1 Mechanics and radioactivity

Int 1 Mechanics

Introduction

Mechanics describes the effects of forces when they act on bodies that are either at rest (statics) or in motion (dynamics). As you study mechanics, you become aware of the conditions needed for a body to be in equilibrium and how a body moves when acted upon by a resultant force. You use both graphs and equations to describe such motion. You learn about the behaviour of colliding bodies and understand the energy exchanges that are taking place. Most importantly, you find the true meaning of work (at least as it applies to the world of the physicist!).

Things to understand

Density

the density of a material is its mass for a unit volume, usually 1 m³

- the densities of solids are usually larger than those of liquids
- the densities of liquids are much larger than those of gases

Motion in a straight line

- distance (a scalar) measured along a straight line in a particular direction is called displacement (a vector)
- speed (a scalar) is the distance moved per second whereas velocity (a vector) is displacement per second
- velocity is speed in a given direction
- the directions must be taken into account when vectors are added or subtracted (Figure 1.1)
- acceleration (a vector) is the rate of change of velocity or change in velocity per second
- displacement-time, velocity-time and acceleration-time graphs are a useful method for displaying information about the motion of a body (Figure 1.2)
- the gradient at any point on a displacement-time graph is the velocity at that point sometimes called the instantaneous velocity (Figure 1.2)

Helpful hint

1 m³ is quite a large volume (think of a 1 m cube); no wonder the density of platinum is 21 400 kg m⁻³.



Fig 1.1 This ball's velocity changes from -v to +v as it bounces so its velocity changes by [+v - (-v)] = 2v



Fig 1.2 Displacement-time, velocity-time and acceleration-time graphs for a ball thrown vertically upwards (upwards taken as positive)



Fig 1.3 Acceleration—time, velocity—time and displacement—time graphs for a ball dropped from rest (downwards taken as positive)

 the gradient at any point on a velocity-time graph is the acceleration at that point (Figure 1.2)

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- the area enclosed by an acceleration-time graph is the change in velocity (Figure 1.3)
- the area enclosed by a velocity-time graph is the change in displacement (Figure 1.3)
- the following equations describe the motion of an object moving with constant acceleration in a straight line (Table 1.1 defines the symbols used and gives their units)
 - $x = \frac{1}{2} (u + v)t$ v = u + at $x = ut + \frac{1}{2}at^{2}$ $v^{2} = u^{2} + 2ax$

ν	final velocity	m s ⁻¹
и	initial velocity	m s ⁻¹
x	displacement	m
а	acceleration	m s ⁻²
t	time	S

Table 1.1 Symbols used in the equations of motion

Projectile motion

- when air resistance is removed, all objects fall with the same acceleration
- the acceleration of a projected object is vertically down and equal to the acceleration of free fall *g* throughout its flight, whether the object is on its way up, at the top of its path or on its way down
- an object that is projected horizontally falls to the ground with the same acceleration (g) as one falling vertically; horizontal and vertical motions of an object are independent of each other
- the curved path, called a parabola, of a horizontally projected object is the result of a constant horizontal velocity (when air resistance is zero) combined with a uniform vertical acceleration

Forces

- force (a vector) involves the push or the pull of one thing on another
- forces can be gravitational, electrostatic, electromagnetic or nuclear
- both tension (Figure 1.4) and weight (the gravitational pull of the Earth on an object) are forces
- the centre of gravity of a body is the point where all its weight appears to act
- a sketch of a single object that shows all the forces acting on it is called a free-body force diagram
- in situations where the forces do not have the same line of action, a vector diagram can be used to find their resultant; the single force that could replace them all and have the same effect
- in some situations, when analysing the forces acting, it is helpful to split up a single force into two perpendicular components (Figure 1.5)



Fig 1.4 The tension in the rope acts upwards on the load and downwards on the pulley



Fig 1.5 Component $F_1 = 400 \text{ N} \times \cos 35^\circ = 330 \text{ N};$ Component $F_2 = 400 \text{ N} \times \cos 55^\circ = 230 \text{ N}$



Fig 1.8 The ball's momentum changes from -mv to +mv as it hits the wall so its momentum changes by [+mv - (-mv)] = 2 mv

- forces always occur in pairs; when body A exerts a force (an action) on body B, body B automatically exerts a force (a reaction) on body A
 - action and reaction forces are equal in magnitude are opposite in direction act on different bodies are of the same type (e.g. both gravitational) act for the same length of time have the same line of action
- action and reaction forces cannot cancel each other as they act on different bodies

Forces and moments

a force can have a rotational effect on a body; the moment of a force is a measure of its rotational effect

moment of *F* about $O = F \times$ perpendicular distance from *F* to O

- moments can be clockwise or anticlockwise (Figure 1.6)
- a couple (Figure 1.7) consists of two equal and opposite non-aligned forces

moment = one of the forces $F \times$ perpendicular separation d

- for a body in equilibrium
 - the sum of the forces in any direction must be zero the sum of the moments about any point must be zero (i.e. Σ clockwise = Σ anticlockwise)





Fig 1.7 Two equal and opposite forces exerting a couple on a steering wheel

Fig 1.6 The moments of these forces about the point P are both 48 N m

Forces and motion

- the resultant force on either a stationary body or a body moving with constant velocity is zero
- a resultant force is needed to accelerate a body; for the same force, a large mass will accelerate less than a small one
- the acceleration of a body is proportional to the resultant force and occurs in the same direction as this force
- the momentum of a body is the product of its mass and its velocity; it is a vector quantity in the same direction as the velocity (Figure 1.8)

Unit 1



Fig 1.9 The area under a force-time graph is the impulse of that force



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the rate of change of momentum of a body equals the resultant force acting on it and occurs in the same direction as this force

(mv - mu)/t = F = ma

- the impulse of a force is the product of the force and the time for which it acts and, particularly for a changing force, can be found from the area under a force–time graph (Figure 1.9)
- the impulse of a force equals the change in momentum that it produces
- when two bodies collide, they exert equal and opposite impulses on each other (equal and opposite forces for the same length of time) – hence, they undergo equal and opposite changes in their momentum so there is no change in the total momentum and so momentum is conserved

Mechanical energy

- work (a scalar) is done by a force when it causes motion
 - ·work done = average force × distance moved in the direction of the force
 - = applied force × displacement parallel to force
- work done is equal to the area under a force-displacement graph even when the force varies
- energy is transferred when work is done; the system doing work loses energy whereas the system having work done on it gains this energy
- the total amount of energy in an isolated system remains constant
- a moving body possesses kinetic energy due to its motion

kinetic energy = $\frac{1}{2}mv^2$

- kinetic energy is conserved in an elastic collision, whereas some kinetic energy is transferred to other forms in an inelastic collision
- a body raised above the Earth's surface possesses gravitational potential energy due to its position: for a mass raised through a distance Δh

change in gravitational potential energy = $mg\Delta h$

the efficiency of a system indicates the proportion of the energy input that can be usefully used

efficiency = useful output/total input

- power is the rate at which energy is transferred or the rate at which work is being done
- when an applied force is causing motion, the power developed by the force is

power = applied force × velocity

Things to learn

You should learn the following for your Unit PHY1 Test. Remember that it may also test your understanding of the 'general requirements' (see Appendix 1).

5

Equations that will *not* be given to you in the test density = mass/volume $\rho = m/V$ $\rho = \text{density}$ (average) velocity = (total) displacement/time taken $\frac{1}{2}(u+v) = x/t$ u = initial velocityv =final velocity acceleration = change in velocity/time taken a = (v - u)/tresultant force = mass × acceleration F = mamomentum = mass × velocity p = mvp = momentumwork done = applied force × distance moved in the direction of the force $\Delta W = F \Delta x$ Δx = change in displacement power = energy transferred/time taken = work done/time taken P = W/tweight = mass × gravitational field strength weight = mgkinetic energy = $\frac{1}{2} \times \text{mass} \times \text{speed}^2$ k.e. = $\frac{1}{2}mv^2$ change in gravitational potential energy = mass × gravitational field strength × change in height $\Delta p.e. = mg\Delta h$ where Δ = 'change in'

Laws

- Newton's first law: a body will remain at rest or continue to move with a constant velocity as long as the forces on it are balanced
- Newton's second law: the rate of change of momentum of a body is directly proportional to the resultant force acting on it and takes place in the same direction as the resultant force
- Newton's third law: while body A exerts a force on body B, body B exerts an equal and opposite force on body A
- principle of moments: if a body is in equilibrium, the sum of the moments about any point must be zero
- conservation of momentum: provided no external forces act, the total momentum of a system of objects remains constant
- conservation of energy: the energy content of a closed or isolated system remains constant

General definitions

- force: a push or a pull involving at least two bodies; something that can cause a body to accelerate
- resultant force: the single force that could replace all forces acting and have the same effect
- one newton: the resultant force that gives a mass of 1 kg an acceleration of 1 m s⁻²

- moment of a force about a point: the product of the force and its perpendicular distance from that point
- centre of gravity: the point where all the weight of the body appears to act
- impulse: the product of a force and the time for which it acts
- power: the rate of doing work
- elastic collision: a collision in which kinetic energy is conserved
- inelastic collision: a collision in which kinetic energy is not conserved (e.g. some may be dissipated as thermal energy)

Word equation definitions

Use the following word equations when asked to define:

- density = mass/volume
- (average) speed = (total) distance travelled/time taken
- (average) velocity = (total) displacement/time taken
- acceleration = change in velocity/time taken
- momentum = mass × velocity
- work done = force × distance moved in the direction of the force
- efficiency = useful energy output/total energy input

Experiments

Several mechanics experiments involve the measurement of velocity or acceleration. In many cases, suitable measurements can be taken in a number of ways using a variety of apparatus. Whatever method you describe, you must explain what is being measured and how these measurements are then used. You will not get any marks for 'the velocity was obtained by passing the object through an intelligent timer'. The first two experiments describe different methods for measuring velocity and acceleration – only learn one of these methods, the one with which you are most familiar.

1. Measuring velocity

In all methods, a measured distance is divided by a measured time.

Method 1 Using an electronic timer operated by a light gate Attach a card of measured length centrally to the top of the vehicle. Arrange for the card to block a light gate's beam as it passes through it (Figure 1.10).

Electronic timer measures how long card takes to pass through beam. Calculate vehicle's average velocity as it passes the light gate, v = length of card/interruption time.

Method 2 Using tickertape

Attach a length of tickertape to the back of the vehicle which pulls it through a ticker-timer machine.

Measure the length of 10 adjacent gaps between the dots with a metre rule. Time taken = 0.2 s (tickertimer makes 50 dots each second).

Calculate vehicle's average velocity during this time using v =length of 10 gaps/(0.2 s).

Method 3 Using a video camera Video the vehicle moving along in front of a calibrated scale.



Fig 1.10 The timer records the time taken for the card to pass through the light gate's beam

Play the video back a frame at a time.

Measure how far the vehicle advances between frames from the scale. Time between frames is 0.04 s (video camera takes 25 frames each second).

Calculate vehicle's average velocity between frames using v = distance moved between frames/(0.04 s).

2. Measuring acceleration

In all methods, at least two velocities are found and the change in velocity is divided by the measured time for this change to occur.

Method 1 Using an electronic timer operated by two light gates Attach a card of measured length centrally to the top of the vehicle. Arrange for the card to block the beams of two light gates as it passes through them.

Timer measures how long card takes to pass through each light beam (t_1, t_2) . Record time for vehicle to pass between the two gates using a stopwatch (t_3) . Velocity difference = length of card/ t_2 – length of card/ t_1 Acceleration = velocity difference/ t_3

Method 2 Using a timer, a light gate and a double interrupter card Attach two cards of the same measured length symmetrically to the vehicle. Arrange for the cards to block the light gate's beam as they pass through it (Figure 1.11).

Timer measures how long each card takes to pass through the light beam (t_1, t_2) .

Timer also measures time interval between the start of the two interruptions (t_3) .

Velocity difference = length of card/ t_2 – length of card/ t_1 Acceleration = velocity difference/ t_3

Method 3 Using tickertape

Attach a length of tickertape to the back of the vehicle which pulls it through a ticker-timer machine. Measure the length of the first five adjacent gaps with a metre rule. Time taken = 0.1 s (tickertimer makes 50 dots each second). Calculate vehicle's average velocity during this time using v = length of 5 gaps/(0.1 s). Repeat for several consecutive sets of five adjacent gaps. Plot a graph of velocity against time. Acceleration = gradient of graph.

Method 4 Using a video camera

Video the vehicle moving along in front of a calibrated scale. Play the video back a frame at a time. Measure how far the vehicle advances between frames from the scale. Time between frames is 0.04 s (video camera takes 25 frames each second). Calculate vehicle's average velocity between frames using v = distance moved between frames/(0.04 s).

Repeat for several consecutive frames. Plot a graph of velocity against time. Acceleration = gradient of graph.

3. Measuring the acceleration of free fall

The acceleration of free fall can be measured by dropping a double interrupter card through a light gate.



Fig 1.11 The time taken for each card to pass through the light gate's beam is recorded by the timer, together with the time interval between the start of the two interruptions



Fig 1.12 With the switch in position *A*, the electromagnet attracts the ball bearing



Fig 1.13 Acceleration of gravity = 2 × gradient



Fig 1.14 Finding the acceleration a produced by the force F



Fig 1.15 Investigating a collision where two gliders join together

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The following method involves timing an object as it falls from rest (u = 0) over a measured distance and using the equation $x = \frac{1}{2}at^2$ to find its acceleration. A best-fit straight-line graphical method is used to average the results and the acceleration is found from the gradient of the graph. The electromagnet attracts the ball bearing (Figure 1.12).

Measure the height h from the bottom of the ball to the trapdoor switch. When the switch is moved to B, the ball is released and the timer starts. The timer stops when ball hits and opens the trapdoor switch. Record the time of fall.

Find average time of fall t from at least three attempts. Repeat for a range of different heights; tabulate values for h and t. Plot a graph of h against t^2 to get a straight line through origin (Figure 1.13).

Comparing $h = \frac{1}{2}at^2$ with y = mx + c shows that the gradient is $\frac{1}{2}a$. So acceleration of free fall = 2 × gradient.

4. The relationship between force and acceleration for a fixed mass

This experiment involves applying different known forces to a fixed mass and measuring the acceleration that is produced.

The following method uses a forcemeter and a double interrupter card with light gate to measure these two quantities.

Tilt the runway so that, after an initial push, the trolley runs down it at a constant speed (no acceleration). The runway is now friction compensated. Attach two cards of the same measured length symmetrically to the trolley so that they block a light gate's beam as they pass through it.

Use a forcemeter to apply a constant force *F* to the trolley (Figure 1.14).

The timer measures how long each card takes to pass through the light beam (t_1, t_2) and the time interval between the start of the two interruptions (t_3) .

Acceleration $a = (\text{length of } \text{card}/t_2 - \text{length of } \text{card}/t_1)/t_3$ Repeat for a range of forces.

either

Plot a graph of acceleration against force.

A straight line through the origin shows that acceleration and force are directly proportional.

or

Calculate F/a for each force used.

If answers are the same, acceleration and force are directly proportional.

5. Conservation of linear momentum

This experiment involves measuring the velocities of two colliding bodies both before and after a collision.

The simplest collision to describe is where one body is initially at rest and the two bodies join together during the collision. The following method uses light gates to measure the velocities of two gliders colliding on an air track.

Attach a card of measured length centrally to the top of the glider on the left so that it blocks the beams of each of the light gates as it passes through them (Figure 1.15).

Start the left glider moving to the right so that it collides with and sticks to the other glider which is at rest between the two light gates.

Timer measures how long the card takes to pass through each of the two light gates (t_1, t_2) .

Repeat with different initial velocity u and using gliders of different mass. In all cases, momentum is conserved if $m_1 u = (m_1 + m_2)v$. **6. Elastic and inelastic collisions** The apparatus and method for this experiment is similar to that for experiment 5. A second set of results is obtained with spring buffers on the gliders so that they gently bounce off each other when they collide.

of card/ t_2).

For all sets of results, calculate the kinetic energy before the collision $(\frac{1}{2}m_1u_1^2)$ and the total afterwards $(\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2)$.

Calculate the left glider's velocity *u* at the first light beam ($u = \text{length of } \text{card}/t_1$) and their combined velocity *v* at the second light beam (v = length)

Compare the momentum of the left glider before the collision $m_1 u$ with

Measure the mass of each glider (include the card) m_1, m_2 .

that of the joined gliders after the collision $(m_1 + m_2)v$.

Find the percentage of the initial kinetic energy remaining after the collision. Compare these percentages for the two types of collision.

The collision with the spring buffers should be closest to 100% indicating that this collision is the closest to being elastic.

7. Efficiency of energy transfer

The following experiments measure how much of the initial stored energy is converted into kinetic energy.

Method 1 Gravitational potential energy to kinetic energy

Measure height h of the mass m_2 above the floor (Figure 1.16). Position the light gate slightly further than h ahead of the glider.

Attach a card of measured length centrally to the top of the glider so that it blocks the light gate's beam as it passes through it.

Release the mass so it falls to the floor and accelerates the glider. Glider moves at a constant velocity once the mass has hit the floor. Timer measures how long the card takes to pass through the light gate. Calculate the constant velocity v of the glider using length of card/interruption time.

Measure the mass of the glider (include the card) m_1 and the falling mass m_2 .

Find the percentage of the gravitational potential energy (m_2gh) of the falling mass that becomes kinetic energy $[\frac{1}{2}(m_1 + m_2)v^2]$. Repeat using different masses and release heights.

Method 2 Elastic potential energy to kinetic energy

Use a rule to measure the extension of the rubber band when stretched as shown in Figure 1.17 by different forces applied with a forcemeter. Plot a force–extension graph for the rubber band.

Find the elastic potential energy stored in the elastic band for a number of extensions using the area under the graph.

Attach a card of measured length centrally to the top of the glider so that it blocks the light gate's beam as it passes through it.

Use the first extension to catapult the glider along the air track.

Timer measures how long the card takes to pass through the light gate. Calculate the velocity v of the glider using v = length of card/interruption time.

Measure the mass of the glider (include the card) m.

Find the percentage of the elastic potential energy stored in the rubber band at this extension that becomes kinetic energy $\left[\frac{1}{2}mv^2\right]$. Repeat for the other extensions.



Fig 1.16 What percentage of the gravitational potential energy becomes kinetic energy?



Fig 1.17 What percentage of the elastic potential energy becomes kinetic energy?

Checklist

Before attempting the following questions on mechanics, check that you:

- know the definition of density and can describe how to measure the densities of solids (including those with irregular shapes), liquids and gases
- know the meanings of the terms: distance, displacement, speed, velocity and acceleration
- can sketch displacement–time graphs for a body moving with a constant speed and for a body moving with a constant acceleration
- can sketch a velocity–time graph for a body moving with a constant acceleration
- know that the gradient of a displacement–time graph gives velocity and that of a velocity–time graph gives acceleration
- know that the area under a velocity-time graph gives the change in displacement
- can confidently use the equations of motion
- have learnt a description of an experiment to determine the acceleration of a freely falling object
- know that the parabolic path of a projectile results from a constant horizontal speed and a uniform vertical acceleration
- know that a force is a vector that acts at a particular point and that the resultant of a number of forces can be found using a vector diagram drawn to scale
- know how to draw free-body force diagrams and appreciate that the weight of a body is a force that acts through its centre of gravity
- know what is meant by the moment of a force and can state and apply the principle of moments
- know the conditions required for a rigid body to be in equilibrium and can use these to solve static force problems
- 🔲 can calculate the momentum of a moving body
- know what is meant by the impulse of a force and can relate this to the change in momentum that it produces
- laws of motion have learnt a statement of each of Newton's three laws of motion
- have learnt a description of an experiment to investigate the relationship between force and acceleration for a fixed mass
- know how Newton's second law of motion leads to the definition of the newton as the unit of force
- can identify pairs of action and reaction forces and know their properties
- have learnt a statement of the principle of conservation of momentum and appreciate that this principle follows on directly from a combination of Newton's second and third laws
- have learnt a description of an experiment to test the principle of conservation of momentum
- know the meanings of the terms: work, power, kinetic energy, gravitational potential energy and elastic potential energy
- have learnt a statement of the law of conservation of energy
- know the similarities and the differences between an elastic and an inelastic collision

Unit 1

- know how to find the efficiency of an energy transfer process
- are familiar with the 'general requirements' (see Appendix 1) and how they apply to the topic of mechanics

Testing your knowledge and understanding

Answers to these questions, together with explanations, are in the Answers section which follows Chapter 6.



Fig 1.18





Quick test

Select the correct answer to each of the following questions from the four answers supplied. In each case only one of the four answers is correct. Allow about 40 minutes for the 20 questions.

1 Which one of the following is NOT a base unit in the SI system?

A Ampere	B Metre	C Newton	D Mole
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- **2** In the equation $c = \sqrt{(k/\rho)}$, *c* represents a speed and ρ a density. The units in which the quantity *k* is measured are
 - **A** kg m s⁻² **B** kg^{$\frac{1}{2}$} s **C** kg m s⁻¹ **D** kg m⁻¹ s⁻²
- **3** The density of sand is 2500 kg m⁻³. What is the volume in m³ of 50 kg of sand?
 - **A** 0.005 **B** 0.010 **C** 0.020 **D** 0.040
- **4** A body falls freely under gravity after being released from rest. Neglecting air resistance, which of the graphs in Figure 1.18 represents the variation of the height *h* of the body with time *t*.
- **5** The graph in Figure 1.19 shows how a trolley moved at a constant speed along a corridor.

Its constant speed was

A

A
$$0.5 \text{ m s}^{-1}$$
 B 2.0 m s^{-1} **C** 0.5 m s^{-2} **D** 2.0 m s^{-2}

6 A lunar landing module is descending to the Moon's surface at a steady velocity of 10 m s⁻¹. At a height of 120 m, a small object falls from its landing gear. If the Moon's gravitational acceleration is 1.6 m s⁻², at what speed in m s⁻¹ does the object strike the surface of the Moon?

7 A ball is suspended from an electromagnet attached to a trolley that is travelling as shown in Figure 1.20 at a steady speed of 1 m s^{-1} . The trolley is illuminated by a stroboscope that flashes at a regular rate. The ball is released and a stroboscopic photograph taken using a camera that is also moving to the right at 1 m s^{-1} .





The photograph obtained is





12



F2

Q

 F_3



Fig 1.22



Fig 1.23







Fig 1.26





- 8 A rocket is accelerating upwards through the atmosphere due to the thrust of its jets. The force required by Newton's third law to pair with the weight of the rocket is the
 - A Earth's gravitational pull on the rocket
 - **B** thrust of the jets on the air
 - C thrust of the air on the jets
 - D rocket's gravitational pull on the Earth
- 9 Figure 1.22 shows a person sitting on a box that rests on the ground, together with a free-body force diagram for the box. Which of the following statements is correct?
 - **A** force Q > force P + force R
 - **B** P is the push of the box on the Earth
 - C Q is the pull of the box on the Earth
 - **D** R is the push of the person on the box
- **10** Figure 1.23 shows four systems, each having three coplanar forces acting at a point. The lengths of the force vectors represent the magnitudes of the forces. Which system of forces could be in static equilibrium?
- 11 Figure 1.24 shows a rigid light rod PQ in equilibrium under the action of three forces F_1 , F_2 and F_3 . Which one of the following statements is true?

$$\mathbf{A} \quad F_1 \times d_1 = F_2 \times d_2$$

B
$$F_2 \times d_1 = F_3 \times d_2$$

$$\mathbf{C} \quad F_1 \times d_1 = F_2 \times (d_1 + d_2)$$

$$\mathbf{D} \quad F_2 \times d_1 = F_3 \times (d_1 + d_2)$$

2) 12 A uniform metal rod is 60 cm long and carries a weight of 10 N at one end and a weight of 20 N at the other end. The rod is supported in equilibrium by a knife-edge placed under it at a distance of 35 cm from the end carrying the 10 N weight as shown in Figure 1.25.

Fig 1.24

What is the weight of the rod?

	A	10 N	B 20 N	C 30 N	D 50 N
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13 Figure 1.26 shows the forces acting on an aircraft as it climbs at a steady speed at an angle θ to the horizontal.

Which one of the following is true?

- **A** lift $\times \sin \theta$ = weight
- **B** the resultant force is zero
- **C** lift $\times \cos \theta$ = weight
- **D** the resultant force acts in the direction of the thrust
- 14 A body of mass 4 kg is accelerated from rest by a steady force of 5 N. What is its speed in m s⁻¹ when it has travelled for 8 s?

15 The graph in Figure 1.27 shows how a physical quantity Y, relating to a body of fixed mass, varies with time t.

The impulse experienced by the body over the time interval $(t_2 - t_1)$ is equal to the shaded area if Y is the

- **A** displacement of the body
- **B** resultant force acting on the body
- **C** momentum of the body
- **D** velocity of the body



Fig 1.28

16 In laboratory experiments with colliding trolleys, the total momentum measured before a collision is hardly ever exactly the same as that measured after. This is because the total momentum is

- A altered by the action of external forces
- B conserved only when averaged over a large number of collisions
- C conserved only in perfectly elastic collisions
- **D** conserved only in totally inelastic collisions
- 17 An object of mass *m* passes a point X with a velocity *v* and rises up a frictionless incline to point Y that is at a height *h* above X as shown in Figure 1.28.

A second object of mass $\frac{1}{2}m$ passes X with a velocity of $\frac{1}{2}v$. To what height will it rise?

A <i>h</i> /8	B <i>h</i> /4	C h/2	D h
A 11/0	D <i>n</i> /1	0 11/2	D

18 A cricket ball of mass 150 g is caught by a fielder who stops the ball in a distance of 0.4 m with an average force of 27 N. What was the speed in m s⁻¹ of the ball just before the fielder caught it?

- **19** Two spheres of equal mass m travel towards each other with equal speed v on a smooth horizontal surface. They have a perfectly elastic head-on collision.
 - A Before impact the total momentum of the two spheres is mv
 - **B** After impact the total momentum of the two spheres is 2mv
 - **C** Before impact the total kinetic energy of the two spheres is $2mv^2$
 - **D** After impact the total kinetic energy of the two spheres is mv^2
- **20** A girl of mass 50 kg runs up a flight of stairs 5 m high in 4 s. Taking the acceleration of gravity as 10 m s⁻², what is her power rating in W in raising herself through this vertical height?

A 40.0	B 62.5	C 400	D 625

Worked example

Study the following worked examples on mechanics carefully. Make sure you fully understand their answers before attempting the practice assessment questions.

Worked example 1

The diagram shows a mass attached by a piece of string to a glider, which is free to glide along an air track.

Glider Air track 00000 1111

Fig 1.29

0

ſ

A student finds that the glider takes 1.13 s to move a distance of 90 cm starting from rest.

Show that the speed of the glider after 1.13 s is approximately 1.6 m s ⁻¹ .	
Calculate its average acceleration during this time.	
low would you test whether or not the acceleration of the glider is constant?	

onstant? [3] (Total 9 marks)

[3]

[3]

(Edexcel Module Test PH1, January 1997, Q. 5)

Unit 1

In all answers, each tick indicates the awarding of a single mark – note that no half-marks are ever awarded.

Helpful hint

Always give your answer to a 'show that' question to at least one more significant figure than the value asked for in the question.



You often find that a 'show that' value is needed later on in the same question. Either use the value provided or your own if you are happy with it.

Helpful hint

This question starts with a couple of

remembered to include the 'General

Requirements' in your revision!

easy marks provided you've

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Answer: First find the average speed of the glider over the distance of 90 cm. average speed = distance/time = (0.90 m)/(1.13 s) \checkmark

Since the glider starts from rest final speed = $2 \times \text{average speed}$ \checkmark = $2 \times (0.90 \text{ m})/(1.13 \text{ s}) = 1.59 \text{ m s}^{-1}$ \checkmark

average acceleration = change in velocity/time taken \checkmark = (1.59 m s⁻¹)/(1.13 s) \checkmark = 1.41 m s⁻² \checkmark

To answer the last part, you can briefly refer to any of the methods described in Experiment 2: measuring acceleration. However your method must compare values of acceleration as the glider moves along the air track. So, if using one of the light gate timing methods, it is important to say that the experiment has to be repeated with the light gate(s) placed at different positions along the air track.

For all methods the mark scheme will be similar:

selection of correct apparatus collection and processing of correct results

how results used to show acceleration is constant.

For example: if you describe a tickertape method:

glider pulls a length of tickertape through a ticker-timer cut tape up into equal time lengths and place side by side if constant acceleration, chart will show a constant rate of rise.

Worked example 2

State the difference between scalar and vector quantities. [2] A lamp is suspended from two wires as shown in the diagram. The tension in each wire is 4.5 N.



Fig 1.30

Calculate the magnitude of the resultant force exerted on the lamp by the wires. [3] What is the weight of the lamp? Explain your answer. [2]

(Total 7 marks) (Edexcel Module Test PH1, January 1999, Q. 3)

Answer:

scalar quantities do not include a direction \checkmark vector quantities do include a direction \checkmark

Split each tension into a horizontal and a vertical component. The two horizontal components act in opposite directions and cancel. So the resultant force on the lamp is the sum of the two upward vertical components.

vertical component of one tension = $4.5 \text{ N} \times \cos 40^{\circ}$ resultant force = $2 \times 4.5 \text{ N} \times \cos 40^{\circ}$ = 6.9 N (vertically upwards).

The two wires support the lamp and so no resultant force acts on it. weight of lamp = 6.9 N ✓ as it is in equilibrium (vertical force down = vertical force up). ✓

Worked example 3

The diagram shows part of a roller coaster ride. In practice, friction and air resistance will have a significant effect on the motion of the vehicle, but you should ignore them throughout this question.



The vehicle starts from rest at A and is hauled up to B by a motor. It takes 15.0 s to reach B, at which point its speed is negligible. Complete the energy conversion shown below for the journey from A to B.

Useful work done by motor \rightarrow [1]

The mass of the vehicle and the passengers is 3400 kg. Calculate

(i) the useful work done by the motor
 (ii) the power output of the motor.

At point D the motor is switched off on

Fig 1.31

At point B the motor is switched off and the vehicle moves under gravity for the rest of the ride. Describe the overall energy conversion which occurs as it travels from B to C. [1]

Calculate the speed of the vehicle at point C.

On another occasion there are fewer passengers in the vehicle; hence its total mass is less than before. Its speed is again negligible at B. State with a reason how, if at all, you would expect the speed at C to differ from your previous answer. [2]

(Total 11 marks)

[4]

[3]

(Edexcel Unit Test PHY1, June 2001, Q. 5)

Answer: Useful work done by motor \rightarrow gravitational potential energy. \checkmark (i) useful work done by motor = $mg\Delta h$ = 3400 kg × 9.81 N kg⁻¹ × 30 m \checkmark = 1.00 MJ \checkmark (ii) power output = work done/time = 1.00 MJ/(15.0 s) \checkmark = 67 kW \checkmark Overall energy conversion from B to C:

gravitational potential energy \rightarrow kinetic energy. \checkmark

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Fig 1.34

Time/s

 $\frac{1}{2}mv^2$ at C = $mg\Delta h$ from B to C where Δh = 30.0 m - 12.0 m = 18.0 m 🗸 $\frac{1}{2}v^2 = 9.81 \text{ m s}^{-2} \times 18.0 \text{ m}$ $V = \sqrt{(353 \text{ m}^2 \text{ s}^{-2})} = 18.8 \text{ m s}^{-1}$

speed will be the same 🗸 since both gravitational potential energy and kinetic energy are proportional to m so

Practice questions

The following are typical assessment questions on mechanics. Attempt these questions under similar conditions to those in which you will sit your actual test.

1 The graph in Figure 1.32 shows how the volume of 1.000 kg of water varies with temperature.

State the temperature at which the density of water is a maximum.

[1]Sketch a graph of how the density of water varies with temperature between 0 °C and 10 °C. [2]

Suggest how you could demonstrate that the volume of water when heated from 0 °C to 10 °C behaves in the manner indicated by the graph. You may be awarded a mark for the clarity of your answer.

> [4] (Total 7 marks)

(Edexcel Unit Test PHY1, June 2001, Q. 6)

2 Figure 1.33 shows a toy truck, about 30 cm long, accelerating freely down a gentle incline.

Explain carefully how you would measure the average speed with which the truck passes the point A. [4]

You find that the measured average speed of the truck is 1.52 m s⁻¹ when it passes the point A and 1.64 m s^{-1} when it passes the point B. The distance from A to B is 1.20 m. Calculate the acceleration of the [2]

(Total 6 marks)

(Edexcel Module Test PH1, June 1999, Q. 3)

The graph in Figure 1.34 shows the speed of a racing car during the first 2.7 s of a race as it accelerates from rest along a straight line.

Use the graph to estimate

- the displacement 1.5 s after the start [2]
- (ii) the acceleration at 2.0 s
- (iii) the kinetic energy after 2.5 s given that the mass of the racing car is 420 kg. [2]

(Total 6 marks)

[2]

(Edexcel Module Test PH1, June 1999, Q. 2)



Fig 1.35 A



Fig 1.35 B



Fig 1.36 A



Fig 1.36 B

4 Figure 1.35A shows a child crouching at rest on the ground. Free-body force diagrams for the child and the Earth are shown in Figure 1.35B.

Complete the following table describing the forces A, B and C. [4]

	Description of force	Body which exerts force	Body the force acts on
Force A	Gravitational	Earth	Child
Force B		asion of particles	ad electromagnetic
Force C	The driver has a	obar exteriosent to	the intervence

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

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

[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. [3]

(Total 9 marks)

(Edexcel Unit Test PHY1, June 2001, Q. 3)

5 Two campers have to carry a heavy container of water between them. One way to make this easier is to pass a pole through the handle as shown in Figure 1.36A.

The container weighs 400 N and the weight of the pole may be [1] neglected. What force must each person apply? An alternative method is for each person to hold a rope tied to the

handle as shown in Figure 1.36B. Draw a free-body force diagram for the container when held by the ropes. [2]

The weight of the container is 400 N and the two ropes are at 40° to the horizontal. Show that the force each rope applies to the container is about 300 N. [3]

Suggest **two** reasons why the first method of carrying the container is easier. [2]

Two campers using the rope method find that the container keeps bumping on the ground. A bystander suggests that they move further apart so that the ropes are more nearly horizontal. Explain why this would not be a sensible solution to the problem. [1]

(Total 9 marks)

(Edexcel Unit Test PHY1, June 2001, Q. 4)

6 Define linear momentum. [1]

[1]

The principle of conservation of linear momentum is a consequence of Newton's laws of motion. An examination candidate is asked to explain this, using a collision between two trolleys as an example. He gives the following answer, which is correct but incomplete. The lines of his answer are numbered on the left for reference.

- 1 During the collision the trolleys push each other.
- 2 These forces are of the same size but in opposite directions.
- 3 As a result, the momentum of one trolley must increase at the same rate as the momentum of the other decreases.
- 4 Therefore the total momentum of the two trolleys must remain constant.

In which line of his argument is the candidate using Newton's second law?

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[1]

[2]

[4]

[2]

The student is making one important assumption which he has not stated. State this assumption. Explain at what point it comes into the argument. Describe how you would check experimentally that momentum is conserved in a collision between two trolleys. (Edexcel Unit Test PHY1, January 2001, Q. 3) 7 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 50 kg. Calculate the momentum of the driver before the crash. Calculate the average resultant force on the driver during impact. [3] Explain why the resultant force is not the same as the force exerted on the driver by the seatbelt. 8 60 m assence capsule Ground make one complete revolution. from point B to point D? each axis.

18

 0.20 m s^{-1}

Fig 1.37

[1]

(Total 6 marks)

(Total 9 marks)

(Edexcel Unit Test PHY1, June 2001, Q. 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 in Figure 1.37.

In which line is he using Newton's third law?

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 [2]

What is the change in the velocity of a passenger when he travels [2]

When one particular passenger ascends from point A to point C, his gravitational potential energy increases by 80 kJ. Calculate his mass. [3]

Sketch a graph showing how the gravitational potential energy of this passenger would vary as he ascended from A to C. Add a scale to [3]

Discuss whether it is necessary for the motor driving the wheel to supply this gravitational potential energy. [2]

> (Total 12 marks) (Edexcel Unit Test PHY1, January 2001, Q. 2)

RADIOACTIVITY

rt 2

Radioactivity

\leq Introduction

Radioactivity is the spontaneous emission of particles and electromagnetic waves from the atomic nucleus of certain elements. It was first discovered in 1896 and soon used in the scattering experiment that led to the development of the nuclear model of an atom, in a similar way to that in which electrons are used today to reveal the quark structure of protons and neutrons. As you study radioactivity, you learn about alpha, beta and gamma emissions, their properties and the way in which they each alter their parent nucleus. You find that despite radioactivity being a random process, the rate of decay of a given radioactive material follows a predictable pattern.

Things to understand

The nuclear atom

- the structure of an atom was discovered by scattering alpha particles from gold foil
- an atom consists of a very small, central nucleus, containing almost all the atom's mass, around which electrons orbit
- an atom is neutral: the nucleus is positive, electrons are negative
- a nucleus consists of a mixture of particles known as nucleons, where a nucleon is either a proton (positive) or a neutron (neutral)
- a nuclear atom is often represented by its nuclear symbol (Figure 1.38) from which the numbers of protons, neutrons and orbiting electrons can be determined
- atoms with the same number of protons in their nuclei can have different numbers of neutrons and so form different isotopes of the same element
- both protons and neutrons are now known to have their own substructure of particles known as quarks
- the quark structure of a nucleus can be revealed by scattering experiments using high energy electrons

Radiations released during radioactive decay

- all emissions from radioactive decay come from the nucleus
- alpha (positive), beta (usually negative but can be positive) and gamma (no charge) radiations are emitted by a variety of nuclei
- alpha radiation produces a lot of ionisations as the alpha particles push their way through a material – consequently alpha radiation soon runs out of energy and has a very short range

⁷⁹ Br

Fig 1.38 An atom of bromine-79 has a nucleus containing 35 protons and 44 neutrons (a total of 79 nucleons) surrounded by 35 orbiting electrons

208 84 Po ► $\frac{204}{82}$ Pb + $\frac{4}{2}$ α

Fig 1.39 Polonium-208 decays by alpha emission into lead-204



Fig 1.40 (a) A neutron in the nucleus decays into a proton and an electron; the electron is then emitted as a negative beta particle (b) Copper-66 decays by beta-minus emission into zinc-66

$^{23}_{12}Mg \longrightarrow ^{23}_{11}Na + ^{0}_{1}\beta$

Fig 1.41 Magnesium-23 decays by beta-plus emission into sodium-23

- alpha particles are helium nuclei and alpha decay removes two protons and two neutrons from the parent nucleus (Figure 1.39)
- beta radiation produces fewer ionisations and so its particles can travel further than alpha particles before running out of energy
- a beta-minus particle is an electron produced when a neutron in a nucleus splits up into a proton and an ejected 'beta' electron (Figure 1.40)
- a beta-plus particle is a positron (a positive electron) produced when a proton in a nucleus changes into a neutron and an ejected 'beta' positron (Figure 1.41)
- gamma radiation produces very few ionisations along its path and so has a very large range
- gamma radiation is an electromagnetic wave that takes away any surplus energy that a nucleus may have been left with after it has emitted either alpha or beta particles

Radioactive decay rates

- all radioactive decay is random; the time at which a particular nucleus will decay is unpredictable
- the activity of a source depends on the total number of nuclei present at that time
- the activity of a source decreases with time as the decays taking place reduce the number of nuclei left to decay
- an activity-time graph produces an exponential decay curve
- the average time taken for the activity to drop to half its value (the halflife) is the same throughout a given decay but varies from source to source
 - all activity measurements should be adjusted to remove the background activity produced by naturally occurring radio-isotopes and cosmic rays

\leq Things to learn

You should learn the following for your Unit PHY1 Test. Remember that it may also test your understanding of the 'general requirements' (see Appendix 1).

Equations

All radioactivity equations are provided but you do need to learn the nuclear symbols for the following particles to complete radioactive decay equations:

alpha particle	$\frac{4}{2} \alpha$ or $\frac{4}{2}$ He
beta-minus particle	$^{0}_{-1}\beta \text{ or }^{0}_{-1}e^{-1}$
beta-plus particle	${}^{0}_{1}\beta \text{ or }{}^{0}_{1}e^{+}$
gamma radiation	⁰ ₀ γ or γ
neutron	1_0 n
proton	1 p

General definitions

nucleus: very small, positive centre of an atom in which nearly all the atom's mass is concentrated

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- nucleons: protons and neutrons the basic particles from which the nucleus of an atom is constructed
- quarks: the basic particles from which protons, neutrons and many other sub-atomic particles are constructed
- isotopes: atoms that have the same number of protons but a different number of neutrons in their nuclei
- background radiation: random emissions from naturally occurring radio-isotopes that must be taken into account whenever performing radioactivity experiments
- activity: the number of nuclei of a source that decay in one second
- becquerel (Bq): a unit of activity; a count rate of one disintegration per second
- decay constant: the proportion of the nuclei present that decay in one second
- half-life: the average time taken for half the nuclei of that radioactive element to decay *or* the average time for the activity to fall to 50% of its original value

Word equation definitions

Use the following word equation when asked to define:

decay constant = activity/number of nuclei present

Experiments

Although you will not have performed all these experiments yourself, you may still be asked to describe them!

1. Alpha particle scattering experiment

Alpha particles are fired at thin gold foil (Figure 1.42). The coated screen flashes when an alpha particle hits it.

Most of the alpha particles pass almost straight through the foil.

Some alpha particles deflect through small angles.

A very small minority of alpha particles (about 1 in 8000) deflects through more than 90° .

Conclusions:

- 1 an atom has a very tiny charged centre (the nucleus), containing most of the atom's mass
- 2 the nuclei have comparatively large distances between them.

2. Penetration of the radiations emitted by radioactive sources

Use a Geiger–Muller (GM) tube with a thin window so that alpha particles can pass into it and so be detected.

Record a number of count rates with no source present and obtain an average background count.

Keep each source a fixed distance from the GM tube (e.g. 1 cm for the alpha source, 3 cm for the beta source and 6 cm for the gamma source). Measure the corrected count rate for the alpha source for different this large part of page a between it and the CM tube (Figure 1.42).

thicknesses of paper between it and the GM tube (Figure 1.43). Repeat for the beta source using thin pieces of aluminium as the absorber.

Repeat for the gamma source using different thicknesses of lead absorbers.



Fig 1.42 The alpha particle scattering experiment



Fig 1.43 Thin paper stops alpha particles

Protactinium-234 is used as it has a

Results:

- 1 alpha particles are stopped by thin paper
- 2 beta particles can penetrate up to several millimetres of aluminium
- 3 gamma radiation can still be detected after passing through several centimetres of lead.

3. Measuring the half-life of protactinium-234

Record a number of count rates with no source present and obtain an average background count.

Shake the 'protactinium generator' to transfer the protactinium compound from the lower water-based layer to the upper organic layer.

When the layers re-establish, place the GM tube alongside the top layer (Figure 1.44).

Record the count rate at intervals of 10 s for 5 min.

Plot a graph of corrected count rate against time (Figure 1.45).

From the graph determine how long it takes for the count rate at any given time to halve its value.







Fig 1.45 The half-life of this isotope is about 1 min

Checklist

Before attempting the following questions on radioactivity, check that you:

- have learnt a description of the alpha particle scattering experiment and know how its results led to the nuclear model of an atom
- \Box appreciate that the diameter of an atom is about 10^{-10} m and that of a nucleus is about 10⁻¹⁵ m
- know the structure of a nucleus and how to find the number of protons and neutrons it contains from its nuclear symbol
- understand the term 'isotope'
- can compare the similarities and differences between the alpha particle scattering experiment and deep inelastic scattering of electrons
- appreciate that both protons and neutrons have a sub-structure consisting of three quarks
- know the nature of the radiations emitted by a radioactive source
- lack have learnt the nuclear symbols for an alpha particle, both types of beta particle, gamma radiation, a neutron and a proton
- can complete and balance nuclear equations

know how to distinguish experimentally between alpha, beta and gamma radiations with reference to their ranges in air and their penetrations through different absorbers

half-life of about 1 min and therefore its activity falls significantly during a 5-min period.



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- appreciate the link between a radiation's ionising ability and its penetrating power or range
- know some sources of background radiation
- appreciate that the random and unpredictable nature of an individual decay still leads to an overall predictable decay pattern for the source as a whole
- know the meanings and units of 'activity', 'decay constant' and 'halflife'
- can use the equations that relate these quantities
- have learnt a description of an experiment to measure the half-life of a radioisotope with a half-life of about a minute
- are familiar with the 'general requirements' (see Appendix 1) and how they apply to the topic of radioactivity

K Testing your knowledge and understanding

Quick test

Select the correct answer to each of the following questions from the four answers supplied. In each case only one of the four answers is correct. Allow about 40 min for the 20 questions.

- **1** Experiments in which beams of alpha particles were fired at thin metal foils provided evidence for the existence of
 - A quarks **B** isotopes **C** positrons **D** nuclear atoms
- **2** Three of the following statements about a neutral atom of an element are correct. Which is the incorrect statement?
 - **A** The number of electrons in the atom equals the number of protons in the nucleus
 - **B** The proton number is the same for all atoms of all isotopes of the same element
 - C The proton number is the nearest integer to the mass number
 - **D** Neutron number = nucleon number proton number
- **3** The nuclear symbol for an isotope of bismuth is ²⁰⁹₈₃Bi. An atom of this isotope consists of
 - A 83 protons, 43 neutrons, 83 electrons
 - **B** 83 protons, 126 neutrons, 83 electrons
 - C 83 protons, 209 neutrons, 209 electrons
 - D 126 protons, 83 neutrons, 126 electrons
- **4** ${}_{2}^{4}$ He represents the helium nucleus. Three of the following statements about the helium nucleus are correct. Which is the incorrect statement?
 - A It contains two neutrons
 - **B** It contains two protons
 - **C** It has to gain four orbital electrons to become a helium atom
 - D It is called an alpha particle when emitted by a radioactive source
- 5 A proton consists of
 - **A** a mixture of nucleons
 - **B** a neutron and an electron
 - C a mixture of quarks
 - **D** a nucleus and an electron -

Answers to these questions, together with explanations, are in the Answers section which follows Chapter 6. 24

- 6 The radiation from a radioactive source is found to pass through a sheet of paper without any reduction in its intensity but is completely absorbed by a piece of aluminium 1 cm thick. The radiation consists of

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- A alpha radiation only
- **B** beta radiation only
- C a mixture of alpha and beta radiations
- **D** a mixture of alpha, beta and gamma radiations
- 7 When a Geiger counter is brought near to a closed lead box containing a radioactive source, the measured count rate rises from 0.1 to 0.9 Bq. The increase in the count rate is due to
 - A background radiation + beta and gamma radiation from the source
 - **B** background radiation + gamma radiation from the source
 - C beta and gamma radiation from the source
 - **D** gamma radiation from the source
- **8** An isotope of radon, $\frac{220}{86}$ Rn, decays by emitting alpha radiation. Which of the following represents the product of this alpha decay?

A
$$^{224}_{88}$$
Ra **B** $^{222}_{90}$ Th **C** $^{216}_{84}$ Po **D** $^{218}_{82}$ Pb

9 When an unstable radioactive isotope X emits beta-minus radiation, a stable isotope Y is formed. The decay can be represented by the nuclear equation $X \rightarrow Y + \beta^{-}$. Which of the following statements is correct?

- **A** X has a smaller proton number than Y
- **B** X and Y have the same proton number
- C X and Y are isotopes of the same element
- D X and Y have different nucleon numbers
- **10** After the nucleus of a cobalt atom, ${}^{60}_{27}$ Co, has emitted gamma radiation the number of protons in the resulting nucleus is

A 25	B 27	C 33	D 60
			AP 00

11 A radioactive nuclide of gold, $^{197}_{79}$ Au, decays to form a nuclide of platinum, ¹⁹⁷₇₈Pt. The gold decayed by emitting

- A an alpha particle
- **B** a beta-minus particle
- C a beta-plus particle
- **D** gamma radiation
- 12 The boron isotope ${}^{10}_{5}$ B reacts with another particle to produce the lithium isotope $\frac{7}{3}$ Li and an alpha particle. The other particle is

A an electron **B** a neutron **C** a positron **D** a proton 13 A radioactive isotope of element P has a proton number Z and a nucleon number A. It emits an alpha particle to become element Q which then emits a negative beta particle to become element R. What is the proton

- A Z-1 and A-2
- **B** Z 4 and A 2
- \mathbb{C} Z 1 and A 4
- **D** Z 4 and A 4
- 14 Which of the following radioactive disintegrations will result in the formation of a different isotope of the parent substance?
 - A Gamma radiation
 - **B** An alpha particle + a beta particle
 - C An alpha particle + two beta particles

number and the nucleon number of element R?

D Two alpha particles + a beta particle

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- **15** A sample of the radioactive gas, radon, is placed in a container where it causes some of the air to ionise. The amount of ionisation is found to decrease with time. The decrease is most likely due to
 - A a decrease in the number of radon gas atoms present
 - **B** a decrease in the number of air atoms present
 - **C** mixing of the radon gas with the air
 - **D** a chemical reaction between the radon gas and the air
- **16** A radioactive element emits alpha particles. It has a half-life of 10 days. What will be the mass of this element remaining after 40 days in a sample initially containing 48 g?

17 The radioactive element ²²⁶₈₈Ra has a half-life of about 1600 years. An old sample of ²²⁶₈₈Ra is observed at a certain time to be emitting radiation at approximately 100 counts per minute. At what approximate rate, in counts per minute, would the sample have been emitting radiation 16 years previously?

A 100	B 160	C 1600	D 10 000
	100	0 1000	

- **18** Radon has a half-life of 50 s. Three of the following statements about a sample of 8 g of radon are correct. Which is the incorrect statement?
 - A The count rate will have fallen to about $\frac{1}{4}$ of its initial value after 100 s
 - **B** There will be about 1 g of undecayed radon left after 150 s
 - **C** The count rate will have fallen to about 1/16 of its initial value after 200 s
 - **D** There will be about $\frac{1}{4}$ g of undecayed radon left after 200 s
- **19** In order to trace the line of a water-pipe buried 0.4 m below the surface of a field, an engineer wishes to add a radioactive isotope to the water. Which isotope should he choose?
 - A A beta emitter with a half-life of a few hours
 - **B** A beta emitter with a half-life of a several years
 - **C** A gamma emitter with a half-life of a few hours
 - **D** A gamma emitter with a half-life of a several years
- **20** The decay rate for a sample of radon gas at a particular instant is 7560 Bq. The decay constant for radon is 0.0126 s⁻¹ and its mass number is 220. The number of radon nuclei present in the sample at this particular instant is
 - **A** 95 **B** 17 460 **C** 600 000 **D** 1 660 000

Worked examples

Study the following worked examples on radioactivity carefully. Make sure you fully understand their answers before attempting the practice assessment questions.

Worked example 1-

Figure 1.46 shows a diagram of the tracks produced by alpha particles emitted by a radioactive source.

Suggest properties of the alpha particles that can be deduced from this diagram?
[4]



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Helpful hint

Link your knowledge of alpha particles with details in the photograph. As with most 'suggest' questions, there are a number of ways of achieving the maximum 4 marks.



You cannot use an absorber to stop the beta particles as this will also stop all the alpha particles. You have to stop the particles that you are trying to count! A different source emits both alpha and beta particles. How would you use a Geiger counter to determine the approximate count rate due to the alpha radiation only? [3] (Total 7 marks) (Edexcel Module Test PH2, June 1999, Q. 2) Answer: alpha particles are strongly ionising/are charged (dense tracks) and, consequently, will have a short range </ alpha particles travel in straight lines/have large (straight tracks) mass/momentum 🗸 alpha particles are emitted with the same energy/speed or (same length tracks) have the same range 🗸 (two track lengths) For example, find count rate using a thin window GM tube placed close to the source 🗸

(this will be the combined count rate for the alpha and beta particles) find count rate with thick paper between GM tube and source \checkmark (this will be the count rate for the beta particles only) alpha count rate = difference in these two readings. \checkmark

Worked example 2

Tritium 3_1 T decays by beta-minus emission. 3_1 T has a half-life of 12 years.[1]Of which element is 3_1 T an isotope?[1]Complete the following nuclear equation for this decay.[2] 3_1 T \rightarrow X + 3_2 [2]Define the term half-life.[2](Total 5 marks)

(Edexcel Module Test PH2, January 1998, Q. 1)

Answer:

Proton number of tritium = 1 so tritium is an isotope of hydrogen.

Beta-minus particle = ${}^{0}_{-1}\beta$ so ${}^{3}_{1}T \rightarrow {}^{3}_{2}X + {}^{0}_{-1}\beta$

Half-life: the average time taken \checkmark for half the nuclei of that radioactive element to decay.

Worked example 3-

It is thought that an extremely short-lived radioactive isotope $^{269}_{110}X$, which decays by alpha emission, has a half-life of 200 µs. After a series of decays the element $^{A}_{104}Y$ is formed from the original isotope. There are no beta decays. Deduce the value of A. [3] Show that the decay constant of $^{269}_{110}X$ is approximately 3500 s^{-1} . [2] 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 $^{269}_{110}X$. [2] Why is this value for the activity only approximate? [1] (Total 8 marks)

(Edexcel Module Test PH2, January 1999, Q. 2)

Helpful hint

Make sure you are familiar with the

layout and contents of the formulae sheet. Don't waste precious exam time hunting for an equation that

might not even be there!

number by 2 \checkmark proton number has decreased by 110 - 104 = 6 requiring 3 alpha decays \checkmark nucleon number will decrease by $3 \times 4 = 12$ so A = 269 - 12 = 257 \checkmark

Answer: Each alpha decay decreases the nucleon number by 4 and the proton

decay constant $\lambda = 0.69/t_{\frac{1}{2}}$ (no credit as equation provided in exam) = $0.69/(200 \times 10^{-6} \text{ s})$ \checkmark

 $= 3450 \text{ s}^{-1}$

 $\approx 3500 \text{ s}^{-1}$ as required.



Either

since radioactivity is a random process, activity fluctuates from one moment to the next making it impossible to calculate the exact activity at a given instant (*or* idea of half-life being an average value) \checkmark

or

a half-life of 200 μs is so short that it is very difficult to measure and would itself only be an approximate value \checkmark

Practice questions

The following are typical assessment questions on radioactivity. Attempt these questions under similar conditions to those in which you will sit your actual test.

 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. [3]

Explain why these observations led to the conclusion that an atom was composed mainly of space, with a very small, relatively massive, charged nucleus. [3]

State an approximate value for the diameter of (i) a gold atom and (ii) a gold nucleus. [2]

(Total 8 marks)

(Edexcel Module Test PH2, June 1996, Q. 1)

2 Complete the following table which compares alpha particle scattering and deep inelastic scattering experiments.

[2]

	Alpha particle scattering	Deep inelastic scattering
Incident particles	Alpha particles	
Target	Shou	Nucleons

Write a short paragraph describing the conclusion from each experiment.

(Total 6 marks)

[2, 2]

(Edexcel Unit Test PHY1, January 2001, Q. 7)

Helpful hint

Answers to these questions, together with explanations, are in the Answers section which follows Chapter 6.



3	A student has a sample of a radioactive element which is thought to	1
	be a pure beta emitter. The student has only the following apparatus	
	available:	

- a thin window Geiger-Muller (GM) tube connected to a counter 6
- a piece of aluminium 3 mm thick 0
- a clock
- a half-metre rule.

How would the student determine the background radiation level in [2] the laboratory?

The student investigates how the count rate varies with distance from the source to the GM 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. [5]

(Total 7 marks)

(Edexcel Unit Test PHY1, January 2001, Q. 6)

4 Protactinium, Pa, decays to uranium ²³⁴₉₂U by emitting a beta-minus particle. The uranium produced is itself radioactive and decays by alpha emission to thorium, Th.

Mark and label the position of $^{234}_{92}$ U on the grid in Figure 1.47. [1] Pat B NG

Draw arrows on the grid showing both the beta-minus and the alpha decays referred to above. Label your arrows α and β . [3]

(Total 4 marks)

(Edexcel Unit Test PHY1, June 2001, Q. 8)

A student carries out an experiment to determine the half-life of a 5 radioactive isotope M. The student subtracts the mean background count from the readings and plots the smooth curve shown in Figure 1.48.

From this graph the student concludes that the isotope M is not pure, but contains a small proportion of another isotope C with a relatively long half-life. State a feature of the graph that supports this [1] conclusion. [1]

Estimate the activity of isotope C.

Determine the half-life of isotope M, showing clearly how you obtained your answer. [3]

Isotope M decays by beta-minus emission. Write down a nuclear equation showing how the beta-minus particles are produced within [1] the nucleus.

Describe briefly how the student could determine the nature of the radiation emitted by isotope C. [3]

(Total 9 marks)

(Edexcel Module Test PH2, June 1998, Q. 3)

6 State the number of protons and the number of neutrons in ${}^{14}_{6}$ C. [2] The mass of one nucleus of ${}^{14}_{6}$ C = 2.34 × 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} m³. [2] Determine the density of this nucleus. [2] How does your value compare with the densities of everyday materials? [1]



Carbon-14 is a radioisotope with a half-life of 5700 years. What is meant by the term half-life? [2] Calculate the decay constant of carbon-14 in s⁻¹. [2] (Total 11 marks) (Edexcel Unit Test PHY1, January 2001, Q. 4) 7 A student measured the background radiation in a laboratory at 4.0 Bq. State two sources of background radiation. [2] Sodium-22 decays by beta-plus radiation to neon. Complete the following nuclear equation for this decay ensuring each symbol has the appropriate nucleon and proton numbers. $^{22}_{11}$ Na \rightarrow Ne + [2] Write down another possible isotope of sodium. [1]

Sodium-22 has a half-life of 2.6 years. Determine the decay constant
of sodium-22 in s⁻¹.[2]A sample of common salt (sodium chloride) is contaminated with
sodium-22. The activity of a spoonful is found to be 2.5 Bq. How
many nuclei of sodium-22 does the spoonful contain?[2]Explain whether your answer suggests that the salt is **heavily**
contaminated.[1]

(Total 10 marks) (Edexcel Unit Test PHY1, June 2001, Q. 7)

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