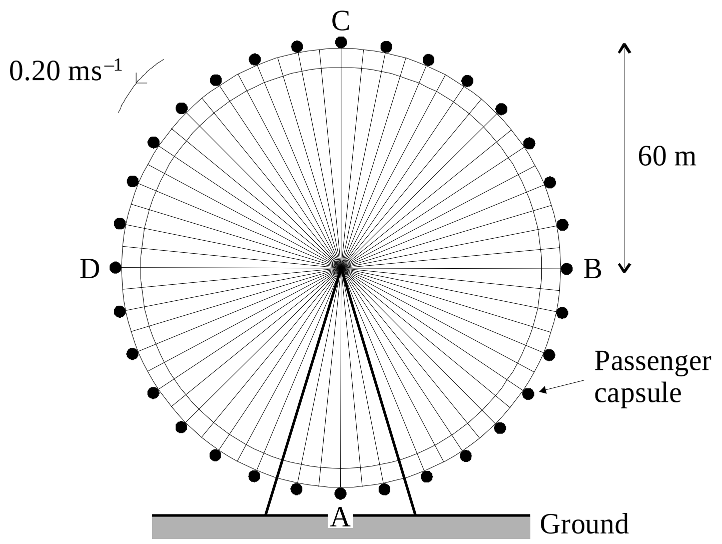
1. The ‘London Eye’ is a large wheel which rotates at a slow steady speed in a vertical plane about a fixed horizontal axis. A total of 800 passengers can ride in 32 capsules equally spaced around the rim.

A simplified diagram is shown below.



On the wheel, the passengers travel at a speed of about 0.20 m s^{-1} round a circle of radius 60 m. Calculate how long the wheel takes to make one complete revolution.

Circumference = 2п × radius = 2п × 60 = 376m

time = distance / speed = 376 / 0.2 = 1885s = 00:31:24.96

Time = 31 minutes

(2)

What is the change in the passenger’s velocity when he travels from point B to point D?

Passenger’s velocity changes direction by 180°

....

....

....

(2)

When one particular passenger ascends from point A to point C his gravitational potential energy increases by 80 kJ. Calculate his mass.

ΔGPE = mgΔh = m × 9.81 × 120

80000 = 1177m

m = 68.0kg

Mass = 68kg

(3)

On the axes below sketch a graph showing how the passenger's gravitational potential energy would vary with time as he ascended from A to C. Add a scale to each axis.

(3)

Graph has an ogive ("stretched-s") shape

Discuss whether it is necessary for the motor driving the wheel to supply this gravitational potential energy.

NO if passenger on other side of wheel is losing GPE.

YES if wheel is unloaded or unevenly loaded.

....

....

(2)
(Total 12 marks)

2. The acceleration of free fall *g* can be measured by timing an object falling from rest through a known distance. Explain one advantage and one disadvantage of making this distance as large as possible.

Advantages: ....

Time/distance can be measured more accurately.

....

Disadvantages: ....

Object reaches terminal velocity and is no longer in freefall.

....

(2)

In a typical laboratory measurement of g, a steel sphere is dropped through a distance of the order of one metre. With the help of a labelled diagram, describe and explain an experimental method of measuring the time it takes the sphere to fall.

(1) Timer start mechanism

(1) Timer stop mechanism

(1) Releasing ball starts timer

(1) Ball falls known distance and stops timer

....

....

(4)

At any given place, the weight of a body is proportional to its mass. Explain how measurements of g support this statement.

Weight = mass × gravity

Gravitational field strength is the same for all objects

....

(2)
(Total 8 marks)

3. A man is pushing a shopping trolley at a speed of 1.10 m s^{-1} along a horizontal surface. There is a constant frictional force opposing the motion. The man stops suddenly, letting go of the trolley, which rolls on for a distance of 1.96 m before coming to rest. Show that the deceleration of the trolley is approximately 0.3 m s^{-2}.

v = 0ms^{-1}; u = 1.10ms^{-1}; x = 1.96m

$v^2 = u^2 + 2ax$

$0 = 1.21 + 3.92a$

a = 0.307ms^{-2}

(3)

The total mass of the trolley and its contents is 28.0 kg. Calculate the frictional force opposing its motion.

F = ma

F = 28 × 0.307

F = 8.64N

Frictional force = 8.64N

(2)

Calculate the power needed to push the trolley at a steady speed of 1.10 m s^{-1}.

Power = force applied to object × velocity of object

P = 8.64 × 1.10

P = 9.51W

Power = 9.51W

(2)

The man catches up with the trolley. Calculate the steady force he must now apply to it to accelerate it from rest to 1.10 m s^{-1} in 0.900 s.

a = (v−u) / t = 1.10 / 0.900 = 1.22ms^{-2}

F = ma = 28 × 1.22 = 34.2N

In order for trolley to accelerate frictional forces must be overcome

Answer = 34.2 + frictional force = 34.2 + 8.64

Answer = 42.9N

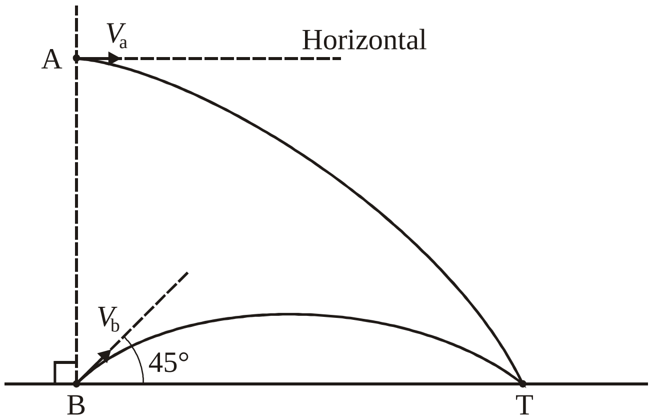
……………………………………………………………………………………………………

Force = 42.9N

(3)

(Total 10 marks)

4. A student is investigating projectiles. He fires two small identical balls, A and B, simultaneously. Their trajectories are shown in the sketch below. The balls land at the same instant at the target, T.



(a) The initial velocity of ball A is V_a and that of ball B is V_b. Explain why the magnitude of V_b must be greater than that of V_a.

Horizontal distance travelled by both balls is the same. Therefore horizontal component of v_a and v_b is the same.

Ball B also travels horizontally so $v_b > v_a$

(b) The paths AT and BT have different lengths. However, balls A and B take the same time to reach the target T. Explain how this is possible. You may be awarded a mark for the clarity of your answer.

(1) QoWC mark

(1) v_a is horizontal component of v_b and balls travel same horizontal distance.

(1) Vertical component of v_b does not affect horizontal motion

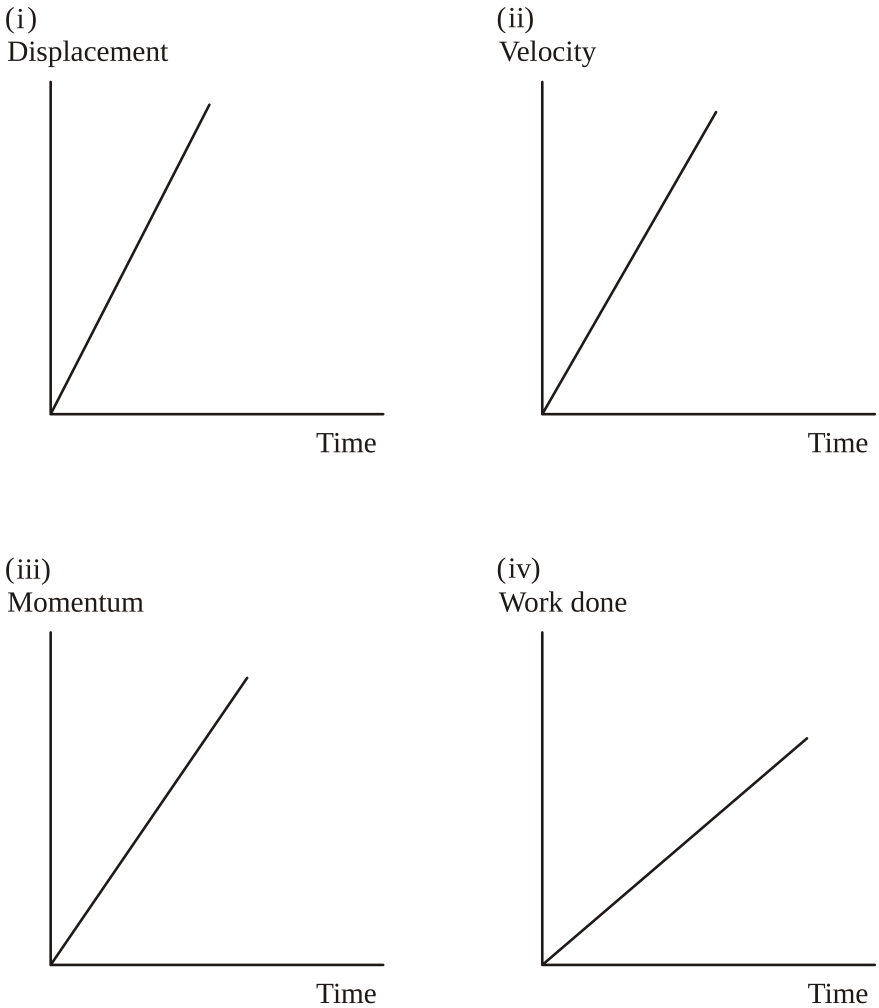
....

....

....

(Total 5 marks)

5. What physical quantity does the gradient of each of the following graphs represent? Give your answers in the table below the graphs.

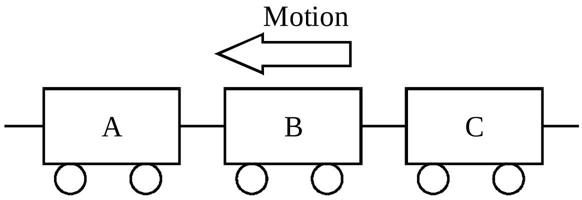


Graph	Physical quantity represented by the gradient
(i)	(constant) velocity
(ii)	(constant) acceleration
(iii)	force
(iv)	power

Do not allow "speed" for (i)

(Total 4 marks)

6. The diagram shows three trucks which are part of a train. The mass of each truck is 84 000 kg.



The train accelerates uniformly in the direction shown from rest to 16 m s^{-1} in a time of 4.0 minutes. Calculate the resultant force on each truck.

a = (v–u) / t = 16 / (4 × 60) = 0.0667ms^{-2}

F = ma = 84000 × 0.0667 = 5600N

....

Resultant force = 5600N

(3)

The force exerted by truck B on truck C is 11 200 N. Draw a free-body force diagram for truck B, showing the magnitudes of all the forces. Neglect any frictional forces on the trucks.

Truck shown as blob or block

(1) Force upwards 84000g = 823759N

(1) Force downwards 84000g = 823759N

(1) Force left 11200 + 5600 = 16800N

(1) Force right 11200N

(4)

The total mass of the train is 3.0 × 10^{6} kg. Calculate the average power delivered to the train during the accelerating process.

KE = ½*mv*^{2} = ½ × 3.0×10^6 × 16^2 = 384×10^{6}J = 384MJ

Power = Energy transferred / time = 384×10^6 / (4 × 60)

P = 1.60×10^6 = 1.6MW

Average power = 1.6MW

(3)

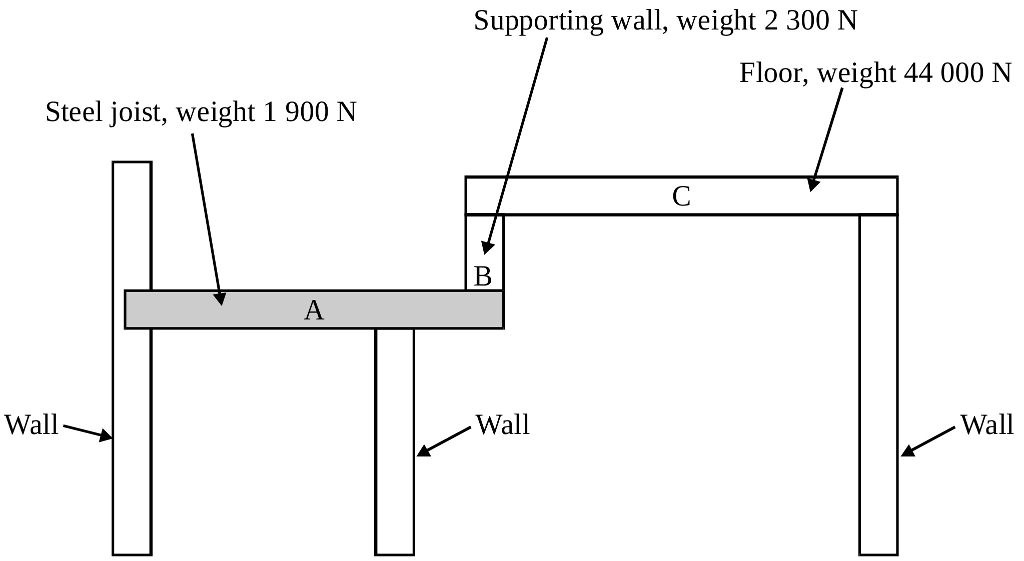
The locomotive is powered by an overhead cable at 25 kV. Neglecting any power dissipation, calculate the average current drawn from the supply during the accelerating period.

current = power / voltage = 1.6×10^6 / 25×10^3 = 64A

Average current = 64A

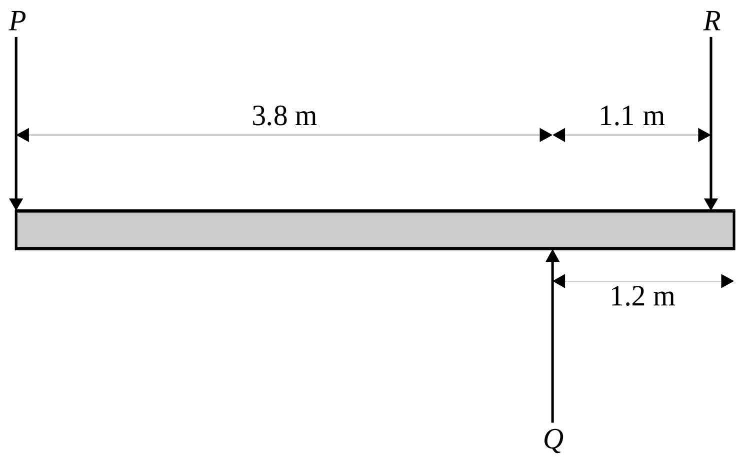
(2)
(Total 12 marks)

7. The diagram shows part of a steel and concrete building.



The steel joist A supports the supporting wall B and the left-hand side of floor C. Both the joist and floor C may be treated as uniform bars.

Below is an incomplete free-body force diagram for joist A.



Show that force R equals 24 300 *N*.

R is equal to weight of wall B plus half the weight of wall C

R = 2300 + (½ × 44000) = 24300N

(1)

Add the remaining force acting on joist A to the diagram, indicating its magnitude and the position where it acts.

(1) 1900N (1) downward arrow added to joist A at (1) centre of mass

(2)

Calculate the forces *P* and *Q*.

Body is in equilibrium; taking moments about *Q*

$(24300 \times 1.1) = (P \times 3.8) + (1900 \times 1.3)$

$P =$ <u>6384N</u>

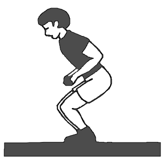
$P + R + W = Q$

$6384 + 24300 + 1900 = Q$

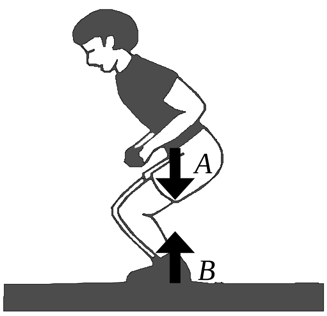
$Q =$ <u>32584N</u>

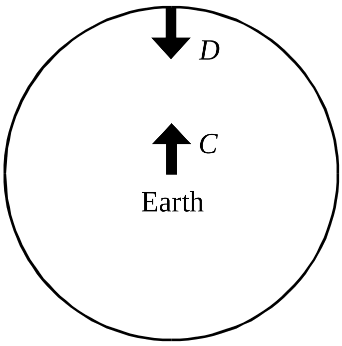
(3)
(Total 6 marks)

8. A child is crouching at rest on the ground



Below are free-body force diagrams for the child and the Earth.





Complete the following table describing the forces *A*, *B* and *C*.

Force	Description of force	Body which exerts force	Body the force acts on
A	Gravitational	Earth	Child
B	Normal reaction	Earth	Child
C	Gravitational	Child	Earth

(4)

All the forces *A*, *B*, *C* and *D* are of equal magnitude.

Why are forces *A* and *B* equal in magnitude?

Child is at rest (in equilibrium) therefore forces are balanced

....

Why must forces *B* and *D* be equal in magnitude?

Newton's 3rd law; *D* is third law pair of *B*

....

(2)

The child now jumps vertically upwards. With reference to the forces shown, explain what he must do to jump, and why he then moves upwards.

(1) Push down, increasing *D*

(1) *B* therefore increases

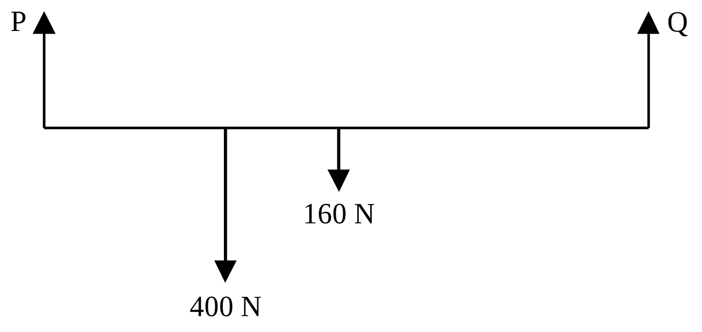
(1) *B* > *A* and therefore child moves in direction of *B*

....

....

(3)
(Total 9 marks)

9. A uniform beam of length 4.0 m and weight 160 N is suspended horizontally by two identical vertical wires attached to its ends. A load of 400 N is placed on the beam 1.2 m from one end. The diagram is a free-body force diagram for the beam.



Calculate the tension in each suspended wire.

Body is in equilibrium; taking moments about *P*

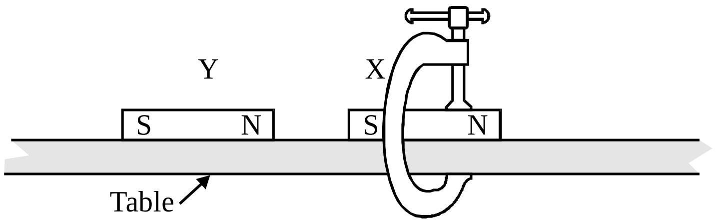
$(400 \times 1.2) + (160 \times 2) = Q \times 4$

$Q = \underline{200\text{N}}$

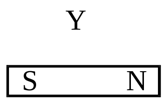
$P = 400 + 160 - Q = \underline{360\text{N}}$

(Total 4 marks)

10. A magnet X is clamped to a frictionless table. A second magnet Y is brought close to X and then released.



Add labelled forces to the free-body diagram below for magnet Y to show the forces acting on it just after it is released.



(1) Normal upwards

(1) Weight downwards

(1) Magnetic force to right

(3)

According to Newton's third law, each of the forces in your diagram is paired with another force. Write down one of these other forces, stating its direction and the body it acts upon.

The weight of the magnet is paired with the gravitational attraction (upwards) of the Earth by the magnet.

....

(2)
(Total 5 marks)

11. The **work done by a force,** and the **moment of a force about a point,** are both defined as the product of the force and a distance. Explain the essential difference between the two definitions.

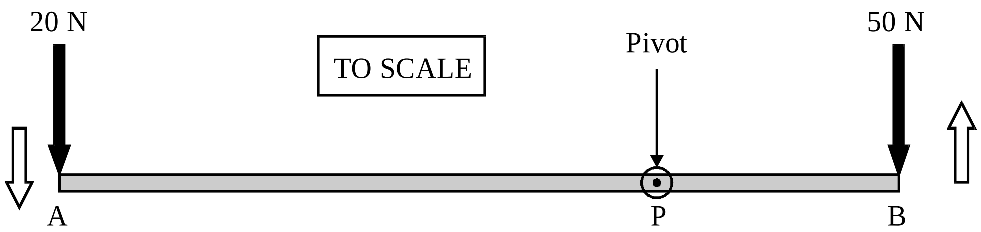
Work done depends on force acting parallel to distance travelled

Moment depends of force acting perpendicular to distance.

....

(2)

The diagram below shows, full size, a rigid lever AB pivoted **at P**. **The weight of the lever can be neglected**. **A 20 N force applied at A is balancing a 50 N** load applied at B.



By means of suitable measurements on the diagram, show that the principle of moments is obeyed.

In equilibrium moments clockwise = moments anticlockwise

AP = 80mm; PB = 32mm

$20 \times 80 = 50 \times 32$

1600Nm = 1600Nm

(2)

End A of the lever moves vertically down 6.0×10^{-3} m. Using the principle of conservation of energy, or otherwise, calculate the distance the load at B is raised.

By similar triangles:

$6\times10^{-6} \times (32 / 80) = d_b$

$d_b = 2.4\times10^{-6}$m

Distance = 2.4×10^{-6}m

(3)
(Total 7 marks)

12. Determine the resultant force on the object below.

Defining positive forces as acting from left to right:

Resultant = 6 + (−2) = 4N in direction of 6N force

(1)

What can be deduced about the motion of an object

(i) when the resultant force on it is zero,

Object is stationary or moving at constant speed in straight line

(ii) when the resultant force on it is vertically upwards,

Object accelerates upwards

....

(iii) when the resultant force on it is in the opposite direction to its motion?

Object decelerates

....

(3)

Newton's third law of motion is sometimes stated in the form: "To every action there is an equal and opposite reaction". A student argues that, in that case, the resultant force on an object must always be zero and so it can never be moved. Explain what is wrong with the student's argument.

(1) Forces act on different bodies

(1) Therefore forces cannot cancel out

....

....

(2)

(Total 6 marks)

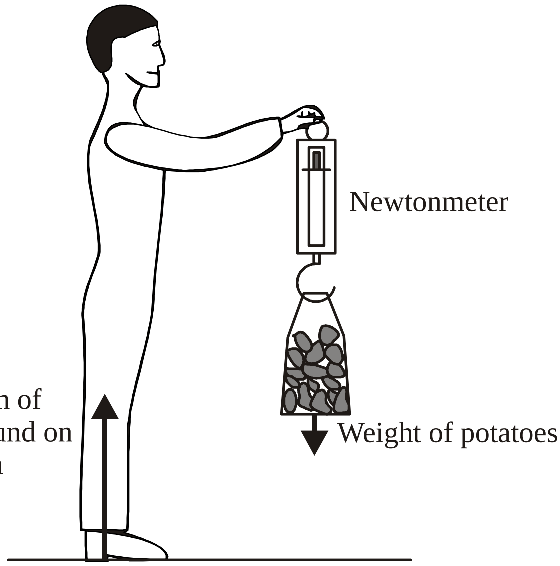
13. (a) Complete the following statement of Newton's third law of motion.

"If body A exerts a force on body B, then body B exerts an force of equal magnitude on body A in the opposite direction.

...."

(2)

(b) A man checks the weight of a bag of potatoes with a newtonmeter. Two of the forces acting are shown in the diagram.



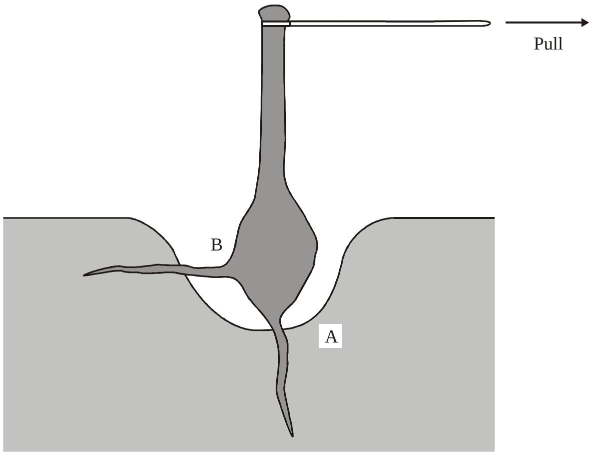
The table below gives these forces. For each force there is a corresponding force, the 'Newton's third law pair force'. In each case state

- the body that the Newton's third law pair force acts upon
- the type of force (one has been done for you)
- the direction of the Newton's third law pair force.

Force	Body the Newton's third law pair force acts upon	Type of force	Direction of the Newton's third law pair force
Weight of potatoes	Earth	Gravitational	Upwards
Push of ground on man	Ground	Normal contact force	Downwards

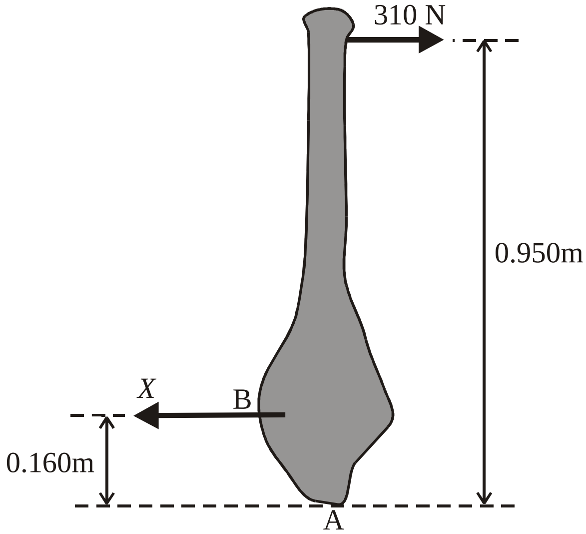
(3)
(Total 5 marks)

14. A gardener is trying to remove a tree stump. He has dug away the soil around it, but it is still anchored by a vertical root at A and a horizontal root at B.



The gardener pulls horizontally on the top of the stump with a force of 310 N, but it does not move.

Below is a diagram showing some of the horizontal forces on the stump. Force X is the tension in the root at B.



One horizontal force is missing from the diagram. Add an arrow to represent this force and label it Y.

Arrow to the right at A labelled Y

(1)

Using the principle of moments, determine force X. (You should ignore the vertical forces on the tree stump.)

Taking moments about A; $310 \times 0.950 = X \times 0.160$

$X = 1841\text{N}$

X = 1841N

(2)

Explain why, in this moments calculation, it is reasonable to ignore the vertical forces on the stump.

Moment is force × perpendicular distance to pivot

For vertical forces perpendicular distance = 0; therefore moment = 0

(1)

Calculate force *Y*.

$X = Y + 310$; $Y = 1841 - 310 = 1531$N

……………………………………………………………………………………………………

Y = 1531N

(2)

If a tree stump is to be removed, it is a mistake to cut it off very close to the ground first. Using the concept of moments, explain why.

Easier to lever the stump out of ground than to pull it out vertically.

If tree stump is cut close to the ground then effect of lever is small.

(2)
(Total 8 marks)

15. A car travelling at 30 m s^{-1} collides with a wall. The driver, wearing a seatbelt, is brought to rest in 0.070 s.

The driver has a mass of 50kg. Calculate the momentum of the driver before the crash.

$p = mv = 50 \times 30 = 1500 kgms^{-1}$

Momentum = $1500 kgms^{-1}$

(2)

Calculate the average resultant force exerted on the driver during impact.

Driver comes to halt so momentum after = 0; $\Delta p = 1500 kgms^{-1}$

Δp = force × time = Ft

$F = 1500 / 0.070 = 21429$N = 21.4kN

Average resultant force = 21.4kN

(3)

Explain why the resultant force is not the same as the force exerted on the driver by the seatbelt.

There will be friction between the driver and the seat.

allow effect of air bags; impact with steering wheel etc.

(1)
(Total 6 marks)

16. State the principle of conservation of linear momentum.

If no resultant force acts then the sum of momenta remains constant.

....

....

(2)

This principle is a consequence of two of Newton's laws of motion. Which two?

N2L and N3L

(1)

In one experiment to test the principle of conservation of momentum, a moving trolley collides with and sticks to an identical trolley which is initially at rest on a horizontal bench. Describe how you would check whether momentum was conserved.

(2) Use two sets of light gates and datalogging interface/software

(1) Measure velocity of trolley before and after collision

(1) Trolleys have the same mass so velocity of combined trolleys after collision should be one half of single trolley's velocity before collision.

....

(4)

A student performing this experiment found that the final momentum was always slightly smaller than the initial momentum. Assuming that the measuring technique was accurate, suggest a reason for this.

Collision is not perfectly elastic; some kinetic energy is lost doing work against friction.

....

(1)

In a test laboratory, a car is crashed into a concrete wall and comes to rest. There is no damage to the wall. Explain how the principle of conservation of momentum applies to this situation.

The wall and the Earth recoil with the same momentum as the car.

....

....

(2)
(Total 10 marks)

17. A door which cannot be opened by pushing steadily on it can often be kicked open. By considering what happens to the foot as it hits the door, explain why the kick is more effective. You should refer to Newton's second and third laws of motion in your answer. You may be awarded a mark for the clarity of your answer.

(1) In both situations momentum is imparted to the door.

(1) Pushing steadily imparts momentum over long time. Sudden kick imparts same momentum over short time, therefore a larger force is applied.

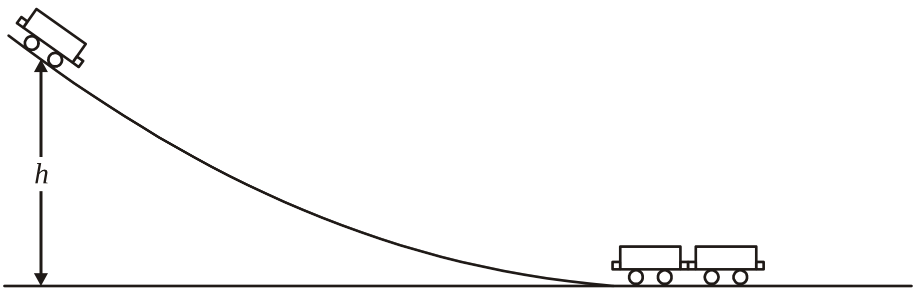
(1) The door pushes against the foot, decelerating it (N2L).

(1) The foot pushes against the door, opening it (N3L).

....

(Total 4 marks)

18. (a) A toy truck of mass 80 g is released from a height *h* and rolls down a slope as shown below.



What would the height *h* have to be for the truck to reach a speed of 4.0 m s^{-1} at the bottom of the slope? You may assume that any friction at its axles is negligible.

Kinetic energy of toy = $\frac{1}{2}mv^2$

$= \frac{1}{2} \times 0.080 \times (4.0)^2$

$= 0.64$J

Loss in KE = Gain in GPE = mgh

$0.64 = 0.080 \times 9.81 \times h$

$h = 0.81$m

Height = 0.81m

(3)

(b) On reaching the bottom, it joins magnetically to two stationary trucks, identical to the first, and the trucks all move off together.

(i) State the law of conservation of linear momentum.

Providing that no external force acts the sum of momenta is a constant.

....

....

....

(2)

(ii) Use this law to calculate the speed of the trucks immediately after the collision.

$m_{1t} = 0.080\text{kg}; \; m_{3t} = 0.240\text{kg}$

$v_{1t}m_{1t} = v_{3t}m_{3t} = 0.080 \times 4$

$0.240v_{3t} = 0.320\text{kgms}^{-1}$

$v_{3t} = 1.33\text{ms}^{-1}$

Speed = 1.33ms−1

(2)

(c) One of the stationary trucks has a total frictional force of 0.12 N at its axles. How much time does it take for the three trucks to stop moving if this is the only frictional force acting?

$F = ma; \; -0.12 = 0.240 \times a$

$a = -0.5\text{ms}^{-2}$

$v = u + at; \; 0 = 1.33\text{ms}^{-1} + (-0.5\text{t})$

$1.33 = 0.5\text{t}$

$t = 2.67\text{s}$

Time = 2.67s

(3)

(Total 10 marks)

19. A student has a sample of a radioactive element which is thought to be a pure beta emitter. The student has **only** the following apparatus available:

- a thin window Geiger-Muller tube connected to a counter
- a piece of aluminium 3 mm thick, and
- a half-metre rule

How would the student determine the background radiation level in the laboratory?

(1) Move any (possible) sources away from detector.

(1) Take repeated readings of count rate over 1 minute periods.

....

....

(2)

The student investigates how the count rate varies with distance from the source to the G-M tube and also the effect of inserting the aluminium absorber. From these experiments explain how the student could confirm that the sample was a pure beta emitter. You may be awarded a mark for the clarity of your answer.

(1) QoWC

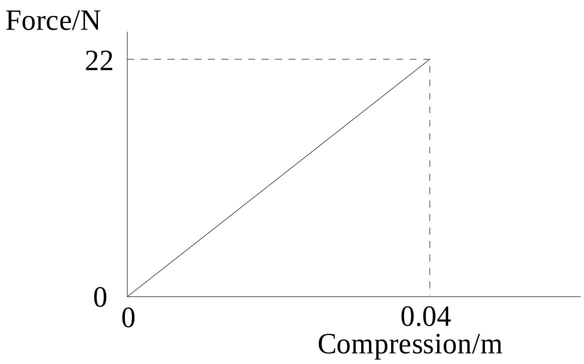
(2) Count rate unaffected by 5cm of air: alpha not present

(2) Count rate drops to background with aluminium plate in place: indicates that beta is present and gamma is not present.

No marks at all for not RTFQ and waffling on about paper stopping alpha sources – the question asks about a specific set of equipment.

(5)
(Total 7 marks)

20. A toy frog has a spring which causes it to jump into the air. The force-compression graph for the spring is shown below.



Calculate the work done on the spring when it is compressed by 4.0 cm.

Work done = force × distance = area under graph

Work done = ½ × 22 × 0.04 = 0.44J

....

Work done = 0.440J

(3)

The frog has a mass of 24 g and rises 0.60 m vertically into the air. Calculate the gravitational potential energy gained by the frog.

$\Delta GPE = mg\Delta h = 0.024 \times 9.81 \times 0.60 = 0.141J$

....

Energy = 0.141J

(2)

Compare your two answers for energy and explain how they are consistent with the law of conservation of energy.

(1) Some energy not transferred.

(1) Due to change in the internal energy of the spring

allow answer with reference to friction, air resistance etc.

....

(2)
(Total 7 marks)

21. (a) State Newton's second law of motion in terms of momentum.

The force acting on a body is equal to the rate of change of momentum.

....

....

(2)

(b) A wind blows steadily against a tree. The area of the tree perpendicular to the direction of the wind is 10 m^2 and the velocity of the wind is 20 m s^{-1}.

(i) Show that the mass of air hitting the tree each second is about 250 kg. (Density of air is 1.23 kg m^{-3}.)

Volume of air per second = area of tree × velocity of air

Volume of air per second = $200 m^3 s^{-1}$

Mass = volume × density = 200 × 1.23 = 246kg

246kg ≈ 250kg

(2)

(ii) Calculate the momentum of this mass of air when it is moving at 20 m s^{-1}.

momentum = mass × velocity = 246 × 20 = $4920 kgms^{-1}$

Momentum = 4920kgms−1

(iii) Assuming that all the air is stopped by the tree, state the magnitude of the force exerted on the tree by the wind.

all momentum transferred to tree in 1s; Δp = $4920 kgms^{-1}$

$\Delta p = Ft$; t = 1s ; F = 4920N

Force = 4920N

(2)

(Total 6 marks)

22. An athlete of mass 55.0 kg runs up a flight of stairs of vertical height 3.60 m in 1.80 s.

Calculate the gain in gravitational potential energy of the athlete in doing this.

Power = force × velocity = (55 × 9.81) × (3.6 / 1.80) = 1079.1W

Energy = power × time = 1079.1 × 1.80 = 1942J

....

Gain in g.p.e. = 1942J

Calculate the power that this athlete develops in doing this.

From previous = 1079W

....

Power = 1079W

(4)

One way of comparing athletes of different sizes is to compare their power-to-weight ratios. Find a unit for the power-to-weight ratio in terms of SI base units.

Ratio is division of one quantity by another

Power / weight = watts / newtons = kgm^2s^{-3}/ $kgms^{-2}$

= ms^{-1}

....

(2)

Calculate the athlete's power-to-weight ratio.

Power / weight = 1079 / (55 × 9.81) = 2.00ms^{-1}

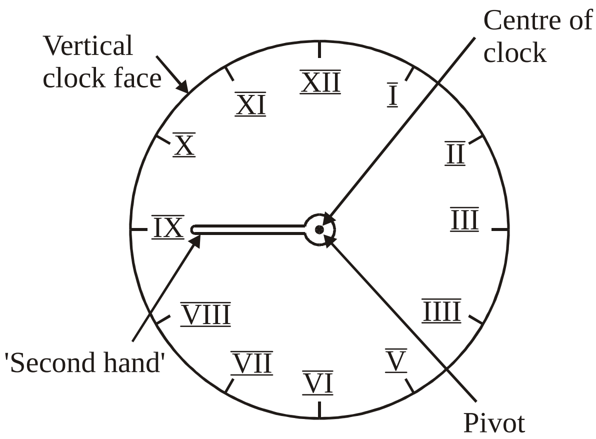
....

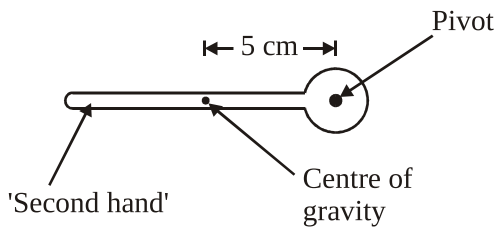
Power-to-weight ratio = 2.00ms−1

(2)

(Total 8 marks)

23. The diagram shows the 'second hand' of a clock whose face is vertical. This hand rotates once every 60 s.





This 'second hand' has a mass of 1.0×10^{-4} kg. Its centre of gravity is 5.0 cm from the pivot as shown on the diagram.

(a) Calculate the moment of the 'second hand' about the pivot when at the position shown above.

Moment = force × perpendicular distance from pivot to force

Moment = $(1.0\times10^{-4} \times 9.81) \times 5.0\times10^{-2} = 4.90\times10^{-5}$Nm

....

Moment = 4.90×10−5Nm

(2)

(b) The clock mechanism lifts the 'second hand' during the next second.

Show that the work done against the gravitational force by the mechanism during this second is approximately 5×10^{-6} J.

Angle raised through = 360/60 = 6°

Distance raised through = $\sin(6) \times 5\times10^{-2} = 5.23\times10^{-3}$m

$\Delta GPE = mg\Delta h = 1.0\times10^{-4} \times 9.81 \times 5.23\times10^{-3} = 5.12\times10^{-6}$J

$5.12\times10^{-6}\text{J} \approx 5\times10^{-6}$J

....

(3)

(c) The work done against gravitational force when the 'second hand' moves in the second immediately before the XII position is much smaller than 5×10^{-6} J. Explain why.

Distance moved is not in direction of gravitational force

....

(1)

(d) Calculate the average power needed to move the ‘second hand’ from the VI position (Figure 1) to the XII position (Figure 2). Neglect any work done against forces other than the gravitational force.

Figure 1

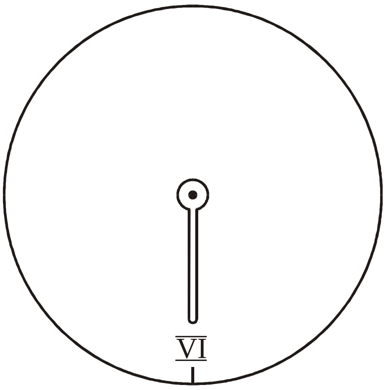
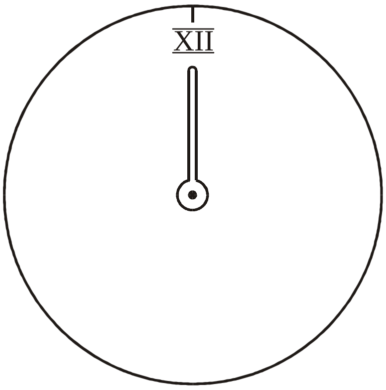


Figure 2



Total difference in height of centre of gravity = 10cm

$\Delta GPE = mg\Delta h = 1.0\times10^{-4} \times 9.81 \times 10\times10^{-2} = 9.81\times10^{-5}$J

Power = energy / time = $9.81\times10^{-5} / 30 = 3.27\times10^{-6}$W

....

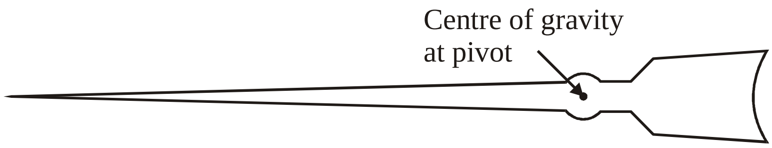
....

....

Average power = 3.27×10−6W

(2)

(e) The diagram below shows a different design for the ‘second hand’.



Explain why this design would require less power.

(1) Centre of gravity is closer to pivot

(1) Height change is smaller, therefore power required is less

....

(2)
(Total 10 marks)

24. A weightlifter raised a bar of mass of 110 kg through a height of 2.22 m. The bar was then dropped and fell freely to the floor.

(i) Show that the work done in raising the bar was about 2400 J.

Work done = force × distance moved in direction of force

Work done = (110 × 9.81) × 2.22 = <u>2395J</u>

....

(2)

(ii) It took 3.0 s to raise the bar. Calculate the average power used.

Power = energy transferred / time = 2395 / 3 = 798W

....

....

Power = 798W

(2)

(iii) State the principle of conservation of energy.

Energy cannot be created or destroyed, only transferred from one form to another.

....

(2)

(iv) Describe how the principle of conservation of energy applies to

(1) lifting the bar,

(2) the bar **falling** to the floor. Do not include the impact with the floor.

(1) Chemical potential energy in the weightlifter's body is transferred to kinetic energy of his arms and an increase in the gravitational potential energy of the bar.

(2) The gravitational potential energy of the bar is transferred (by the force of gravity) into kinetic energy

....

....

(3)

(v) Calculate the speed of the bar at the instant it reaches the floor.

Loss in gravitational potential energy = gain in kinetic energy

$\Delta GPE = mg\Delta h = 110 \times 9.81 \times 2.22 = 2395J$ *(see 24(i))*

$\Delta GPE = \Delta KE$; $2395 = \frac{1}{2}mv^2 = \frac{1}{2} \times 110 \times v^2$

$v = \sqrt{43.5} = 6.59ms^{-1}$

Speed = 6.59ms−1

(3)

(Total 12 marks)

25. In 1909 Geiger and Marsden carried out an important experiment to investigate alpha particle scattering. Alpha particles were directed towards a thin gold sheet and detectors were used to observe the distribution of scattered alpha particles.

State what was observed in this experiment.

(1) Most alpha particles went through undisturbed

(1) Some were deflected through small angles

(1) Very few were deflected by ≥90°

....

(3)

Explain why these observations led to the conclusion that an atom was composed mainly of space, with a very small positive nucleus.

(1) Most particles undisturbed suggests atom is mainly "empty space"

(1) Deflection indicates nucleus is positively charged

(1) Low number of particles deflected ≥90° suggests nucleus is very small

....

(3)

State an approximate value for

(i) the diameter of a gold atom

10^{-10}m

(ii) the diameter of a gold nucleus

10^{-15}m

(2)

(Total 8 marks)

26. It is thought that an extremely short-lived radioactive isotope $^{269}_{110}X$, which decays by α-emission, has a half-life of 200 μs.

After a series of α decays the element $^{A}_{104}Y$ is formed from the original isotope. There are no β decays.

Deduce the value of A.

Proton number has decreased by 6; therefore 3 α decays

Mass number is therefore = 269 – (3 × 4) = <u>257</u>

(2)

Calculate the decay constant λ of $^{269}_{110}X$.

$\lambda = \ln(2) / t_{½} = \ln(2) / 200\times10^{-6} = 3466 s^{-1}$

....

λ = $3466 s^{-1}$

(1)

The number of nuclei N of $^{269}_{110}X$ in a sample of mass 0.54 μg is 1.2×10^{15}. Determine the activity of 0.54 μg of $^{269}_{110}X$

$A = \lambda N = 3466 \times 1.2\times10^{15} = 4.16\times10^{18}$ Bq

Activity = 4.16×10^{18} Bq

(2)

Why is this value for the activity only approximate?

Radioactivity is a random process.

....

....

(1)
(Total 6 marks)

27. Geiger and Marsden carried out a scattering experiment which led to a revised understanding of the structure of the atom. The tables below refer to this experiment. Complete the tables and sentences.

	Name
Incoming particle	
Target atoms	

Observation	**Conclusion about atomic structure**
The incoming particles were mostly undeflected.	
A few particles were deflected by angles greater than 90°.	

The diameter of an atom is approximately 10^{-15} m.

The diameter of an atom's nucleus is approximately 10^{-11} m.

(Total 6 marks)

28. State the number of protons and the number of neutrons in ${}^{14}_{6}C$.

Number of protons = 6

Number of neutrons = 8

(2)

The mass of one nucleus of ${}^{14}_{6}C = 2.34 \times 10^{-26}$ kg.

The nucleus of carbon-14 has a radius of 2.70×10^{-15} m.

Show that the volume of a carbon-14 nucleus is about 8×10^{-44} m^3.

volume sphere = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times (2.70\times10^{-15})^3 = 8.24 \times 10^{-44} m^3$

....

(2)

Determine the density of this nucleus.

density = mass / volume = $2.34\times10^{-26} / 8.24\times10^{-44}$

= 2.84×10^{17}kg/m^3

....

Density = 2.84×10^{17}kg/m^3

(2)

How does your value compare with the densities of everyday materials?

It is higher by thirteen or fourteen orders of magnitude

(1)

Carbon-14 is a radioisotope with a half-life of 5700 years. What is meant by the term half-life?

(1) Average time taken (1) for half of atoms in a radioactive substance to decay

(2)

Calculate the decay constant of carbon-14 in s^{-1}

5600 years = 180×10^9s

$\lambda = \ln(2) / t_{½} = \ln(2) / 180\times10^9 = 3.85\times10^{-12}s^{-1}$

....

Decay constant 3.85×10^{-12} s^{-1}

(2)
(Total 11 marks)

29. Phosphorus $^{32}_{15}P$ is unstable and decays by β^- emission to sulphur, S. Write a nuclear equation for this decay.

$^{32}P \rightarrow {}^{32}S + \beta^-$

(1)

Describe how, using a Geiger counter and suitable absorbers, you could show that an unstable nuclide of long half-life emitted *only* β^- radiation.

(1) QoWC

(1) Count rate unaffected by 5cm of air (or sheet of paper) – alpha not present

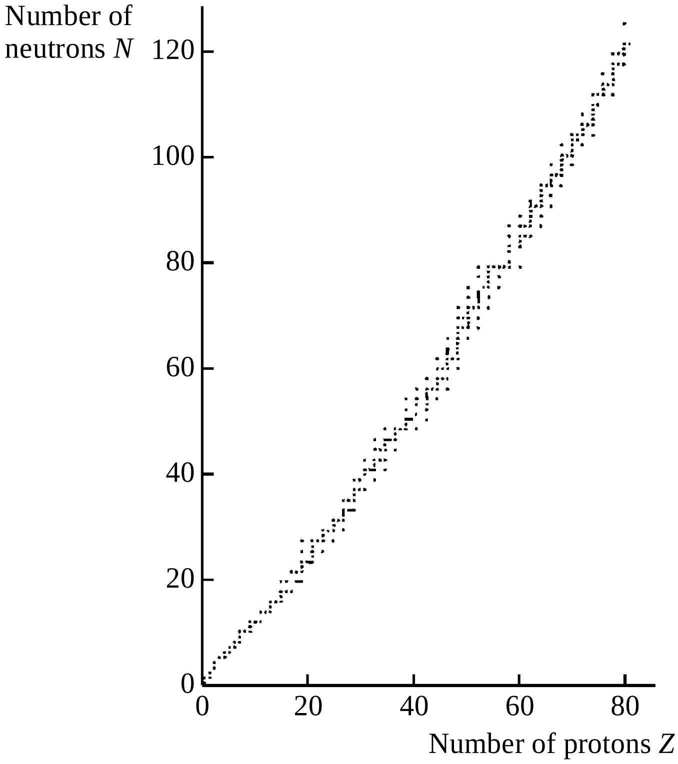
(1) Background rate detected when using both 5mm aluminium absorber and 50mm lead absorber – gamma not present.

(1) Count rate affected by 5mm aluminium – beta present.

....

(4)

The scatter diagram shows the relationship between the number of neutrons and the number of protons for stable nuclides.



Show on the diagram the region where nuclides which decay by β^- emission would be found.

Use the diagram to help you explain your answer.

Indicate region above and to the left of plots

Beta-minus decay converts neutrons to protons

Isotopes in indicated area have not enough protons and too many neutrons

....

(3)
(Total 9 marks)

30. A Physics department has an old radium source which is thought to emit alpha, beta and gamma radiation. A student performs some experimental tests to find out whether this is correct. She uses a metre rule, a I mm thick sheet of aluminium, a 5 mm thick sheet of aluminium and a suitable Geiger-Müller tube with a ratemeter. Her results are as follows:

Test number	Procedure	Observations on ratemeter
1	The source is held very close to the GM tube.	Count rate is high.
2	The source is moved a few centimetres away from the GM tube.	Count rate suddenly drops.
3	With the source 20 cm from the GM tube, 1 mm of aluminium is inserted between them.	Count rate drops significantly.
4	With source still 20 cm from the GM tube, 5 mm of aluminium is inserted between them.	Count rate is still well above background.

Which test(s) lead to the conclusion that each of alpha, beta and gamma radiation is emitted by the source? Justify your answers.

Alpha:

Test 2 indicates alpha is present because count rate drops when alpha particles are blocked by few centimetres of air

Beta:

Test 3 indicates beta is present because beta particles are blocked by sheet of aluminium.

Gamma:

Test 4 indicates gamma is present because count rate is still above background when lead shield (which blocks alpha/beta) is in place.

(Total 4 marks)

31. The **range** of nuclear radiation in matter depends on how strongly the radiation **ionises** matter. Explain the meanings of the terms in bold type.

range the distance a particle will travel before stopping

....

ionises the removal of an electron from an atom

....

(2)

State and explain the qualitative relationship between range and ionising ability.

Stronger ionisation means shorter range because particles give up energy when ionising.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

(2)

Beta radiation from a certain source can be stopped completely by a sheet of aluminium 3.0 mm thick. Calculate the mass of a square sheet of aluminium of this thickness measuring 1.0 m × 1.0 m.

(Density of aluminium = 2.7×10^3 kg m^{-3})

$V = 1 \times 1 \times 0.003 = 0.003\text{m}^3$

$m = \rho V = 2.7\times10^3 \times 0.003 = 8.1\text{kg}$

……………………………………………………………………………………………………

Mass = 8.1kg

(2)

To a fair approximation, the ability of any sheet of material to stop beta radiation depends only on the mass per square metre of a sheet of the material. Estimate the thickness of lead sheet needed to stop the same beta radiation completely.

(Density of lead = 11.3×10^3 kg m^{-3})

Lead is 4.19 times denser than aluminium.

Therefore sheet must be 4.19 times thinner to have same mass.

$3\times10^{-3} / 4.19 = 0.716\times10^{-3}\text{m} = 0.716\text{mm}$

……………………………………………………………………………………………………

Thickness = 0.716mm

(2)

(Total 8 marks)

32. A smoke detector contains a small radioactive source. A typical source contains 1.2×10^{-8} g of americium-241, which has a half-life of 432 years. Show that the decay constant of americium-241 is approximately 5×10^{-11} s^{-1}.

432 years = 13.6×10^9s

$\lambda = \ln(2) / t_{½} = \ln(2) / 13.6\times10^9 = \underline{5.08\times10^{-11}\text{s}^{-1}}$

(2)

Calculate the number of nuclei in 1.2×10^{-8} g of americium-241, given that 241 g contains 6.0×10^{23} nuclei.

$(1.2\times10^{-8} / 241) \times 6.0\times10^{23} = 3.00\times10^{13}$

....

Number of nuclei = 3.00×10^{13}

(1)

Hence calculate the activity of 1.2×10^{-8} g of americium-241.

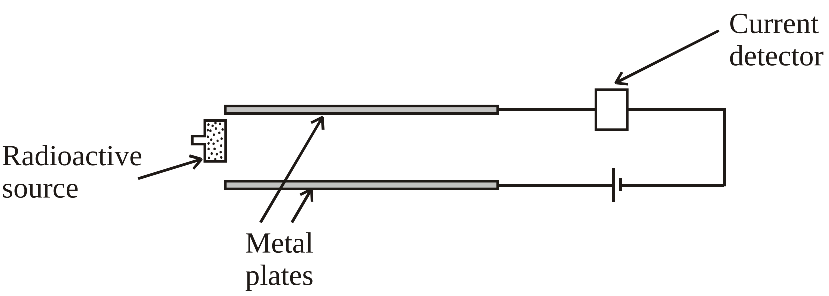
$A = \lambda N = 5.08\times10^{-11} \times 3.00\times10^{13} = 1524\text{Bq}$

....

Activity = 1524Bq

(2)

The diagram below shows the principle of the smoke detector.



Radiation from the source ionises the air between the plates, and a small current is detected. If smoke enters the detector, the ions 'stick' to the smoke particles, reducing the current and triggering an alarm.

Americium-241 is an alpha emitter. Explain why an alpha emitter is a suitable source for this apparatus.

(1) Only travels a few centimetres in air – not hazardous

(1) Highly ionising – will be stopped by smoke particle.

....

(2)

Discuss other features of this americium sample which make it a suitable source for the smoke detector.

Long half life means detector "good" for > 5 years

Source has high count rate – easily detected over background

Low range – not hazardous

....

(3)
(Total 10 marks)