4

- A force of 10N moves a body 6m in 3 seconds.
  - What work was done by the force?
  - What is the power output from this force?
- A mass of 10kg is lifted 1m off the ground.
  - How much P.E. has the mass now got?
  - How much work was done to lift the mass this 1metre?
  - If the mass was now dropped and allowed to fall under gravity what would be its K.E just before it hit the ground?
- A hawk of mass 2kg is flying at 3m per sec. What is its kinetic energy?
  - 1.5J
  - 6J
  - 9J
  - 18J
- A forklift lifts a 20kg crate 5m in 4seconds.
  - Calculate the work done on the crate
  - Calculate the power output of the forklift.
- A drag car with a mass of 200kg has a motor with a maximum power rating of 200kW. From a standing start, it accelerates to  $50\text{ms}^{-1}$  ( $178\text{ km/hr}$ ) in a distance of 400m in 5 seconds.
  - Calculate the acceleration of the car
  - Calculate the fore on the car
  - Calculate the work done by the engine
  - Calculate the power output of the engine.
- An ant with a mass of 1g lifts a 5 g leaf up an anthill 3m high. The ant has a power output of 3mW. How long did the ant take to climb the anthill?
- The power output of a 40kg student is 800 W. She runs up some stairs in 10sec.
  - Calculate the weight force of the girl
  - Calculate the height of the stairs.

8. A weightlifter lifts a weight of 40kg to a height of 2.5m in 2 seconds.
- Calculate the work done by the weightlifter.
  - Calculate the power exerted by the weight lifter
  - How much gravitational potential energy is gained by the weight at the top of the lift?
  - The weight was dropped at the top of the lift. What is the kinetic energy of the weight just before it hit the ground?
9. Work is the product of :
- Force and distance
  - Force and acceleration
  - Mass and acceleration
  - Force and mass
10. A boy and his younger sister are playing on a see – saw. The boy weighs 800Newton.
- As the see-saw goes up and down, the boy moves through a vertical of one metre. Calculate how much potential energy he loses as e moves the top position to the bottom position.
  - How much energy is transferred to the girl as she moves from the bottom position to the top position?
  - Each time the boy reaches the ground he gives a slight push with his feet. Explain why he has to do this to keep the see-saw going.
11. A loaded container of 200kg mass is lifted 25metres up from the hold of a ship. If the gravitational field strength is taken as 10N/kg, the work done during the lift will be:
- |          |          |
|----------|----------|
| a. 5kg   | c. 50kg  |
| b. 250kg | d. 500kg |
12. A wheelbarrow and its contents have a weight force of 500N. it is lifted 20cm and wheeled 4m across the garden with a force of 50N.
- Calculate the work done on the wheelbarrow. The wheelbarrow stopped. Where has the energy gone that was transferred to the barrow by the work done