1. No mark scheme available

2. The list gives some quantities and units. *Underline* those which are base quantities of the International (SI) System of units.

coulomb force <u>length</u> mole newton <u>temperature interval</u>

(2 marks)

Define the volt.

Volt = Joule/Coulomb or Watt/Ampere

(2 marks)

Use your definition to express the volt in terms of base units.

Volt = J/C

$= kg\ m^2\ s^{-2}/A\ s$

$= kg\ m^2\ s^{-3}\ A^{-1}$

(3 marks)

Explain the difference between scalar and vector quantities

Vector has magnitude and direction

Scalar has magnitude only

(2 marks)

Is potential difference a scalar or vector quantity?

Scalar

(1 mark)
[Total 10 marks]

3. Explain how a body moving at constant speed can be accelerating.

A body can change direction while moving at constant speed. Its velocity (a vector quantity) will be changing. It will, therefore, be accelerating.

(3 marks)

The Moon moves in a circular orbit around the Earth. The Earth provides the force which causes the Moon to accelerate. In what direction does this force act?

Towards the Earth

(1 mark)

There is a force which forms a Newton's third law pair with this force on the Moon. On what body does this force act and in what direction?

On the Earth
Towards the moon

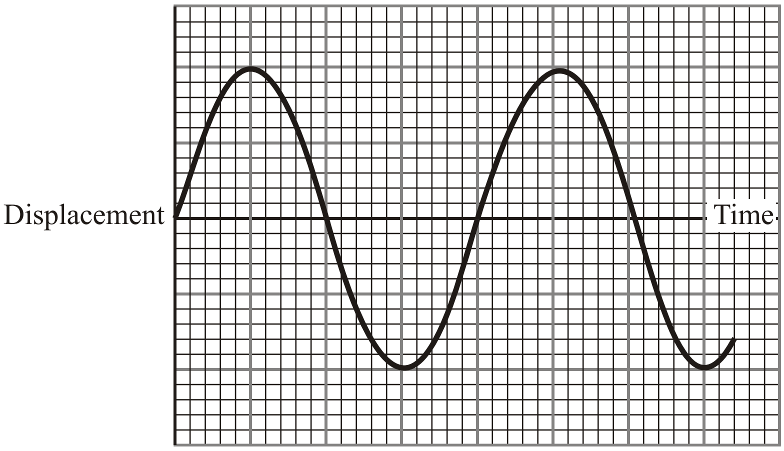
(2 marks)
[Total 6 marks]

4. Define simple harmonic motion.

In words / equation with symbols defined

(2 marks)

The curve labelled A shows how the displacement of a body executing simple harmonic motion varies with time.



Add the following to the graph:

(i) A curve labelled B showing how the acceleration of the same body varies with time over the same time period.

B: – sine curve : constant frequency (1) + (1)

(2 marks)

(ii) A curve labelled C showing how the velocity of the same body varies with time over the same time period.

C: cosine curve : constant frequency (1) + (1)

(2 marks)

Which pair of curves illustrates the definition of simple harmonic motion?

A and B (1)

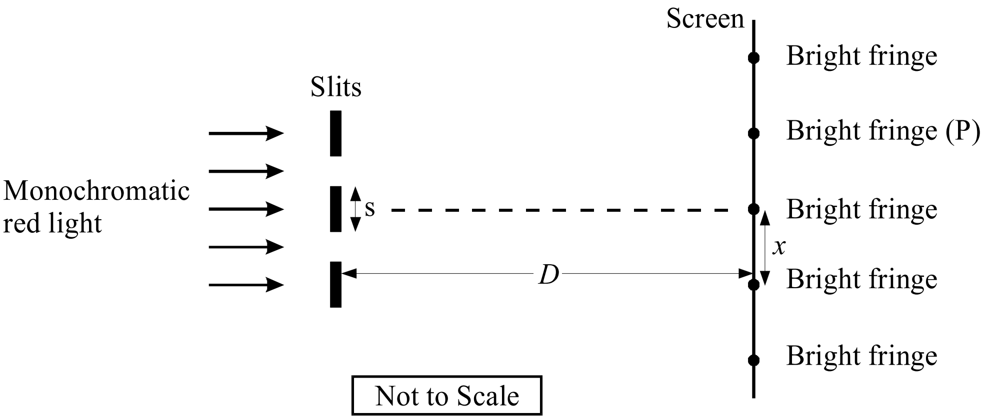
Explain your answer.

proportionality discussed [not just max – zero – max] (1)

+/– relationship discussed (1)

(3 marks)
[Total 9 marks]

5. The diagram shows an arrangement to produce interference fringes by Young's two slits method.



State suitable values for *s* and *D* if clearly observable fringes are to be produced.

s **0.1mm → 1.0 mm**

D **0.5 m → 10 m** **Units essential (1)**

Explain how the bright fringe labelled P is formed.

Diffraction occurs at slits (1)

Waves set off in phase / equivalent (1)

Path difference = 1λ (1)

Constructive interference / superposition at P (1)

Any 3 points

(4 marks)

What would be the effect on the fringe width *x* of

(i) increasing the slit separation *s*,
Decrease *x* (1)

(ii) illuminating the slits with blue light?
Decrease *x* (1)

(2 marks)

To obtain an interference pattern the light from the two slits must be coherent. What is meant by the term *coherent?*

Constant phase relationship (1)

(1 mark)
[Total 7 marks]

6. (a) The following equation describes the release of electrons from a metal surface illuminated by electromagnetic radiation.

$$hf = k.e._{\text{max}} + \phi$$

Explain briefly what you understand by each of the terms in the equation.

hf **Energy of a photon (1)**

$k.e._{\text{max}}$ **Kinetic energy of emitted electron/equivalent (1)**

ϕ **Energy to release electron from surface / equivalent (1)**

(3 marks)

(b) Calculate the momentum *p* of an electron travelling in a vacuum at 5% of the speed of light.

$\boldsymbol{p = mv}$ **(1)**

$\mathbf{= 9.11 \times 10^{-31}\ kg \times 0.05 \times 3 \times 10^{8}\ m\ s^{-1}}$ **(1)**
(no ecf for incorrect mass)

$\mathbf{p = 1.37 \times 10^{-23}\ N\ s/kg\ m\ s^{-1}}$ **(1) Unit penalty**

(3 marks)

What is the de Broglie wavelength of electrons travelling at this speed?

$\lambda = \dfrac{6.63\times10^{34}}{1.37\times10^{-23}}$ **ecf (b) (1)**

λ = 4.84 × 10^{-11} m Unit penalty (1)

(2 marks)

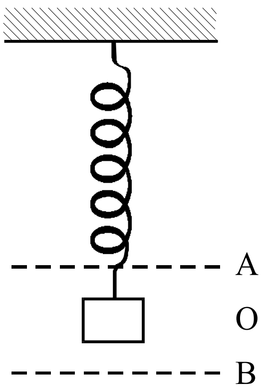
Why are electrons of this wavelength useful for studying the structure of molecules?

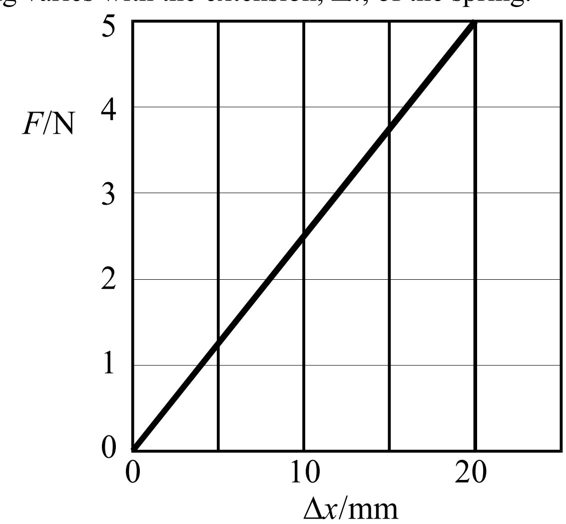
λ </similar to size / spacing atoms / molecules (1)

Diffraction occurs (1)

(2 marks)
[Total 10 marks]

7. The diagram below shows a mass of 0.51 kg suspended at the lower end of a spring. The graph shows how the tension, F, in the spring varies with the extension, Δx, of the spring.





Use the graph to find a value for the spring constant k.

a correct pair of values from graph (1)

k = 250 N m^{-1} / 0.25 N mm^{-1} (1)

(2 marks)

The mass, originally at point O, is set into small vertical oscillations between the points A and B. Choose A, B or O to complete the following sentences.

The speed of the mass is a maximum when the mass is at *O* (1)

The velocity and acceleration are both in the same direction when the mass is moving from *A* (or *B)* to *O*. (1)

(2 marks)

Calculate the period of oscillation T of the mass.

$$T = 2\pi\sqrt{\frac{0.51\,\text{kg}}{250\,\text{N m}^{-1}}} \text{ OR } 2\pi\sqrt{\frac{0.51\,\text{kg}}{0.25\,\text{N mm}^{-1}}} \quad \textbf{(1)}$$

Period of oscillation T = 0.28 s (0.3 s) (1)

No error carry forward

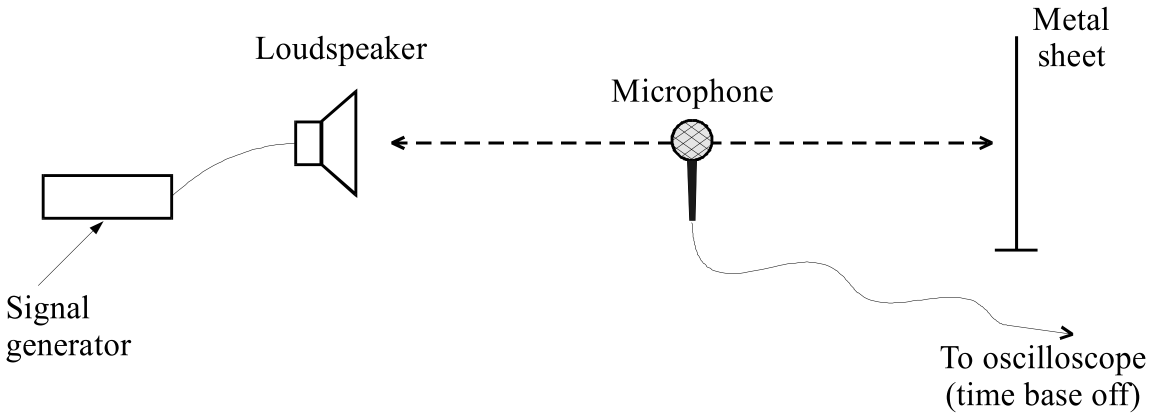
(2 marks)

What energy transformations take place while the mass moves from B to O?

Elastic potential energy/equivalent (1)
to kinetic and gravitational potential energy (1)

(2 marks)
[Total 8 marks]

8. The diagram below shows a loudspeaker which sends a note of constant frequency towards a vertical metal sheet. As the microphone is moved between the loudspeaker and the metal sheet the amplitude of the vertical trace on the oscilloscope continually changes several times between maximum and minimum values. This shows that a stationary wave has been set up in the space between the loudspeaker and the metal sheet.



How has the stationary wave been produced?

by superposition/interference (1)

with a reflected wave/wave of same speed and wavelength in opposite direction (1)

(2 marks)

State how the stationary wave pattern changes when the frequency of the signal generator is doubled. Explain your answer.

Maxima/nodes/equivalent are closer together (1)
since wavelength is halved (1)

(2 marks)

What measurements would you take, and how would you use them, to calculate the speed of sound in air?

Measure distance between minima/equivalent (1)

Repeat/take average (1)

Method of finding frequency (1)

λ = 2 × (node – node)/equivalent (1)

$V = f \times \lambda$ (1)

(Four marks maximum)

Other methods eligible for full marks.

(4 marks)

Suggest why the minima detected near the sheet are much smaller than those detected near the loudspeaker.

Near the sheet there is almost complete cancellation (1)

since incident and reflected waves are of almost equal amplitude (1)

(2 marks)
[Total 10 marks]

9. A 60 W light bulb converts electrical energy to visible light with an efficiency of 8%. Calculate the visible light intensity 2 m away from the light bulb.

60 W × 8/100 (1)

$$\times \frac{1}{4\pi\,(2\,\mathrm{m})^2}$$ **(1)**

Intensity = 0.1 W m^{-2}

(3 marks)

The average energy of the photons emitted by the light bulb in the visible region is 2 eV. Calculate the number of these photons received per square metre per second at this distance from the light bulb.

Idea that "N" × 2 → Intensity (1)

Number of photons = 3 × 10^{17} m^{-2} s^{-1} (1)

OR $$\frac{\text{Error carried forward } I \text{ Wm}^{-2}}{3.2\times10^{-19}\,\text{J}}$$

(2 marks)
[Total 5 marks]

10. (a) Describe briefly how you would demonstrate in a school laboratory that different elements can be identified by means of their optical spectra

Discharge tube/flame test (1)

Diffraction grating/prism (1)

Each element has its own pattern of lines (1)

(3 marks)

(b) The diagram below is a simplified energy level diagram for atomic hydrogen.

	________________	0 eV
First excited state	________________	–3.4 eV
Ground state	________________	–13.6 eV

A free electron with kinetic energy 12 eV collides with an atom of hydrogen and causes is to be raised to its first excited state.

Calculate the kinetic energy of the free electron (in eV) after the collision.

Kinetic energy = 1.8 eV (1)

Calculate the wavelength of the photon emitted when the atom returns to its ground state.

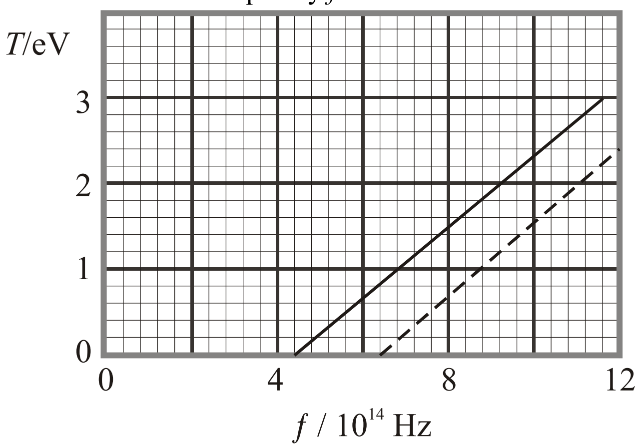
ΔE = 10.2 eV (1)

λ = hc/Energy value in Joules (1)

Wavelength = 1.2×10^{-7} m (1)

(4 marks)
[Total 7 marks]

11. The graph shows how the maximum kinetic energy T of photoelectrons emitted from the surface of sodium metal varies with the frequency f of the incident radiation.



A parallel line (1)
starting at a higher frequency (1)

Why are no photoelectrons emitted at frequencies below 4.4×10^{14} Hz?

Photon energy too small/less than ϕ (1)

(1 mark)

Calculate the work function ϕ of sodium in eV.

If using $\phi = hf - T$

then a valid pair of points (1)

with both points in the same units (1)

OR

If using $hf_o = \phi$

with $f_o = 4.4 \times 10^{14}$ Hz (1)

Work function = 1.8 eV (1)

(3 marks)

Explain how the graph supports the photoelectric equation $hf = T + \phi$

$T = hf - \phi$ is similar to $y = mx + c$ (1)

Straight line shows T/f relationship (1)

Negative intercept T axis shows ϕ (1)

Any two

(2 marks)

How could the graph be used to find a value for the Planck constant?

From the gradient (1)

(not necessary to mention conversion factor)

(1 mark)

Add a line to the graph to show the maximum kinetic energy of the photoelectrons emitted from a metal which has a greater work function than sodium. (See graph.)

(2 marks)
[Total 9 marks]

12. A simple pendulum has a period of 2.0 s and oscillates with an amplitude of 10 cm. What is the frequency of the oscillations?

Frequency = 0.5 Hz / s^{-1} (1)

(1 mark)

At what point of the swing is the speed of the pendulum bob a maximum?

Centre/equivalent/sketch (1)

Calculate this maximum speed

$v_{MAX} = 2\pi f x_0$/substitutions (1)

Maximum speed = 0.31 m s^{-1}/31cm s^{-1} (1)

(3 marks)

At what points of the swing is the acceleration of the pendulum bob a maximum?

Top / equivalent / sketch (1)

Calculate this acceleration.

$a_{max} = \pi^2 \times 0.1$ m (1)

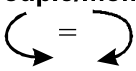
Maximum acceleration = 0.99/1.0 m s^{-2} (1)

or in cm s^{-2}

(3 marks)
[Total 7 marks]

13. (a) (i) **Y = <u>637 N to 650 N</u> (1)**
X = <u>520 N</u> (1)

(ii) **Component Y and the weight (638 N) form/**
there is an anticlockwise couple/moment/torque (1)

Equilibrium is achieved if  **(1)**

(4 marks)

(b) **Attempt to use $ma = F$ (1)**
(65 kg)a = 520 N (1)

$\Rightarrow a$ = <u>8.0 m s^{-2}</u> (1)

Force X reduces as she slows/ X depends on speed (1)

(4 marks)

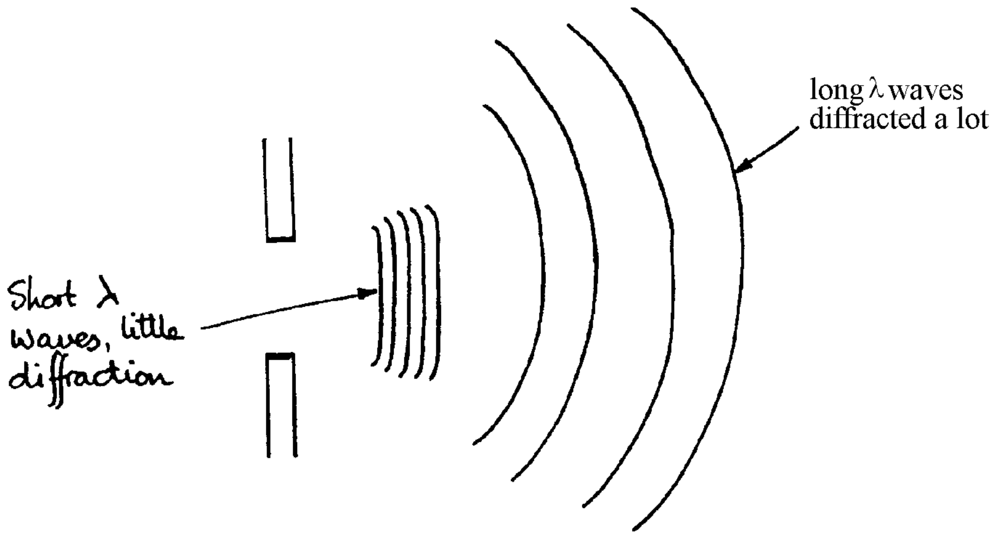
(c) (i) **Moving in curved path means added sideways component of force/accelerating centripetally (1)**
and more/extra force/tow rope pull is required for this (1)

(2 marks)

(ii) **The only vertical force on her is her weight/gravity (1)**
(not "no vertical reaction")
(so) she accelerates vertically at 9.8 m s^{-2}/g /in free fall (1)

(2 marks)

(d)



Word "diffraction" in text or on diagram (1)

Long λ further on than short λ (1)

Gap (2 m) and waves reasonable scale (1)

Short λ shown with little diffraction (1)

Long λ shown with lots of diffraction (1)

(4 marks)
[Total 16 marks]

14. With the aid of an example, explain the statement "The magnitude of a physical quantity is written as the product of a number and a unit".

Both number and unit identified in an example (1)

followed by the idea of multiplication (1)

(2 marks)

Explain why an equation must be homogeneous with respect to the units if it is to be correct.

If the units on one side differ from those on the other, then the two sides of the equation relate to different kinds of physical quantity. They cannot be equal [or similar positive statements] (1)

(1 mark)

Write down an equation which is homogeneous, but still incorrect.

Any incorrect but homogeneous algebraic or word equation :
$2mgh = ½mv^2$, 2 kg = 3 kg, pressure =stress/strain (2 or 0)

(2 marks)
[Total 5 marks]

15. A satellite orbits the Earth once every 120 minutes. Calculate the satellite's angular speed.

Correct substitution into angle/time (1)

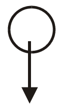
Answer with correct unit (1)

r.p.m. etc. not allowed

Angular speed = **e.g. 0.052 rad min^{-1} 180°h^{-1}**

(2 marks)

Draw a free-body force diagram for the satellite.



(1 mark)

(If the Earth is shown, then the direction must be correct)

The satellite is in a state of free fall. What is meant by the term *free fall?* How can the height of the satellite stay constant if the satellite is in free fall?

Free fall – when gravitational force is the <u>only</u> force acting on an object (1)

Height – (1) for each clear and relevant physics statement (1) + (1)

(3 marks)
[Total 6 marks]

16. A student was studying the motion of a simple pendulum the time period of which was given by $T = 2\pi\ (l/g)^{½}$.

He measured T for values of l given by

$$l/m = 0.10, 0.40, 0.70, 0.70, 1.00$$

and plotted a graph of T against $\sqrt{l}$ in order to deduce a value for g, the free-fall acceleration. Explain why these values for l are poorly chosen.

An inadequacy PLUS a reason why (many possibilities) e.g. some values too short to produce accurate T values; when the values are square rooted; spacing is unsatisfactory. (1)

(1 mark)

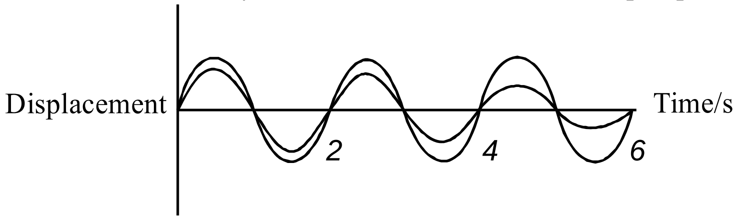
How would the student obtain a value of g from the gradient of the graph?

Gradient = $\frac{2\pi}{\sqrt{g}}$ **(1)**

Hence *g* = $\frac{4\pi^2}{(gradient)^2}$ **(1)**

(2 marks)

The graph below shows three cycles of oscillation for an undamped pendulum of length 1.00 m.



Add magnitudes to the time axis and on the same axes show three cycles for the same pendulum when its motion is lightly air damped.

T = 2 s (1)

$T_{damped} = T_{original}$ (1)

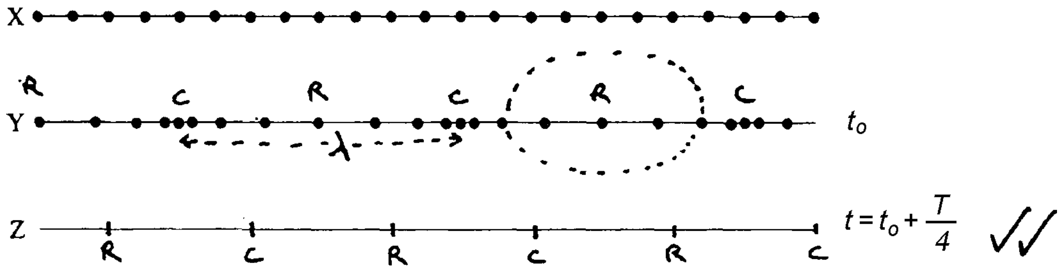
Amplitude reduced (1)

Continuous reduction in amplitude (1)

(4 marks)
[Total 7 marks]

17. Sound travels by means of longitudinal waves in air and solids. A progressive sound wave of wavelength λ and frequency f passes through a solid from left to right. The diagram X below represents the equilibrium position of a line of atoms in the solid.

Diagram Y represents the positions of the same atoms at a time $t = t_0$



Explain why the wave is longitudinal.

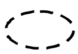
Vibrations/Oscillations of atoms is ↔ and wave / energy travels → (1)

/ along direction of / parallel to / equivalent

(1 mark)

On diagram Y label

(i) two compressions (C),
Any two C's within / . . . / (1)

(ii) two rarefactions (R),
Any two R's anywhere inside  **(1)**

(iii) the wavelength λ of the wave.
Any correct place (1)

(3 marks)

The period of the wave is T. Give a relationship between λ, T and the speed of the wave in the solid.

Speed/symbol = $\frac{\lambda}{T}$ **or υT = λ or T =** $\frac{\lambda}{\upsilon}$ **(1)**

(1 mark)

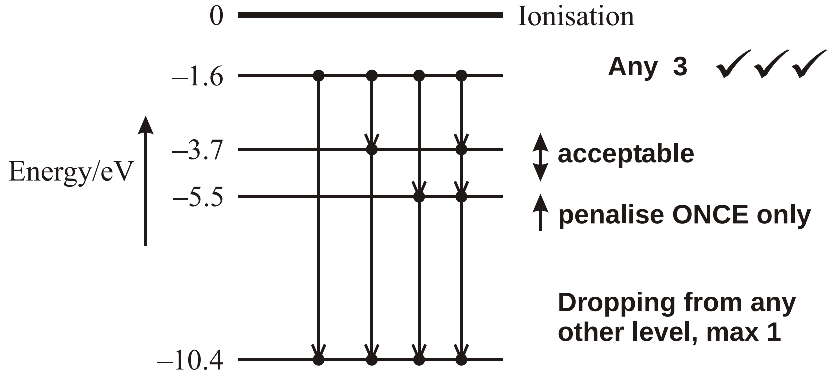
Along the line Z mark in the positions of the two compressions and the two rare factions at a time t given by $t = t_0 + T/4$.

1st Mark: 2 C's or 2 clusters moved ¼ <u>their</u> λ

2nd mark: To the right

(2 marks)
[Total 7 marks]

18. The diagram shows some of the outer energy levels of the mercury atom.



Calculate the ionisation energy in joules for an electron in the -10.4 eV level.

any use of 1.6 × 10^{-19} (1)

Ionisation energy = **1.66/1.7 × 10^{-18} (J) (1)**
[-1.66 × 10^{-18} → (1 only)]

Any other unit : unit penalty

(2 marks)

An electron has been excited to the –1.6 eV energy level. Show on the diagram all the possible ways it can return to the –10.4 eV level.

(3 marks)

Which change in energy levels will give rise to a yellowish line (λ = 600 nm) in the mercury spectrum?

Substitution in $\frac{hc}{\lambda}$ $\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{600 \times 10^{-9}}$ **(1)**

÷ 1.6 × 10^{-19} (1)

= 2.07 (2 – 2.1) (eV) (1)

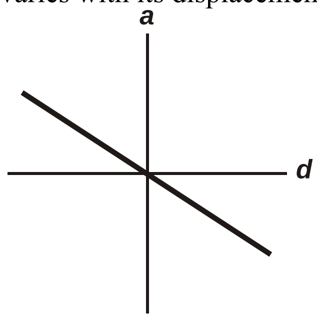
Level change -1.6 to -3.7 (1)

[Insist on '-' sign AND on higher → lower level, i.e. NOT -3.7 to -1.6]

Whole thing done backwards ⇒ 591 nm, can get 4/4

(4 marks)
[Total 9 marks]

19. A body oscillates with simple harmonic motion. On the axes below sketch a graph to show how the acceleration of the body varies with its displacement.



Straight line through origin (1)

Negative gradient (1)

(2 marks)

How could the graph be used to determine *T*, the period of oscillation of the body?

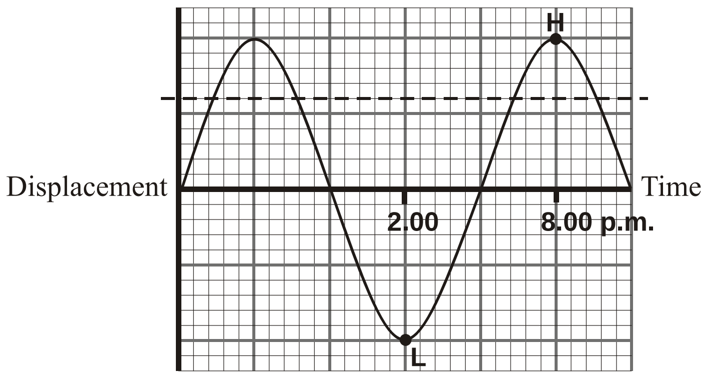
Reference to gradient of line (1)

Gradient = (-) ω^2 <u>or</u> = (-)$(2\pi f)^2$

<u>OR</u> T = $\frac{2\pi}{\sqrt{(-)gradient}}$ **(1)**

(2 marks)

A displacement-time graph from simple harmonic motion is drawn below.



(i) H and L ✓

(ii) – – – – – – – – – ✓

(iii) 2.00 and 8.00 p.m. ✓

The movement of tides can be regarded as simple harmonic, with a period of approximately 12 hours.

On a uniformly sloping beach, the distance along the sand between the high water mark and the low water mark is 50 m. A family builds a sand castle 10 m below the high water mark while the tide is on its way out. Low tide is at 2.00 p.m.

On the graph

(i) label points L and H, showing the displacements at low tide and next high tide,

(ii) draw a line parallel to the time axis showing the location of the sand castle,

(iii) add the times of low and high tide.

(3 marks)

Calculate the time at which the rising tide reaches the sand castle.

Use of $x = x \sin \omega t$

15 = 25 sin ωt

$\omega = \frac{\pi}{6}$ or ωt = 37° / t = 1.23 hours

Time = 6.14 p.m. ANY THREE LINES (3)

Full error carried forward from wrong diagram

Alternative using graph:

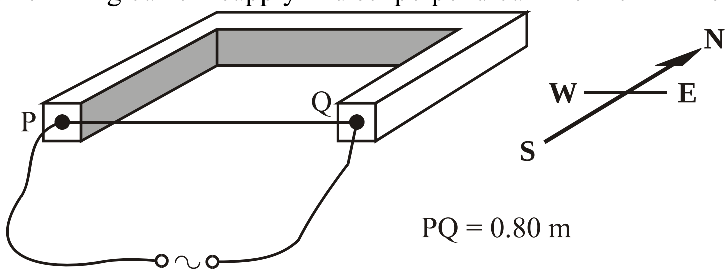
Identify coordinates (1)

Convert to time (1)

Add to reference time (1)

(3 marks)
[Total 10 marks]

20. A thin copper wire PQ, 0.80 m long, is fixed at its ends. It is connected as shown to a variable frequency alternating current supply and set perpendicular to the Earth's magnetic field.



(a) When there is a current from P to Q the wire experiences a force. Draw a diagram showing the resultant magnetic field lines near the wire as viewed from the West. (You should represent the wire PQ as ⊗.)

Explain what is meant by a neutral point.

Circular field round wire (1)

Clockwise (1)

Catapult field (1)

Neutral point: two fields cancel/resultant field zero (1)

(4 marks)

(b) The wire PQ experiences a maximum force of 0.10×10^{-3} N at a place where the Earth's magnetic field is 50×10^{-6} T. Calculate the maximum value of the current and its r.m.s. value.

$F = BIl \Rightarrow I = F/Bl$ (1)

$\Rightarrow I = 2.5$ A (2)

$\therefore I_{rms} = I/\sqrt{2} = 1.77$ A (1)

(4 marks)

(c) A strong U-shaped (horseshoe) magnet is now placed so that the mid-point of the wire PQ lies between its poles. The frequency of the a.c. supply is varied from a low value up to 50 Hz, keeping the current constant in amplitude. The wire PQ is seen to vibrate slightly at all frequencies and to vibrate violently at 40 Hz.

(i) Explain carefully why the wire vibrates and why the amplitude of the vibrations varies as the frequency changes.

Magnetic force/BIl varies (1)

forcing wire to vibrate (1)

At the natural frequency (1)

the amplitude is high/there is resonance (1)

(Max 3 marks)

(ii) Calculate the speed of transverse mechanical waves along the wire PQ.

$PQ = \lambda/2 \Rightarrow \lambda = 1.60$ m (1)

Use of $c = f\lambda$ (1)

$\Rightarrow c = 64$ m/s (1)

(3 marks)

(iii) Describe the effect on the wire of gradually increasing the frequency of the a.c. supply up to 150 Hz.

Wire vibrates slightly at all frequencies (1)

Resonance/max amplitude at 120 Hz/at 80 Hz and at 120 Hz (1)

(2 marks)
[Total 16 marks]

21. A stone on a string is whirled in a vertical circle of radius 80 cm at a constant angular speed of 16 radians per second.

Calculate the speed of the stone along its circular path.

Speed = angular speed × radius (1)

= (16 radians per second) × (0.8 metre)

Speed = 12.8 m s^{-1} (1)

(2 marks)

Calculate its centripetal acceleration when the string is horizontal.

centripetal acceleration (1)

$= \omega^2 r = (16 \text{ rad s}^{-1})^2 (0.80\text{m})$

Acceleration = 205 m s^{-2} (1)

(2 marks)

Calculate the resultant acceleration of the stone at the same point.

Why resultant acceleration = centripetal acceleration (1)

= $\omega^2 r$ = (16 rad s^{-1})^2 (0.80m) (1)

Resultant acceleration =205 m s^{-2} (1)

(3 marks)

Explain why the string is most likely to break when the stone is nearest the ground.

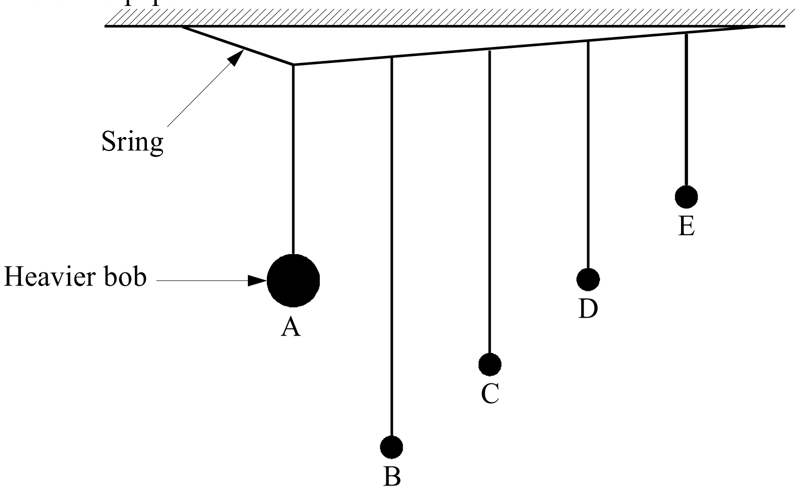
The tension in the string has its maximum value when the stone is nearest the ground (1)

because it equals centripetal force + weight (1)

(mass times centripetal acceleration)

(2 marks)
[Total 9 marks]

22. The diagram shows five pendulums, all suspended from the same string. Pendulum A is displaced by a few centimetres and then released so that it oscillates in a direction perpendicular to the plane of the paper.



By completing the table below, describe the motion of the pendulums over the next few minutes.

	Frequency compared to frequency of A	**Amplitude**
A	Constant	**Decreases** ✓
B	**Same**	**Small (less than A)** ✓
C	**Same**	**Small (less than A)**
D	**Same**	**Largest of B, C, D, E, then decreases** ✓
E	**Same**	**Small (less than A)** ✓

✓

(5 marks)

State what is meant by the term *resonance*. How is resonance demonstrated by this experiment?

A general description or a particular example of a system involving a "driver" and a "driven" oscillator:

When the frequency of the driver matches the natural frequency of the other oscillator. (1)

The driven oscillator vibrates with a large amplitude (1)

D and A have the same length or frequency (so D responds) (1)

(3 marks)
[Total 8 marks]

23. (a) A radio source of frequency 95 MHz is set up in front of a metal plate. The distance from the plate is adjusted until a standing wave is produced in the space between them. The distance between any node and an adjacent antinode is found to be 0.8 m.

Calculate the wavelength of the wave.

Wavelength = 3.2 m (1)

Calculate the speed of the radio wave.

$\upsilon = f\lambda$ (1)

Speed $=3.0 \times 10^8$ m s^{-1} (1) (1)

[3/3 for 1.6 m used to give 1.5×10^8 m s^{-1}]

What does this suggest about the nature of radiowaves?

They are electromagnetic (1)

(5 marks)

(b) The minimum intensity that can be detected by a given radio receiver is 2.2×10^{-5} W m^{-2}.

Calculate the maximum distance that the receiver can be from a 10 kW transmitter so that it is *just* able to detect the signal.

Substitute in $I = P/4\pi r^2$

10×10^3 W (1)

4, π and (2.2×10^{-5}) W m^{-2} (1)

Maximum distance = 6×10^3 m (1)

(3 marks)
[Total 8 marks]

24. Explain what is meant by the term *wave-particle duality.*

The ability of something to exhibit both wave and particle behaviour (1)

Any example, such as light behaves like a wave when it is diffracted (1)

Light behaves like particles in the photoelectric effect (1)

(3 marks)

Calculate the de Broglie wavelength of a snooker ball of mass 0.06 kg travelling at a speed of 2 m s^{-1}

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34} \text{ Js}}{0.06 \text{ kg} \times 2 \text{ m s}^{-1}}$ **for momentum substitution (1)**

Wavelength = 6 × 10^{-33} m (5.5 × 10^{-33}) (1)

(2 marks)

Comment on your answer.

Too small to detect / smaller than γ radiation (1)

(“very small” alone is NOT sufficient)

(1 mark)
[Total 6 marks]

25. (a) Explain the meaning of the following terms as used in the passage:

(i) to ground (paragraph 1),
To the Earth’s surface (1)

(ii) leakage current (paragraph 3),
Current produced by fair weather field (1)
Current in opposite/reverse direction to lightning (1)

(iii) horizontally polarised (paragraph 5).
Waves oscillating in one plane (1)
B or E-field horizontal (1)

(5 marks)

(b) What is the electric field strength at the Earth's surface?
100 V m^{-1} OR **100 N C^{-1} (1)**

Calculate the average electric field strength between the Earth's surface and the conducting ionospheric layer.

$E_{av} = \frac{300 \times 10^3 \text{ V}}{60 \times 10^3 \text{ m}} = 5 \text{ V m}^{-1}$ **(2)**

(3 marks)

Sketch a graph to show the variation of the Earth's fair-weather electric field with distance above the Earth's surface to a height of 60 km.

Graph:

Axes *E* in V m^{-1} and *h* in km (1)
Scales marked N.B. Error carried forward 100 V m^{-1} (1)
Sloping line (1)
Getting less steep with *h* (1)
Passing through 60,5 or 0,100 (1)

(Max 4 marks)

(c) The power associated with a lightning stroke is extremely large. Explain why *there is no scope for tapping into thunderstorms as an energy' source* (paragraph 3).

Idea of storms spread out in space (1)
Low average current per storm e.g. only 1 A (1)
Idea of storms spread out in time (1)
Strike lasts for a very short time (1)

(Max 3 marks)

(d) Show that a total charge of 5 × 10⁵ C spread uniformly over the Earth will produce an electric field of just over 100 V m⁻¹ at the Earth's surface. Take the radius of the Earth to be 6400 km.

$$E = \frac{1}{4\pi \in_o} \frac{Q}{r^2} \quad OR \quad k\frac{Q}{r^2}$$ **(1)**

$$= \frac{1}{4\pi(8.9\times10^{-12}\ \text{F m}^{-1})} \times \frac{5\times10^{5}\ \text{C}}{(6.4\times10^{6}\ \text{m})^{2}}$$ **(1)**

= 109 V m⁻¹ [Accept 110] [No unit required] (1)

(3 marks)

Draw a diagram to show the direction of this fair-weather field.

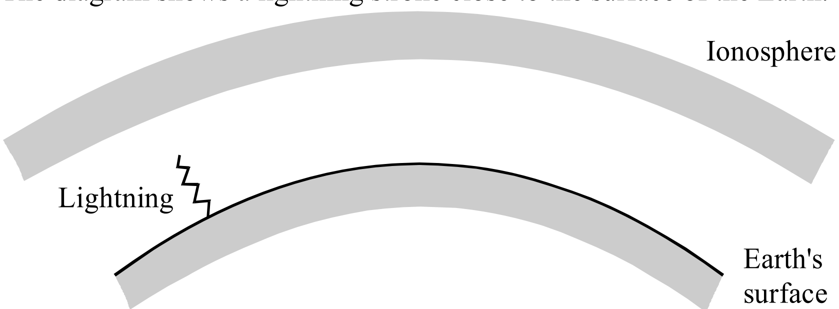
Uniformly spaced radial lines (1)
with downward arrows (1)

Suggest a problem which might arise if the charge on the Earth were very much larger.

More thunderstorms/lightning strikes
or could upset electrical/electronic equipment (1)

(3 marks)

(e) The diagram shows a lightning stroke close to the surface of the Earth.



Copy the diagram and add rays to it to illustrate the propagation of radio waves in the VLF band.

Straight lines (1)
Reflecting (1)
> 1 bounce (1)

On a second copy of the diagram add wavefronts to illustrate the propagation of radio waves in the ELF band.

Equally spaced wavefronts (1)
to Earth's surface (1)
Curved/diffracting (1)

Explain with the aid of a diagram the meaning of the term *radio horizon* used in paragraph 4 with reference to VHF radio waves.

Waves/ray from above
Earth's surface ⇒ horizon idea (1)
[No diagram, no credit]

(7 marks)

(f) List the frequency ranges of VHF, VLF and ELF radio waves.

VHF 30 – 300 MHZ
VLF 10 – 16 kHz
ELF About 1 kHz All correct (1)

Calculate the wavelength of

(i) a typical VHF signal,

$\lambda = c/f$ **(1)**

$$\lambda = \frac{3 \times 10^8 \text{ m s}^{-1}}{30 \text{ to } 300 \times 10^6 \text{ Hz}} \quad \textbf{(1)}$$

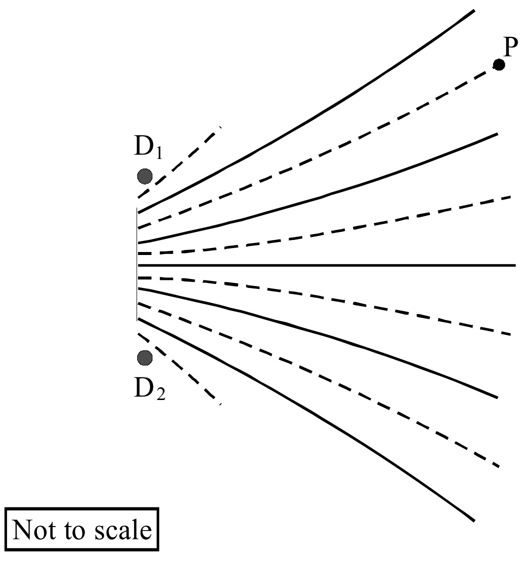
= 10 m to 1 m (1)

(ii) an ELF signal.

Same calculation, cao 3×10^5 m (1)

(Max 4 marks)
[Total 32 marks]

26. (a) The diagram represents an interference pattern produced on the surface of water in a ripple tank when two dippers D_1 and D_2 are vibrating in phase. The full lines indicate regions of maximum disturbance, the dashed lines regions where the water surface is undisturbed.



(i) Explain how waves from D_1 and D_2 can produce zero displacement at P at all times.

Waves arrive at P in antiphase / out of phase (1)

So destructive interference / waves cancel at P (1)

(2 marks)

(ii) The wavelength of the ripples is 3.0 cm. If the distance from P to D is 46.5 cm, what is the distance from P to D_2? Give your reasoning.

$D_2P - D_1P = 1\frac{1}{2}\lambda$ / P is second minimum (1)

$\therefore D_2P$ = 4.5 cm + 46.5 cm (1)

= 51 cm (1)

(3 marks)

(iii) A student says that a stationary wave pattern exists along the line joining D_1 and D_2. Explain what is meant by a stationary wave pattern. Deduce the separation of the dippers.

Stationary wave does not transfer energy/ is formed by a wave and its reflection (1)

Mention of node or antinode (1)

N – N OR A – A = $\lambda/2$ (1)

Here D_1D_2 = 6 or 5½ half to wavelengths (1)

Here D_1D_2 = 9.0 cm/8.25 cm (1)

(Max 4 marks)

(b) The dippers are driven up and down at 50 Hz using short solenoids connected to a low voltage a.c. supply. The dipper itself is a short magnet supported by a copper spring.

(i) Describe the type of motion followed by the dipper. Explain how it is forced to move in this way.

Dipper moves with s.h.m. (1)

at 50 Hz/supply frequency (1)

Magnetic field of solenoid (1)

Alternates/changes (1)

So magnet attracted/repelled OR pushed up and down (1)

(Max 4 marks)

(ii) The amplitude of the dipper's motion is 0.75 mm. Calculate the maximum speed of the dipper.

$v_{max} = 2\pi f x_{max}$ / ωx_{max} (1)

= 2π(50 Hz) (0.75 × 10^{-3} m) (1)

= 0.24 m s^{-1} (1)

(3 marks)
[Total 16 marks]

27. For each of the four concepts listed in the left hand column, place a tick by the correct example of that concept in the appropriate box.

A base quantity	mole	☐	length	✓	kilogram	☐
A base unit	coulomb	☐	ampere	✓	volt	☐
A scalar quantity	torque	☐	velocity	☐	kinetic energy	✓
A vector quantity	mass	☐	weight	✓	density	☐

[Total 4 marks]

28. State the period of the Earth about the Sun.

1 year (1)

Use this value to calculate the angular speed of the Earth about the Sun in rad s^{-1}.

Angular speed $= \frac{2\pi}{T} = \frac{2\pi}{365 \times 24 \times 60 \times 60s}$

$= \mathbf{1.99 \times 10^{-7}}$ **rad** $\mathbf{s^{-1}}$ **(1)**

(2 marks)

The mass of the Earth is 5.98×10^{24} kg and its average disatance from the Sun is 1.50×10^{11} m. Calculate the centripetal force acting on the Earth.

Centripetal force $= m\omega^2 r$

$= (5.98 \times 10^{24}\ \text{kg})(1.99 \times 10^{-7}\ \text{rad s}^{-1})(1.50 \times 10^{11}\ \text{m})$ **(1)**

$= 3.55 \times 10^{22}$ **N (1)**

(2 marks)

What provides this centripetal force?

The gravitational field of the sun.

(1 mark)

[Total 5 marks]

29. What is meant by *simple harmonic motion?*

Oscillatory motion where acceleration / force is proportional to displacement but in the opposite direction. (2)

[Formula with symbols defined is accepted.]

(2 marks)

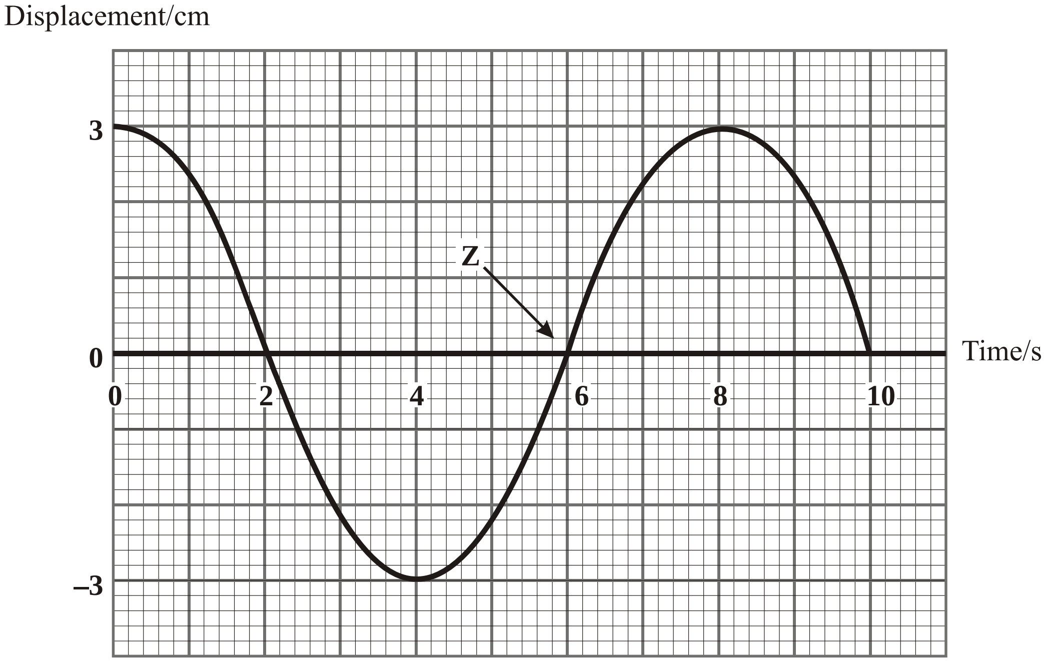
Calculate the length of a simple pendulum with a period of 2.0 s.

Substitution of 2.0 s and 9.8 ms^{-2} **in valid equation. (1)**

Length = 0.99 m (1)

(2 marks)

The graph shows the variation of displacement with time for a particle moving with simple harmonic motion.



What is the amplitude of the oscillation?

3.0 cm (1)

(1 mark)

Estimate the speed of the particle at the point labelled Z.

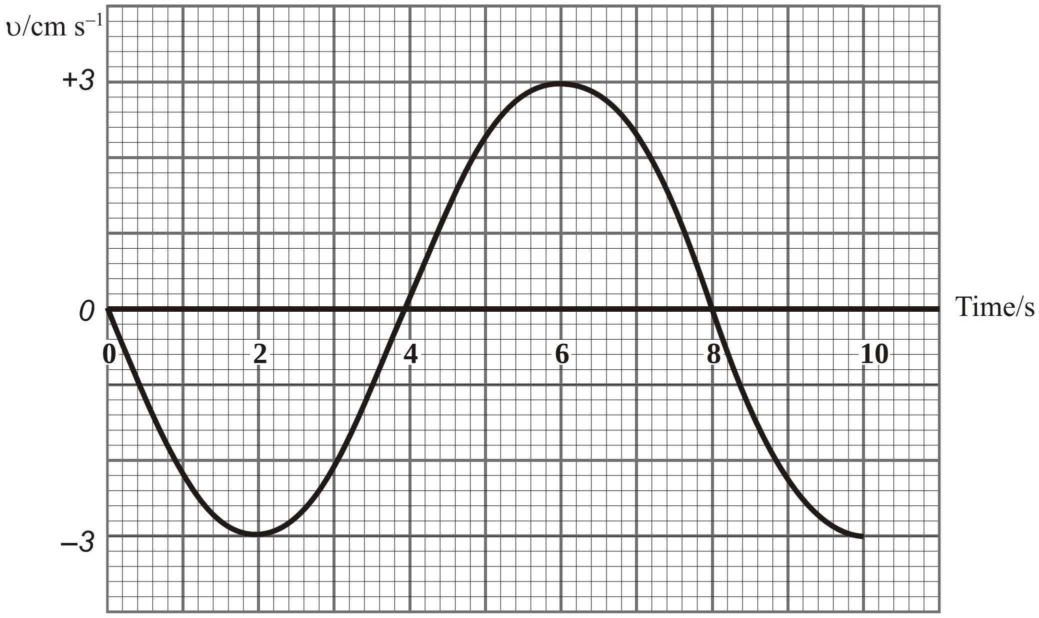
Attempt to find gradient at Z

OR use of $v = \omega \times 3.0$ cm (1)

Speed = 2.5 cm s^{-1} (2.35 → 2.7) (1)

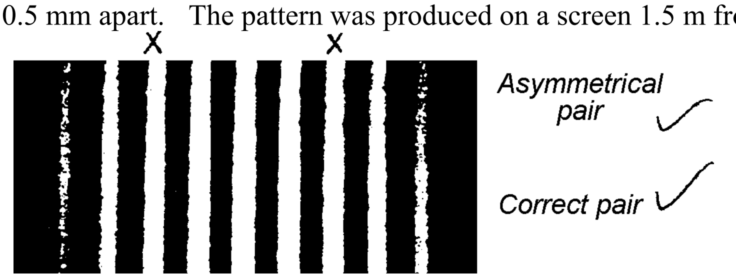
(2 marks)

Draw on the axes below a graph of the variation of velocity v with time for this particle over the same period of time. Add a scale to the velocity axis.



(2 marks)
[Total 9 marks]

30. The photograph shows the interference pattern produced when monochromatic light falls on a pair of slits 0.5 mm apart. The pattern was produced on a screen 1.5 m from the slits.



(2)

The photograph has been magnified by a factor of ×3. Use the photograph to obtain a value for the fringe spacing.

Measure across more than one fringe and divide by 3. (1)

0.2 cm (1)

(2 marks)

Calculate the wavelength of the light used.

Consistent substitutions in $\lambda = \frac{xs}{D}$ **(1)**

Wavelength = 700 nm (1)

(2 marks)

Mark with an X on the photograph the fringe or fringes where light from one slit has travelled a distance of two wavelengths further than the light from the other slit.

Explain why the fringes near the centre of the photograph are clearer than those near the edges of the photograph.

The double slit pattern is modified by the single slit diffraction pattern. (2)

[Other discussions were eligible for credit – see Examiners' Report.]

(4 marks)

In the space below sketch the pattern which would be obtained on the screen if one of the slits were covered up. Label the bright and the dark regions.
(An accurate scale diagram is **not** expected.)

Central bright fringe with narrower side fringes. (1)

Central fringe approximately double width, side fringes approximately equal. (1)

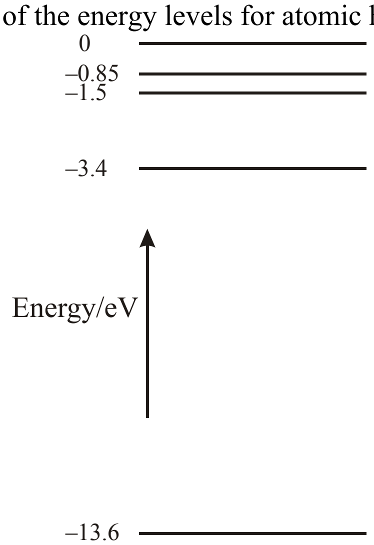
(2 marks)

What additional measurement would you need in order to draw an accurate diagram for this case?

Slit width (1)

(1 mark)
[Total 11 marks]

31. The diagram shows some of the energy levels for atomic hydrogen.



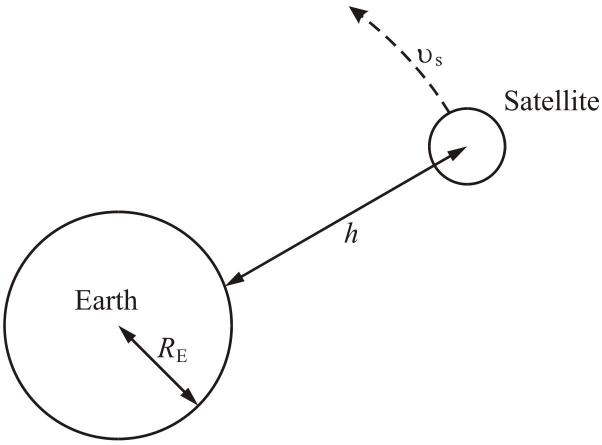
For each of the statements below, indicate whether the statement is true (√) or false (x)

Statement	True/False
The single electron of a hydrogen atom normally occupies the –13.6 eV energy level.	√
An electron of energy 10 eV colliding with a hydrogen atom in its ground state could have an energy of 0.2 eV after the collision.	x
An electron moving from the –3.4 eV to the –0.85 eV level gives out a photon of energy 2.55 eV.	x
Light of wavelength 650 nm has sufficient energy to excite an electron from the –3.4 eV to the –1.5 eV energy level.	√

Use this space for any calculations.

(4 marks)
[Total 4 marks]

32. The diagram (not to scale) shows a satellite of mass *m*, in circular orbit at speed v_s around the Earth, *mass* M_E. The satellite is at a height *h* above the Earth's surface and the radius of the Earth is R_E.



Using the symbols above write down an expression for the centripetal force needed to maintain the satellite in this orbit.

$F = \frac{m_s v_s^2}{R_E + h}$ **(2)**

(2 marks)

Write down an expression for the gravitational field strength in the region of the satellite.

$g = \frac{GM_E}{(R_E + h)^2}$ **(2)**

State an appropriate unit for this quantity.

N kg $^{-1}$ (1)

(3 marks)

Use your two expressions to show that the greater the height of the satellite above the Earth, the smaller will be its orbital speed.

$$\frac{m_s v_s^2}{R_E + h} = \frac{GM_E m_s}{(R_E + h)^2}$$ **(1)**

$v_s^2 = \frac{GM_E}{R_E + h}$ **(1)**

Greater *h* Þ smaller v_s since *G*, M_E constant (1)

(3 marks)

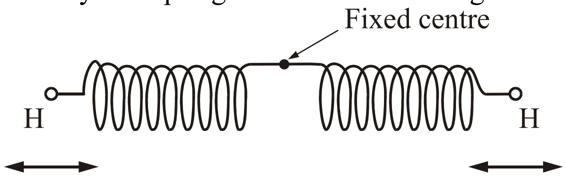
Explain why, if a satellite slows down in its orbit, it nevertheless gradually spirals in towards the Earth's surface.

As it slows $\frac{GM_E m_s}{(R_E + h)^2} > \frac{m_s v_s^2}{R_E + h}$ **(1)**

The "spare" gravitational force not needed to provide the centripetal acceleration pulls the satellite nearer to the Earth (1)

(2 marks)
[Total 10 marks]

33. One simple model of the hydrogen molecule assumes that it is composed of two oscillating hydrogen atoms joined by two springs as shown in the diagram.



If the spring constant of each spring is 1.13×10^3 N m^{-1} and the mass of a hydrogen atom is 1.67×10^{-27} kg, show that the frequency of oscillation of a hydrogen atom is 1.31×10^{14} Hz.

$$T = 2\pi\sqrt{m/k} \quad = \quad 2\pi\sqrt{\frac{1.67\times10^{27}\,\text{kg}}{1.13\times10^{3}\,\text{N m}^{-1}}} \quad = 7.6 \times 10^{-15}\text{ s} \qquad \textbf{(1)}$$

$$f = \frac{1}{T} = \frac{1}{7.6\times10^{-15}\text{ s}} = 1.31 \times 10^{14}\text{ Hz} \qquad \textbf{(1)}$$

(2 marks)

Using this spring model, discuss why light of wavelength 2.29×10^{-6} m would be strongly absorbed by the hydrogen molecule.

$c = f\lambda$ **(1)**

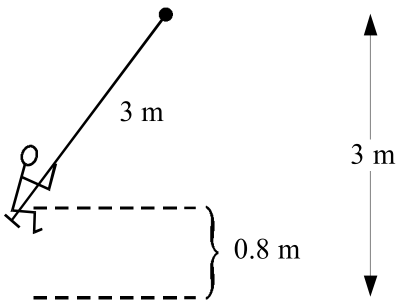
$$f = \frac{3.00 \times 10^{8}\,ms^{-1}}{2.29 \times 10^{-6}\,m} = 1.31 \times 10^{14}\text{ Hz} \qquad \textbf{(1)}$$

This frequency is the same as the hydrogen atom frequency in the model (1)

hence resonance occurs and strong absorption. (1)

(4 marks)
[Total 6 marks]

34. A child of mass 21 kg sits on a swing of length 3.0 m and swings through a vertical height of 0.80 m.



Calculate the speed of the child at a moment when the child is moving through the lowest position.

Speed = $\sqrt{2gh}$

$= \sqrt{2\times(9.81\text{ms}^{-2})(0.8\text{m})}$ **(1)**

Speed = **4.0 ms^{-1} (1)**

(2 marks)

Calculate the force exerted on the child by the seat of the swing at a moment when the child is moving through the lowest position.

mv^2/r = 110 N

mg = 206 N

∴ force = 316 N

(3 marks)

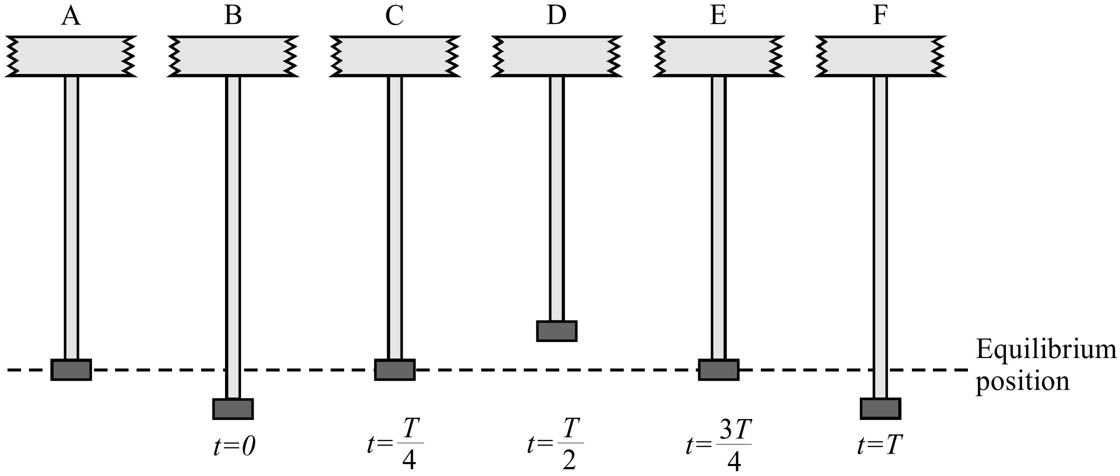
Explain why, as the amplitude of the motion increases, children may lose touch with the seat of the swing.

When the chain of the swing is horizontal, the weight of the child acts downwards (1)

centripetal force is zero (1)

(2 marks)
[Total 7 marks]

35. Diagram A shows a mass suspended by an elastic cord. The mass is pulled downwards by a small amount and then released so that it performs simple harmonic oscillations of period T. Diagrams B–F show the positions of the mass at various times during a single oscillation.



Complete the table below to describe the displacement, acceleration and velocity of the mass at the stages B–F, selecting appropriate symbols from the following list:

maximum and positive → +

maximum and negative → –

zero → 0

Use the convention that *downward* displacements, accelerations and velocities are positive.

	B	C	D	E	F
Displacement	+	0	–	0	+
Acceleration	–	0	+	0	–
Velocity	0	–	0	+	0

Wrong convention Max 3/

(4 marks)

In the sport of bungee jumping, one end of an elastic rope is attached to bridge and the other end to a person. The person then jumps from the bridge and performs simple harmonic oscillations on the end of the rope.

People are bungee jumping from a bridge 50 m above a river. A jumper has a mass of 80 kg and is using an elastic rope of unstretched length 30 m. On the first fall the rope stretches so that at the bottom of the fall the jumper is just a few millimetres above the water.

Calculate the decrease in gravitational potential energy of the bungee jumper on the first fall.

Use of mgh (1)

Change in g.p.e. = 40 kJ (1)

(2 marks)

What has happened to this energy?

Converted to elastic potential energy (1)

(1 mark marks)

Calculate the force constant *k*, the force required to stretch the elastic rope by 1 m.

Use of stored energy ½*kx*² OR ½F*x* (1)

Correct Substitutions (1)

Force constant *k* = 200 N or Nm^{-1} (1)

(3 marks)

Hence calculate *T*, the period of oscillation of the bungee jumper.

$$T = 2\pi\sqrt{\frac{80}{200}} \text{ OR } 2\pi\sqrt{\frac{80}{\text{Their } k}} \quad (1)$$

Period *T* = 4 s (error carried forward) (1)

(2 marks)
[Total 12 marks]

36. (a) A student is given a ripple tank in which plane waves can be generated.

Outline how the student could measure the wave speed *v*, the frequency *f* and the wavelength λ of the waves.

<u>Measurement of *f*</u>

Use of strobe OR Connect oscillator to cro (1)

Vibrator appears stationary Reference to use of time base (1)

<u>Measurement of λ</u>

Measurement across several peaks (1)

and average (1)

<u>Measurement of *v*</u>

Time at least 3 times a wave across tank (1)

Use of $v = \frac{\text{distance across tank}}{\text{time}}$ **(1)**

(6 marks)

(b) The speed v of ocean waves in deep water is given by the relationship

$$\upsilon = \sqrt{\frac{g\lambda}{2\pi}}$$

where g is the acceleration of free fall and λ is the wavelength of the waves.

Derive an expression for T, the period of the waves, in terms of g and λ.

$v = f\lambda$ (1)

$f = \sqrt{\frac{s\lambda}{2\pi}}\Big/\lambda$ (1)

$T = \sqrt{\frac{2\pi\lambda}{g}}$ (1)

(3 marks)

Calculate the value of T when the wavelength of the waves is 8.0 m.

$T =$ **2.3 s (1)**

(1 mark marks)
[Total 10 marks]

37. Explain the term *plane polarised wave.*

A transverse wave (1)

which is restricted to vibrate in one plane only (1)

OR description of plane for 2nd mark

(2 marks)

Describe an experiment using light or microwaves which tests whether or not the waves are plane polarised.

LIGHT

* Light | Polaroid | + Detector

Rotate polaroid
Goes completely dark

MICROWAVE

* μ Wave ≡ Bars + Detector

Rotate bars – detector falls to zero
[If no bars; if detector / source is rotated by 90^0, zero reading occurs] (1)

(2 marks)

For each of the statements below, indicate whether the statement is true (√) or false (**x**).

Statement	True/False	
The speed of sound in air is less than the speed of sound in water.	✓	**(1)**
Since sound waves are longitudinal they cannot be diffracted.	✗	**(1)**
Sound waves transmit pressure but not energy.	✗	**(1)**
A sound wave of frequency 436Hz travelling at 331 m s^{-1} has a wavelength of 75 cm ± 1 cm.	✓	**(1)**

(4 marks)
[Total 8 marks]

38. Experiments on the photoelectric effect show that

- the kinetic energy of photoelectrons released depends upon the frequency of the incident light and not on its intensity,
- light below a certain threshold frequency cannot release photoelectrons.

How do these conclusions support a particle theory but not a wave theory of light?

Particle theory: E = *hf* implied packets/photons (1)

One photon releases one electron giving it k.e. (1)

Increase f ⇒ greater k.e. electrons (1)

Lower f; finally ke = O ie no electrons released Waves (1)

Energy depends on intensity / $(amplitude)^2$ (1)

More intense light should give greater k.e–NOT SEEN (1)

More intense light gives more electrons but no change in maximum kinetic energy (1)

Waves continuous ∴ when enough are absorbed electrons should be released–NOT SEEN (1)

(6 marks)

Calculate the threshold wavelength for a metal surface which has a work function of 6.2 eV.

6.2eV × 1.6 × 10^{-19} C (1)

Use of $\lambda = \frac{hc}{E}$ **(1)**

Threshold wavelength = **2.0 × 10^{-7} m (1)**

To which part of the electromagnetic spectrum does this wavelength belong?

UV ecf their λ (1)

(4 marks)
[Total 10 marks]

39. (a) (i) Mention of reflection **(1)**
Mention of path difference **(1)**
Mention of phase difference/discussion of interference **(1)**
EITHER
In phase = high anti/out of phase = low
OR
Path difference = $n\lambda \Rightarrow$ high path difference = $(n + ½)\,\lambda \Rightarrow$ low **(1)**

(4 marks)

(ii) $140 \text{ mm} = 10 \times \frac{\lambda}{2}$ **(1)**

$\Rightarrow \lambda = 28 \text{ mm}$ **(1)**

(2 marks)

(iii) Measure v: use of ruler and stopclock/watch/ light gates/displacement sensor/ticker timer **(1)**
description of how system works **(1)**
calculate $v = s/t$ **(1)**

Errors: parallax error in length/stop/start human error/ odd reflections/dot error **(1)**
quantitative comment e.g. ± % **(1)**

(5 marks)

(b) (i) Difficulty: any mention of splitting/half a photon/ adding particles cannot give zero **(1)**

(ii) $E = hf = h\frac{c}{\lambda}$ **(1)**

$(6.6 \times 10^{-34} \text{ J s})(3.0 \times 10^{8} \text{ m s}^{-1}) \div 0.030 \text{ m}$ **(1)**
$= 6.6 \times 10^{-24}$ J
Evidence of division by 1.6×10^{-19} **(1)**

(iii) Less/smaller than visible photon **(1)**

(5 marks)
[Total 16 marks]

40. Classify each of the terms in the left-hand column by placing a tick in the relevant box.

[Total 6 marks]

41. Complete the diagram below to show the different regions of the electromagnetic spectrum.

Radio waves	IR	Visible	Uv	X-ray	γ

(2)

(2 marks)

State *four* differences between radio waves and sound waves.

1. **Radio transverse; sound longitudinal. (1)**
2. **Travels through vacuum; requires medium. (1)**
3. **Radio travels at speed of light; sound travels much slower. (1)**
4. **Can be polarised; cannot be polarised. (1)**
5. **Radio electromagnetic; sound pressure. (1)**

(MAX 4 marks)
(4 marks)

Two radio stations broadcast at frequencies of 198 kHz and 95.8 MHz. Which station broadcasts at the longer wavelength?

198 kHz (1)

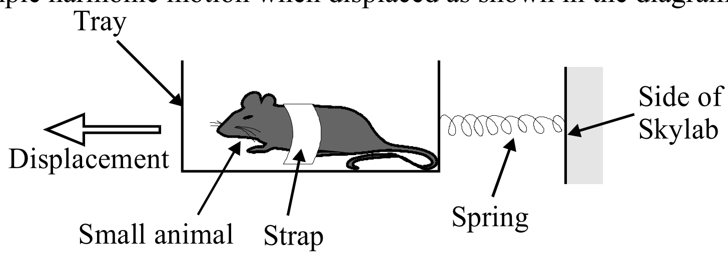
Why do obstacles such as buildings and hills present less of a problem for the reception of the signal from the station transmitting at the longer wavelength?

Longer wavelength diffracts (1)

and waves tend to go to receiver (1)

(3 marks)
[Total 9 marks]

42. The diagram shows a method for determining the mass of small animals orbiting the Earth in Skylab. The animal is securely strapped into a tray attached to the end of a spring. The tray will oscillate with simple harmonic motion when displaced as shown in the diagram and released.



Define *simple harmonic motion*.

When acceleration / force is directly proportional to displacement from a fixed point (1)

and directed towards the point (1)

(2 marks)

The tray shown above has a mass of 0.400 kg. When it contains a mass of 1.00 kg, it oscillates with a period of 1.22 s.

Calculate the spring constant *k*.

m = 1.40 kg (1)

Rearrangement of equation $T = 2\pi\sqrt{\frac{m}{K}}$ **(1)**

k **= 37.1 N m**$^{-1}$ **(1)**

(3 marks)

The 1.00 kg mass is removed and a small animal is now strapped into the tray. The new period of oscillation is 1.48 s. Calculate the mass of the animal.

$T \propto \sqrt{m}$ **(use of) (1)**

Mass = 1.66 kg (1)

(2 marks)

The Skylab astronauts suggest that the calibration experiment with the 1.00 kg mass could have been carried out on Earth before take off. If a similar experiment were conducted on Earth would the time period be greater than, less than, or equal to 1.22 s? Explain your answer.

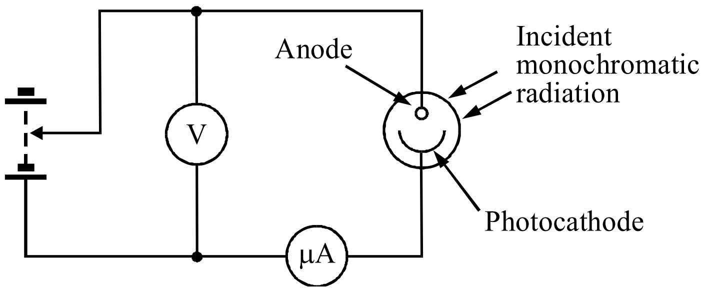
Same (1)

Mass is same everywhere in Universe (1)

k does not change from space to Earth (1)

(3 marks)
[Total 10 marks]

43. The diagram shows monochromatic light falling on a photocell.



As the reverse potential difference between the anode and cathode is increased, the current measured by the microammeter decreases. When the potential difference reaches a value V_s, called the stopping potential, the current is zero.

Explain these observations.

Photons release e⁻ at photocathode; e⁻ travel to anode making a current (1)

Photon energy > work function of photocathode (1)

OR All energy of A photon goes to an electron (1)

Electrons released with a range of kinetic energies (1)

So smaller kinetic energy electrons stopped at lower pds (1)

PD opposes kinetic energy of these electrons (1)

V_S supplies enough energy to stop electrons with kinetic energy max (1)

(MAX 5 marks)
(5 marks)

What would be the effect on the stopping potential of

(i) increasing only the intensity of the incident radiation,
No effect (1)

(ii) increasing only the frequency of the incident radiation?
Increases stopping potential (1)

(2 marks)
[Total 7 marks]

44. (a) **Either**

$E = hc/\lambda$ **(1)**

$\lambda = (6.6 \times 10^{-34}$ J s) $(3.0 \times 10^{8}$ m s$^{-1}) \div (10^{-23}$ J) **(1)**

$\approx 2 \times 10^{-2}$ m **(1)**

Or

$E = hf$ **(1)**

$f = (10^{-23}$ J) $\div (6.6 \times 10^{-34}$ J s) **(1)**

$f = 1.5 \times 10^{10}$ Hz **(1)**

Therefore P is mocrowave/radar/long infra-red **(1)**

Q is infra-red *and* R is visible **(1)**

(Max 4 marks)

(b) Experiment:

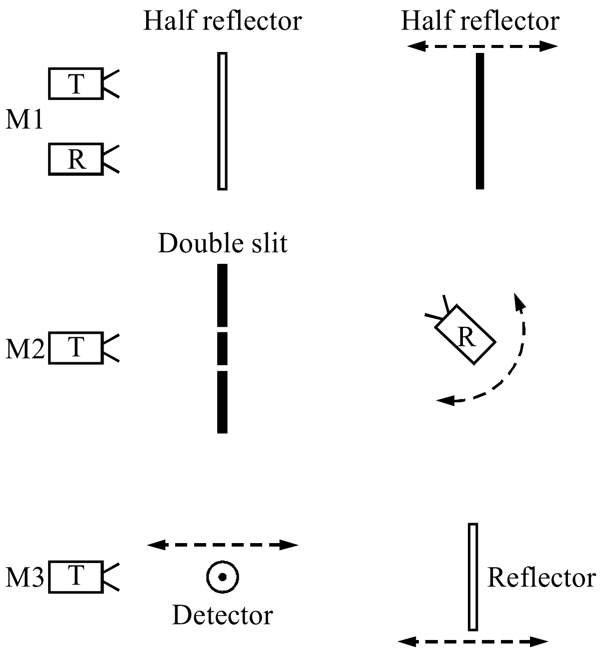


Diagram OR description **(1)**

labelled OR full description applicable **(1)**

to 20 mm electromagnetic waves **(1)**

What moves/is done **(1)**

How λ is found: **(1)**

e.g. M1 reflect moves $\lambda/2$ between max/min

e.g. M2 $S_1P - S_2P = \lambda$ at first max

e.g. M3 $\lambda/2$ between nodes **(1)**

(5 marks)

(c) (i) **Either** $\frac{R_D}{2200\ \Omega} = \frac{1.2\ \text{V}}{4.8\ \text{V}}$ **Or** $I = \frac{6.0\ \text{V} - 1.2\ \text{V}}{2200\ \Omega} = 0.0022$ A **(2)**

$\therefore R_D = 1.2$ V $\div 0.0022$ A

$R_D = 550\ \Omega$ $= 545\ \Omega$ **(1)**

Assumption $R_V \gg 550\ \Omega$ **(1)**

(4 marks)

(ii) **Either** — Put a microammetter/ sensitive ammeter in the circuit/in series; $I \approx 1\ \mu A$, $R_D \approx 1\ M\Omega$

Or — Replace 2,2 kΩ with bigger R **(1)**
of known value **(1)**
Repeat calculation **(1)**

(3 marks)
[Total 16 marks]

45. (a) Experiment:
Heat rapped gas fully immersed in water bath **(1)**
Thermometer labelled **(1)**
Pressure gauge/manometer labelled **(1)**
Precautions:
Stir before measuring/await thermal equilibrium **(1)**
Short/thin link to pressure measurer/parallax with Hg **(1)**

(5 marks)

(b) Units:
Use of Pa as N m^{-2} **(1)**
Use of J as N m **(1)**

(2 marks)

Calculation:
$p \propto T$ / $pV \div T$ = constant/ $pV = nRT$ **(1)**
Therefore $T = 640\text{ K} \times (2800\text{ kPa} \div 900\text{ kPa})$ **(1)**
= 1990 K/2000 K **(1)**
Assumption:
Mass gas/number moles/amount of gas constant **(1)**

(4 marks)

(c) $a = (2\pi f)^2 x/\omega^2 x$ **(1)**
$a_{max} = (2\pi \times \frac{8000}{60}\ s^{-1})^2\ (0.040\text{ m})$ **(1)**
$= 28000\text{ m s}^{-2}$ **(1)**

(3 marks)

Explanation:
High stress in rod/rod needs to have high strength **(1)**
Both tensile and compressive **(1)**

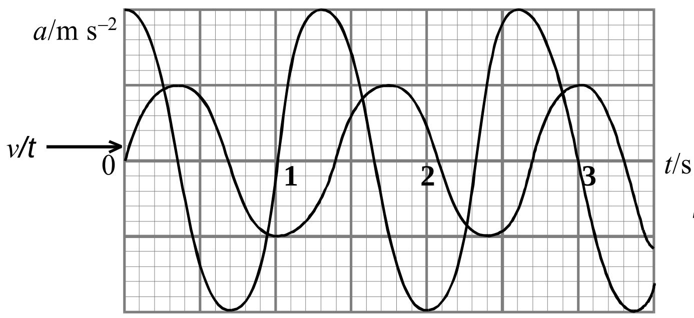
(2 marks)
[Total 16 marks]

46. The following statements apply to a body orbiting a planet at constant speed and at constant height. Indicate whether each statement is true (√) or false (**x**).

Statement	True/False
The body is travelling at constant velocity.	**x**
The body is in equilibrium because the centripetal force is equal and opposite to the weight.	**x**
The only force acting on the body is its weight.	√
The body's acceleration towards the planet equals the gravitational field strength at the position of the body.	√

(Total 4 marks)

47. A body performs simple harmonic oscillations. The graph shows how the acceleration of the body varies with time.



[if inverted, ✓ ✗]

State the frequency of the oscillations.

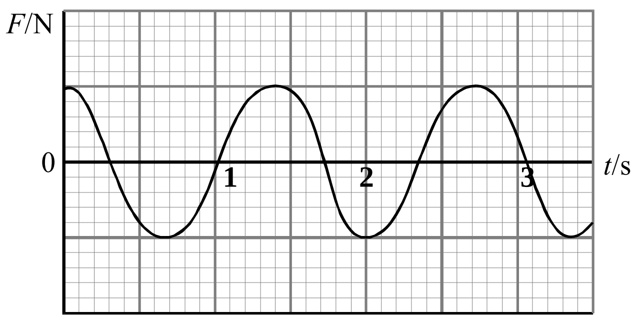
0.7 Hz → 0.8 Hz

(1 mark)

Add to the graph above a curve showing how the *velocity* of the same body varies with time over the same period.

(2 marks)

On the grid below, sketch a graph to show how the *force* acting on the same body varies with time over the same period.



[if inverted, ✓ ✗]

(2 marks)

A mass *m* attached to a spring of force constant *k* oscillates with a period of 1.2 s. Calculate the period of oscillation for a mass 2*m* attached to a spring of force constant 4*k*.

1.2 s = $2\pi\sqrt{\frac{m}{k}}$ **T = $2\pi\sqrt{\frac{2m}{4k}}$ (1)**

T = 1.2 s × $\sqrt{\frac{1}{2}}$

Period of oscillation = **0.85 s (1)**

(2 marks)
[Total 7 marks]

48. Describe an experiment using microwaves to produce and detect a two-slit interference pattern.

Microwave transmitter → obstacle → receiver (1)

2 slits between/in metal sheets (1)

Receiver connected to meter/loudspeaker / equivalent (1)

More receiver in arc / along straight line parallel to slit plane (1)

Note maxima and minima / varying intensity (1)

Labelled diagram acceptable for all marks

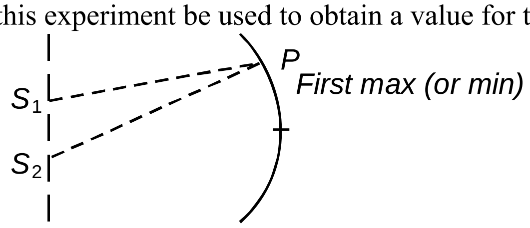
(Max 4 marks)

Suggest an appropriate slit separation for this experiment.

A value between 1 cm and 8 cm

(1 mark)

How could this experiment be used to obtain a value for the wavelength of the microwaves?



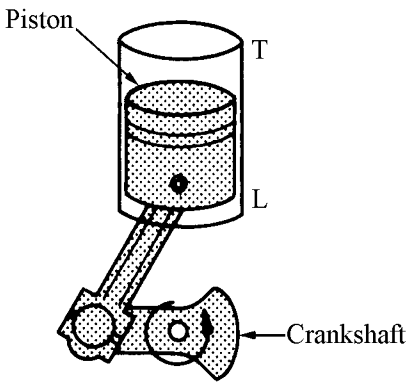
$\lambda = \frac{xs}{D}$ **terms defined (1)**

Measure S_1 P, S_2 P **Details measurement of S (1)**

S_2 P – S_1 P = λ $\left(\text{or } \frac{\lambda}{2}\right)$ **Details measurement *x* (1)**

(3 marks)
[Total 8 marks]

49. The diagram shows one piston of an internal combustion engine.



As the crankshaft rotates through 360°, the top of the piston moves from L to T and back to L. The distance LT is 8.6 cm and the crankshaft rotates at 6000 revolutions per minute.

Calculate the frequency of oscillation *f* of the piston.

f =........**100 Hz (1)**................

(1 mark)

State the amplitude of this oscillation.

4.3 cm. (1)

(1 mark)

The oscillations of the piston are approximately simple harmonic. Calculate the maximum acceleration of the piston.

Substitute in a = – (2 π *f*.)² x

Full values (ecf) above = – (2 π × 100 Hz)² × 4.3 × 10⁻²m (1)

Acceleration = 1.7 × 104 m s-2 (1)

At which position(s) in the movement of the piston will this acceleration be zero?

Halfway between T and L (1)

(3 marks)

Suggest why the motion of the piston *is not* perfectly simple harmonic.

F ≠ kx / friction between piston and cylinder/
speed of rotation not constant (1)

(1 mark)
[Total 6 marks]

50. (a) (i) Energy (per s) = NeV **(1)**

(ii) Use of $E = Pt$ **(1)**
$\Rightarrow E = (2.4\ \text{W})\ (20\ \text{s}) = 48\ \text{J}$ **(1)**
Use of $\Delta Q = mc\Delta t$ **(1)**
$\Rightarrow m = 0.77 \times 10^{-3}$ kg **(1)**

Assume:
All energy transferred to heat/no energy transferred to light **(1)**
No heat conducted away from spot/only spot heated **(1)** **7**

(b) Either

Direct electrical method:

Measure $I\upsilon t$ **(1)**
Measure $m\Delta\theta$ for suitable lump of glass **(1)**
Sketch/description of apparatus **(1)**

Or

Method of mextures:

Measure temperature of hot glass **(1)**
Measure $m_w\, c_w\, \Delta_w$ and measure $m_g\, \Delta\theta_g$ **(1)**
Sketch/description of apparatus **(1)**

Difficulty:

Glass poor conductor linked to experiment **(1)**
Difficult to prevent heat loss linked to experiment **(1)** **5**

51. Work = force × displacement **(1)**
in direction of force **(1)** **2**
[$W = F \times d$ or similar gets zero]

Explanation:
Kinetic energy of particle is constant **(1)**
Work done on particle is zero **(1)**
Distance moved by particle in direction of force is zero **(1)**
Direction of motion must be at right angles to direction of force **(1)** **Max 3**

Diagram:
Identify velocity change ($\upsilon_B - \upsilon_A$) **(1)**
and its direction (perpendicular to AB and towards left) **(1)**
Hence acceleration is towards centre **(1)** **3**
[Total 8 marks]

52. Joule: kg $m^2\ s^{-2}$ **(1)**
Coulomb: Derived unit **(1)**
Time: Scalar quantity **(1)**
Volt: $W \times A^{-1}$ **(1)**
[Total 4 marks]

53. Calculation of period of oscillation:

Gradient calculated or values substituted in $a = -\omega^2 x$ **(1)**
Period of oscillation = 4 s **(1)** **2**

Sketch graph:
Attempt at sine or cosine curve **(1)**
of period found above **(1)**
Max and min at acceleration = ± 5 cm s^{-2} **(1)**
Acceleration a, maximum or minimum at $t = 0$ s **(1)** **4**
[Total 6 marks]

54. Description:

Either	*Or*
Two connected dippers just touching/above the water	Dipping beam or single source **(1)** reaches two slits **(1)**

Vibrated electrically **(1)**
Level tank/shallow water/sloping sides **(1)**

-

Either	*Or*
Illuminate project on to screen	Use stroboscope **(1)** to freeze the pattern **(1)**

Max 5

Diagram:

(i) Correct line A - centre line **(1)**
(ii) Correct line B (above or below A) **(1)**
(iii) Correct line C (between A and B) **(1)**
both B and C correct **(1)** **4**

If only the separation of the sources were increased, the angle between lines A and B would *decrease* **(1)**

If only the wavelength of the waves were increased, the angle between lines A and B would *increase* **(1)**

If only the depth of the water in the ripple tank were increased, the angle between lines A and B would *increase* **(1)** **3**

[Total 12 marks]

55. Ionisation energy:

2810 eV (4.5×10^{-16} J) **(1)**

Calculation of maximum wavelength:
Energy in eV chosen above converted to joules **(1)**
Use of $\lambda = c/f$ **(1)**
Maximum wavelength = 4.4×10^{-10} m **(1)**

Part of electromagnetic spectrum:
γ-ray / X-ray **(1)** **5**

Calculation of the de Broglie wavelength:
$\lambda = h/p$ p identified as momentum **(1)**
Either m or υ correctly substituted **(1)**
Wavelength = 1.1×10^{-13} m **(1)** **3**

[Total 8 marks]

56. Displacement-time graph:

Sine or cosine **(1)**

Max/min at +1.8 and –1.8 **(1)**

T = 0.05 s and at least one cycle **(1)** **3**

Calculation of maximum speed:

Correct *use* of $\upsilon = \omega x_0$ *or* $2\pi f x_0$

$= 2\pi \times 10\ s^{-1} \times 1.8 \times 10^{-2}\ m$ **(1)**

Maximum speed = $2.3\ m\ s^{-1}$ ($226\ cm\ s^{-1}$) **(1)** **2**

Any two places correctly marked M **(1)** **1**

[Total 6 marks]

57. Description and explanation of changes to oscillations of both springs during an experiment:

With small added mass → no/slight increase amplitudes/B

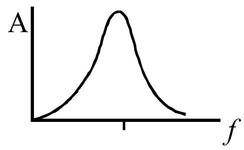
At mass *M:*

When mass on B = *M*, large amplitude on B Resonance occurs
Since A + B = same natural frequency amplitude of A
decreases/A loses energy to B
Now B "becomes driver"/energy to A
When mass on B > *M* small amplitude
Eventually both stop oscillating as energy → air/heat/etc

Relevant reference to $T = 2\pi\sqrt{\frac{m}{k}}$

For all masses, B oscillates at same frequency as A

Resonance curve



[Max 6]

58. Period $T = 10$ s

Calculation of maximum speed of the pendulum:

$27\pi \times (1/10)\ s^{-1} \times 3.25\ m$
$= 2.0\ m\ s^{-1}$

[Error carried forward]

Calculation of maximum acceleration of the pendulum:

$$\alpha = -\omega^2 x = \left(\frac{2\pi}{10s}\right)^2 \times 3.25m$$

$= 1.3\ m\ s^{-2}$ 5

Two sketch graphs:

Two cycles in 20 s

υ axis at least ± 2.0 + correct plot

a axis at least ± 1.5 + correct plot

υ sine or cosine undamped

a graph consistent with υ 5

[10]

59. Calculation of fringe spacing:

Substitution in $x = \frac{\lambda D}{s} = \frac{(690 \times 10^{-9}\ \text{m}) \times 3.5\ \text{m}}{(0.5 \times 10^{-3}\ \text{m})}$

[Ignore powers of I0 errors]

= 4.8 mm

Sketch of pattern observed on screen:

At least four equally spaced fringes, shown either as dark and light bands or as shaded "circles" on plain background. 4

[Lines rather than bands (–1)]

[4.8 mm incorrectly marked (– 1)]

Description of how appearance of fringes would change:

Colour changes to blue/violet

Fringes closer together/narrower 2

Which fringes overlap:

Centre fringes

Third short λ fringe from centre with second long λ fringe 2

[*or* 6th, 4th etc or fringes 9.66 mm from centre, etc]

[8]

60. Use of graph to estimate work function of the metal:

ϕ= (6.63 × 10^{-34} J s) (6.0 × 10^{14} Hz) – (some value)

Value in brackets: (1.6 × 10^{-19} × 0.5 J)

3.2 × 10^{-19} J *or* 2 eV 3

Addition to axes of graph A obtained when *intensity* of light increased:

A starts at –0.5

A → larger than /max

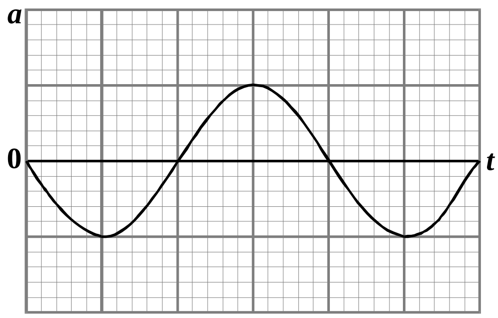
Addition to axes of graph B obtained when *frequency* of light increased:

B starts at less than – 0.5

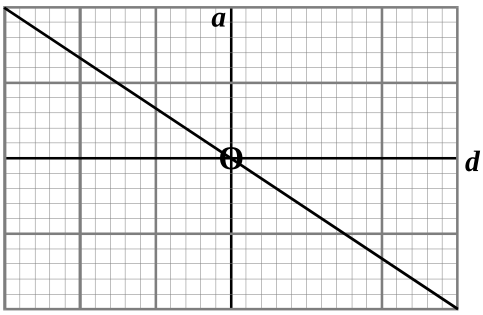
B → same of lower than /max 4

[7]

61. Sketch of two graphs:



Sinusoidal
Negative start



Linear through 0,0
Negative gradient 4

Amplitude of tide = 3.1 m

Next mid-tide at 12.00 (noon)

Next low tide at 15.00 (3 pm) 3

Calculation of time at which falling water levels reaches ring R:

$x = x_0 \sin\left(\frac{2\pi t}{12}\right)$ [Allow cosine]

$1.9 \text{ m} = 3.1 \text{ m} \sin\left(\frac{2\pi t}{12\text{h}}\right)$

[Error carried forward for their amplitude above; not 1.2 ml

$\boldsymbol{t}$ = 1.26 h *or* t = 4.25 h if cosine used

Time at R = 12.00 h + 1.26 h = 13.26 h (1.16 pm) 4

[11]

62. (a) Sound is longitudinal
Vibrations in one direction only
Air is made to vibrate/oscillate

Units:

p as N m^{-2} *and* ρ as kg m^{-3}
the N as kg m s^{-1}
Algebra to show LHS = RHS = m s^{-1} 6

(b) (i) Resistance down
Current up/V_m. + V_R = constant
Hence p.d. across R up Max 2

(ii) Frequency:
5 cycles in 8 cm/1 cycle in 1.6 cm .,
$\therefore T$= (1.6 cm)(250 μ cm^{-1}) = 400 μs

so = $\frac{1}{T} = \frac{1}{400 \times 10^{-6}\text{ s}}$ = 2500 Hz

Amplitude:

Amplitude 1.0/1.05 cm
Multiplied by 0.2 mV $cm^{-1} \rightarrow$ 0.20/0.21 mV 5

(iii) *Either*

Two dippers
Driven up and down
Project water surface

Or

Microwave transmitter
Source and double slit
Move detector across 3

[16]

63. What is meant by “an equation is homogeneous with respect to its units”:
Each side/term has the same units 1

Equation $x = ut + ½ at^2$:

ut - (m s^{-1}) s = m

$at^2/2$ (m s^{-2}) s^2 = m

all 3 terms reduce to m 3

[Allow dimensions]

Explanation:

Wrong numerical constant/wrong variables

Units same, numbers wrong/

Units same, magnitudes wrong 1

Example = 1 kg + 2 kg = 5 kg

[5]

64. A body oscillates with simple harmonic motion when the resultant force F acting on it and its displacement x are related by the expression

$\boldsymbol{F = -kx}$ *or* $\boldsymbol{F \propto -x}$.

The acceleration of such a body is always directed **towards the centre of the oscillation** *or* **in the opposite direction to displacement/*x* =**

0 /equilibrium/similar

The acceleration of the body is a maximum when its displacement is

maximum and its velocity is **maximum** when its displacement is zero. 4

Force constant:
= 14
N m^{-1} *or* kg s^{-2} 2

[6]

65. Circumstances under which two progressive waves produce a stationary wave:

Both transverse/longitudinal/same type
Waves have same frequency/wavelength
and travel/act in *opposite* directions/reflected back. Max 2 marks

Experiment using microwaves to produce stationary waves:

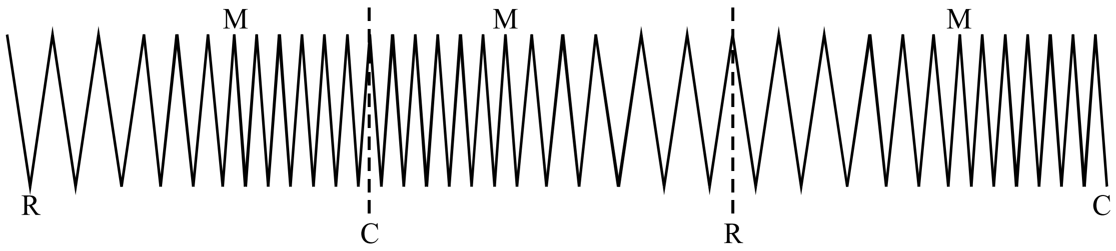
Transmitter

Metal plate *or*
backwards transmitter

Adjust distance of transmitter/plate
How it could be shown that a stationary wave had been produced:
Note readings on probe/detector/receiver form a *series* of maximum
or minimum readings *or* zero 3

[5]

66.



One of compression C and one rarefaction R marked as above.
Wavelength of wave = 11 - 11.6 cm **(**u.e.)
One of maximum displacement M marked as above [M, 5^{th}, 6^{th}, 7^{th}].
Amplitude of wave = 8 (± 1 mm) [consequent mark]

[4]

67. Explanation:
Photons/quanta
Photon releases / used electron
Energy/frequency of red < energy/frequency of ultra violet
Red insufficient energy to release electrons so foil stays 4

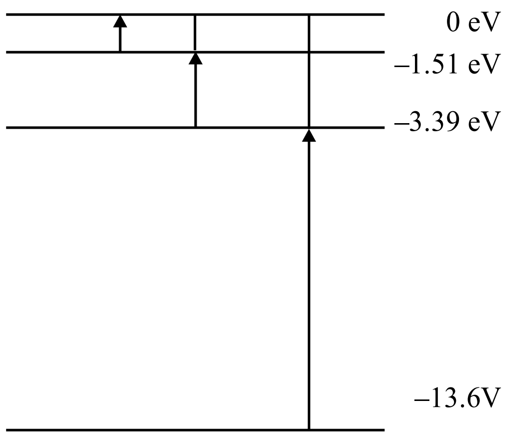
Ultraviolet of greater intensity: foil/leaf collapses quicker/faster
Red light of greater intensity: no change/nothing 2

Observations if zinc plate and electroscope were positively charged:

Foil rises	*or* Foil stays same/nothing
as electrons released it becomes more positive	Released electrons attracted back by positive plate/more difficult to release electrons 2

[8]

68. Energy level diagram:



– 13.6 → 0

$-1.51 \rightarrow 0$ AND $-3.39 \rightarrow 0$ ONLY 2

Why level labelled – 13.6 eV is called ground state:
Correct reference to stability/lowest energy state/level of
the electron/ atom/hydrogen 1

Transition which would result in emission of light of wavelength 660 nm:

Correct use of $c = f\lambda$ *or* $E = hc/\lambda$ *or* $f = \frac{3 \times 10^8 \text{ ms}^{-1}}{660 \times 10^{-9} \text{ m}}$

Correct use of eV/J i.e. $\div 1.6 \times 10^{-19}$

$\Delta E = 1.88$

Transition = $1.5 \rightarrow 3.39$

[May be a downward arrow on diagram] 4

[7]

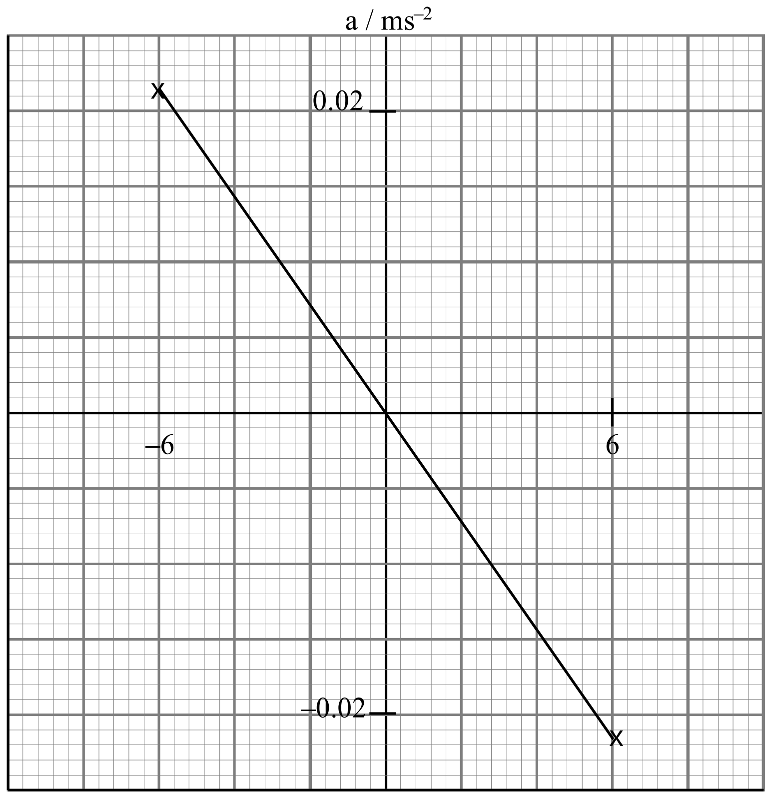
69. Maximum acceleration of mass:

$a = (-)\ \omega^2 x$ with $x = 6.0$ mm used *or* $a = (-)(2\pi f)^2\ x$

$\omega = \frac{2\pi}{3.2}$ *or* $f = \frac{2\pi}{3.2}$

$= 23$ mm s^{-2} [u.e.] 3

Graph:



Straight line
Negative gradient
4 quadrants: line through 0,0
Line stops at 6, 0.023 [e.c.f. *x, a*] 4

Reason why mass may not oscillated with simple harmonic motion:
F not proportional to *x or a* not proportional to *x*
Spring past elastic limit: *K* not constant: spring may swing as well as bounce.
Other possibilities, but not air resistance, energy losses 2

[9]

70. The joule in base units:

kg m^2 s^{-2} [No dimensions] **(1)** 1

Homogeneity of formula:

ρ kg m^{-3} **(1)**

r m, $f = s^{-1}$ **(1)**

(Right hand side units = (kg m^{-3}) $(m)^5$ $((s^{-1})^2)$ [Correct algebra]

= kg m^2 s^{-2} [Only if 1st two marks are earned] **(1)** 3

[Ignore numbers; dimensions OK if *clear*]

Why formula might be incorrect:

The ½ could be wrong **(1)** 1

[5]

71. Explanation:

Changing direction/with no force goes straight on (along tangent) **(1)**

Acceleration/velocity change/momentum change **(1)** 2

Identification of bodies:

A: Earth [*Not* Earth's gravitational field] **(1)**

B: scales [*Not* Earth/ground] **(1)** 2

Calculation of angular speed:

Angular speed = correct angle ÷ correct time [any correct units] **(1)**

= 4.4×10^{-3}rad min^{-1} / 0.26 rad h^{-1}/ 2πrad day^{-1} etc **(1)** 2

Calculation of resultant force:

Force = $mr\omega^2$ **(1)**

= 55 kg × 6400 × 10^3 m × $(7.3 \times 10^{-5}$ rad $s^{-1})^2$ **(1)**

= 1.9 N **(1)** 3

[No e.c.f here unless ω in rad s^{-1}]

Calculation of value of force B:

Force B = 539N – 1.9N **(1)**

= 537 N **(1)** 2

[e.c.f. except where R.F = 0]

Force:

Scales read 537 N (same as B) [allow e.c.f.]

Newton's 3rd law/force student exerts on scales **(1)** 1

[12]

72. Calculation of kinetic energy:

$f = \dfrac{3 \times 10^{8}\ m\,s^{-1}}{\lambda}$ ($E = hf = 1.63 \times 10^{-17}$ J) **(1)**

ϕ converted to J: $6.20 \times 1.6 \times 10^{-19}$ OR Photon energy converted to eV: 1.63 ÷ 1.6 × 10

(Subtract to obtain kinetic energy)

Kinetic energy = $(1.5 – 1.56) \times 10^{-17}$ J[OR 95.7/97.4 eV]

[Beware 1.6398 0/3; > 101 eV 0/3]

Demonstration of speed of electrons:

1.53×10^{-17} J = ½ × 9.11×10^{-31} kg × υ^2 **(1)**
[e.c.f their kinetic energy in joules]

$\upsilon = 5.8 \times 10^{6}$ m s^{-1} **(1)**
[If υ is not between 5 and 7 must comment to get mark] 5

Calculation of de Broglie wavelength:

Use of $p = m\upsilon$ = mass × velocity (accept their velocity] **(1)**

Wavelength = $1.2/1.3 \times 10^{-10}$ m [no e.c.f. allowed] **(1)**

Explanation:

Diffraction occurs **(1)**

as spacing/size of atoms/molecules of same order as wavelength **(1)** 4

[2nd mark is consequent upon first] **(1)**

[9]

73. Why example is resonance:

These are forced vibrations, i.e. 2 systems [driver and driven) **(1)**

The vibrations have max amplitude at one particular frequency or decrease both sides **(1)**

When forcing frequency = natural frequency of steering wheel car/ "system" **(1)** 3

Calculation of maximum acceleration:

Acceleration = $(2\pi \times 2.4)^2$ s^{-2} × 6 mm [accept any attempted conversion to m, e.g. 6×10^{-2}] **(1)**

= 1400 (1360) mm s^{-2} [no e.c.f.] **(1)**
(1.4 m s^{-2}) 2

[5]

74. Calculation of light intensity:

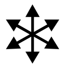
$$60\ \text{W} \times \left(\frac{12}{100}\right) \times \left(\frac{1}{4\pi(3.5)^2}\right)$$

(1) **(1)**

= 0.047 (0.05) W m^{-2} [e.c.f 88% to 0.34 W m^{-2}] **(1)** 3

Effect on intensity of light of sheet of Polaroid:

Intensity reduced/halved [NOT zero]

light was unpolarised OR  **(1)**
[accept becomes polarised] **(1)**

Polarised means reduced to one plane OR  **(1)**

Effect on intensity of light of rotation of Polaroid:

No effect/nothing **(1)** 4

[7]

75. Labelled diagram:

Label light source [lamp with slit or a laser] **(1)**

Double slit, screen [+ travelling microscope for lamp] **(1)**

Appropriate values:

(i) Slit separation: 0.1 mm → 5 mm

(ii) Distance from slits to screen 0.5 → 5 m

BOTH (i) and (ii) above are required for mark **(1)** 3

Fringe width:

Measurement: 8 - 9 mm **(1)**

Evidence of measuring across 3 or more and dividing **(1)**

[Except 6.3/*n*] 2

Completion of sentences:

Light from the two slits has travelled the same distance at position(s) **D** only **(1)**

Light from the two slits is out of phase at position(s) **C** and **F** [–1 each excess] **(1)(1)**

There is a path difference of three wavelengths between light from the two slits at position(s) **A** only **(1)** 4

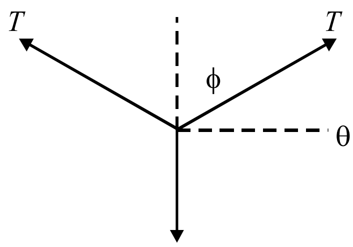
Description of pattern changes

One bright fringe/band/pattern only OR fringes disappear OR no pattern **(1)**

Less sharp / wider / fading out gradually OR single slit diffraction **(1)** pattern/graph [If pattern described 2/2] 2

[11]

76. (a)



Two T arrows and one mg / W arrow [Labels not required] **(1)**

Trigonometry to give $\theta = 3.34°/\phi = 86.66°$ [Method mark] **(1)**

(Resolving vertically) $2T\cos\phi/2T\sin\theta = W/\text{mg}$ [no 2 × → max 3/5 eop]

Substitution in $T = 2mg \div \cos\phi/\sin\theta$

= 4.2 N [e.c.f sin/cos confusion] 5

(b) Ammeter and voltmeter (not ohmmeter) in circuit [could be described] **(1)**

Method of varying current **(1)**

$R = V/I$ stated anywhere [e.g. gradient I/V OR V/I curve] **(1)** 3

(c) (i) 13 A r.m.s. has same heating effect as 13 A d.c. **(1)**

(ii) $\lambda = 2 \times 0.606$ m **(1)**

Use of $c = f\lambda$ **(1)**

$f = 50$ Hz **(1)**

→ $c = 60.6$ m s^{-1} / 121 m s^{-1} [e.c.f. $\lambda = 0.60 \rightarrow 30$ m s^{-1}] **(1)**

(iii) *Either*

mention of resonance/standing wave **(1)**

driving force f equal to natural f_0 **(1)**

Or

Hot-cold cycle **(1)**

leads to pull-relax forces on the wire **(1)** 6

(d) Units for μc^2**:**

kg m^{-1} × (m s^{-1})^2 **(1)**

= kg m s^{-2} which is N **(1)** 2

[16]

77. Correct quantities on diagram:

Upper ellipse	capacitance	[**not** energy]	[Accept capacitance^{-1}]	**(1)**
Lower ellipse	resistance	[**not** power]	[Accept conductance/resistance^{-1}]	**(1)**

2

Explanation:

Base quantities/units [**Not** fundamental] **(1)**

Not derived from other (physical) quantities **(1)**

OR other (physical) quantities are derived from them

OR cannot be split up/broken down

2

[4]

78. Wavelength of the microwaves:

λ = 442 mm – 420 mm **(1)**

= 22 mm [2.2 cm, 0.22 m] **(1)**

Frequency of microwaves:

Use of $c = f\lambda$ with λ from above substituted OR if no attempt, then $C = 3. \times 10^8$ substituted **(1)**

1.4×10^{10} Hz [e.c.f. λ above] **(1)**

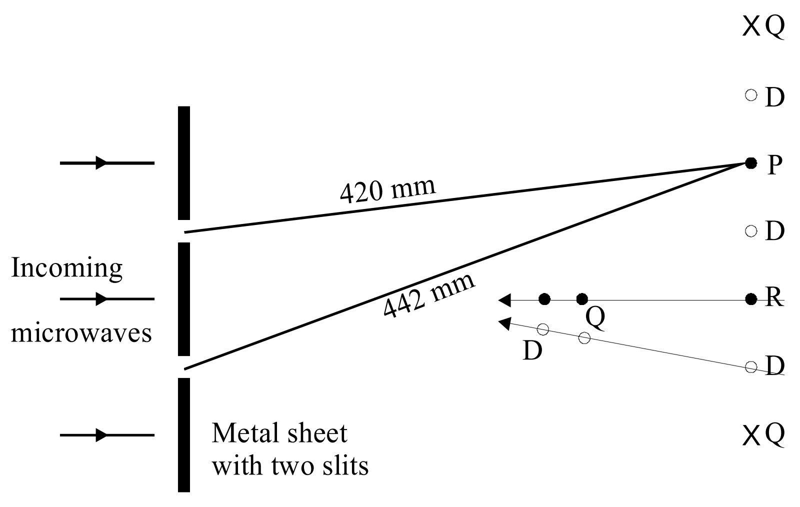
4

Maximum Q and minimum D marked on diagram:

Either Q **(1)**

Any D **(1)**

2



Why a maximum would not be detected at P:

Wavelength of sound wave = 0.3 m **(1)**

Path difference at P is not whole wavelength **(1)**

2

[OR valid reference to phase difference OR λ sound greater so no diffraction with this slit width OR valid reference to $\lambda = xs/D$]

[8]

79. Period of oscillations:

$$T = 2\pi\sqrt{\frac{16\ \text{kg}}{3.9 \times 10^{3}\ \text{N m}^{-1}}}$$

substitutions **(1)**

[Ignore 10^n errors]

0.4 s **(1)**

2

Maximum acceleration of mass:

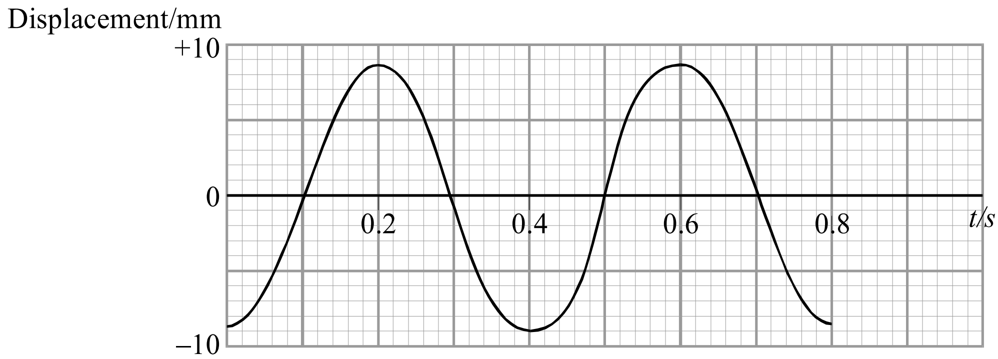
$\omega = \frac{2\pi}{T} = 15.7\ \text{s}^{-1}$ **(1)**

$a = \omega^2 \times 8.4 \times 10^{-3}$ m [Ignore 10^n error] **(1)**

$= 2.07\ \text{m s}^{-2}$ [2 – 2.1] **(1)**

3

Sketch graph of displaced against time:



Sine or cosine **(1)**

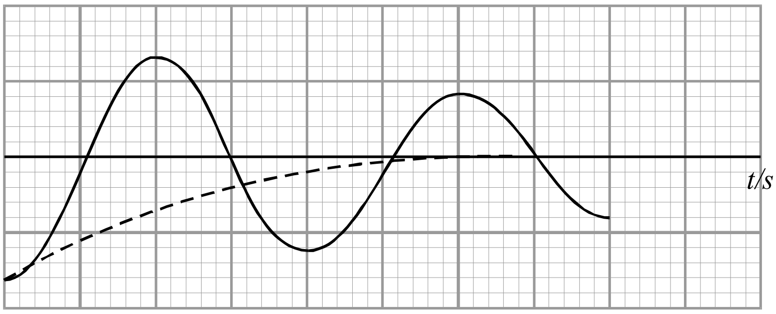
t axis labelled AND 2 cycles their T **(1)**

Displacement axis labelled to at least 10 mm with curve reaching between 8 and 9 mm and undamped **(1)**

Starts max negative **(1)**

4

Displacement-time graph for mass if moving within oil:



Damped continuously or critically damped **(1)**
[Ignore variations in *T*; any starting point]

1

[10]

80. Ionisation energy of atomic hydrogen:

13.6 eV OR 2.18×10^{-18} J [– sign, ***X***] **(1)**
1

Why energy levels are labelled with negative numbers:

Work/energy is needed to raise the electrons/atoms to an energy of 0 eV, so must start negative **(1)(1)**

OR

Work/energy is given out when the electrons/atoms move to the ground state, so energy now less than 0, i.e. negative **(1)(1)**

OR

the ground state is the most stable/lowest energy level of the electrons/atoms and must be less than 0, i.e. negative **(1)(1)**
2

[1st mark essential: e^- highest/maximum/surface/ionised/free has energy = 0eV

2nd mark: raising levels means energy in OR falling levels means energy out ∴ negative levels]

Wavelength of photon:

ΔE = 1.89 (eV) **(1)**

Convert ΔE to joules, i.e. $\times(1.6 \times 10^{-19})$

OR

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.89\ (\times 1.6 \times 10^{-19})}$$ [**Their *E***] **(1)**

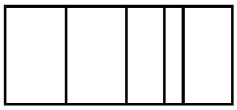
= 6.6×10^{-7} (m) [6.5 – 6.7] **(1)**
3

Production of line spectrum of atomic hydrogen in a laboratory:

Source – hydrogen discharge tube/hydrogen lamp/low *p* hydrogen with high *V* across **(1)**

(view through) diffraction grating/prism/spectrometer/spectroscope **(1)**
2

Sketch:



A few vertical **lines** on a blank background OR sharp bands

Dark on light/light on dark NOT equally spaced **(1)**
1

Absorption spectrum:

White light through gas in container (1)
Diffraction grating/prism/spectrometer (1)
Must be dark lines on bright background (1)

[9]

81. Direction of force, shown on diagram:

Arrow pointing upwards on diagram **(1)**
1

(i) Low frequency:

Wire moves up/vibrates/oscillates, then down, then up, etc
[Not “up and down” – needs implication of repetition]
[Won’t move + justification OK] **(1)**
1

(ii) Increased frequency:

Wire vibrates quicker as frequency increases **(1)**

At $f = 20$ Hz **(1)**

Large amplitude vibrations OR resonance occurs **(1)**

Standing wave set up OR diagram [consequent on 20 Hz] **(1)**

Resonance at 40 Hz OR diagram **(1)**
5

[7]

82. (a) (i) s.h.m.: acceleration $\propto$ displacement [Not $a \ll x$] **(1)**

and directed to centre [Not a minus sign] **(1)**

(ii) *Either* **(1)(1)**

hump with υ zero at both ends

Or

A and B labelled at axis **(1)(1)**

4

(b) (i) ρ as kg m^{-3} **(1)**

G as N m^2 kg^{-2} **(1)**

[G as kg^{-1} m^{-3} s^{-2} marks 2 and 3]

use of $N \equiv$ kg m s^{-2} [Accept $1/\rho G$ has unit s^2 as 1/3] **(1)**

(ii) $\rho_{\text{MOON}} = M_{\text{M}} \div V_{\text{M}}$ and $V = \dfrac{4}{3}\pi r_M{}^3$ [May be all numbers] **(1)**

Correct substitution in t_{AB} / ρ calculated as 4000/4100 kg/m^3
[e.c.f. $\pi r^3 \rightarrow$ 1300/1400] **(1)**

$\Rightarrow t_{\text{AB}}$ = 2980 s OR 49.7 minutes/50 minutes **(1)**

6

(iii) Longer/shorter tunnel has larger/smaller force/acceleration

Reference to component of force (along tunnel) **(1)**

(Hence) high/low speed reached **(1)**

Period is independent of amplitude as it is s.h.m. **(1)**

Max 2

(c) *G:* suspend/pivot masses /(small) mass on top pan balance **(1)**

attract/make swing by large mass(es)/large mass above balance **(1)**

supported by diagram **(1)**

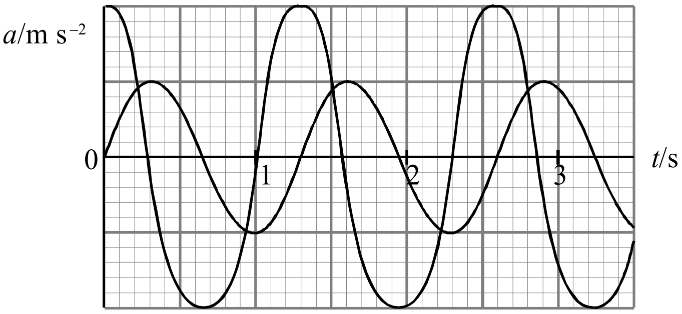
problem: G forces are very small/ convection currents/ vibrations/ electrostatic forces **(1)**

4

[16]

83. Frequency = 0.7 Hz → 0.8 Hz 1

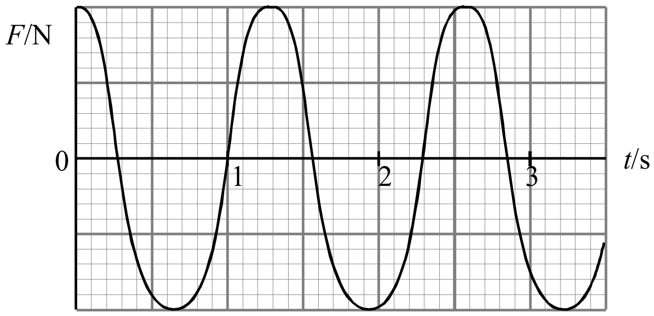
Addition to graph



2

[If inverted, **(1)**, **(0)**]

Graph showing how force varies with time:



2

[If inverted, **(1)**, **(0)**]

$1.2 \text{ s} = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{2m}{4k}}$

$T = 1.2 \text{ s} \times \sqrt{\frac{1}{2}}$

= 0.85 s 2

[7]

84. f = 100 Hz 1

Amplitude = 4.3 cm 1

Substitute in $a = -(2\pi f)^2 x$

$-(2\pi \times 100 \text{ Hz})^2 \times 4.3 \times 10^{-2}$m [allow e.c.f. on both values]

Acceleration = 1.7×10^4 m s^{-2} 2

Half-way between T and L 1

[5]

85. Vibrations/oscillations of atoms is ↔ and wave/energy travels → /along direction of/parallel to/equivalent

Diagram Y: 1

Any two compressions
Any two rarefactions
Any correct place, e.g. centre of compression to centre of compression 3

Diagram Z:

Two compressions or two clusters move ¼ *their* λ
to the right 2

[6]

86. On diagram show at least:
infra red/visible/ultra violet/X ray 1

Radio	Sound
Transverse Travel at speed of light Polarisable Travel through a vacuum Electromagnetic	Longitudinal **(1)** Travel much slower **(1)** (not polarisable) **(1)** (do not travel through vacuum) **(1)** Pressure/mechanical/particles vibrate **(1)**

Max 4

198 kHz 1

Diffraction occurs
Longer wavelengths diffract more round hills/buildings 2

[8]

87. Diagram showing:

Microwave transmitter → obstacle → detector (in correct place)
Two slits between/in metal sheets
Detector connected to meter/amplifier/cro 3

Value between 1 cm and 8 cm 1

Measure from first off-centre maximum to each slit
Difference in these measurements = λ
Repeat other side of centre *or* use 2nd maximum to find 2λ 3

[7]

88. Particle theory:

One photon releases one electron giving it kinetic energy **(1)**

Increase f → greater k.e. electrons **(1)**

Lower f finally k.e. = 0 i.e. no electrons released **(1)**

Waves:
More intense light should give greater k.e.**(1)**

More intense light gives more electrons but no change in maximum kinetic energy **(1)**

Waves continuous ∴ when enough are absorbed electrons should be released **(1)** Max 5

Quality of written communication 1

Line parallel to existing line
to left of existing line 2

[8]

89. Ionisation energy = 2.18×10^{-18} joules 1

Use of $E = hc/\lambda$
Energy converted to eV
giving $\Delta E = 2.54$ eV
between levels –0.85 eV and –3.4 eV 4

On diagram show arrow downwards between levels –0.85 eV and –3.4 eV 1

Hydrogen absorbs energy or photon from the light
to raise an electron/atom to a higher level/state
from –3.4 eV up to –0.85 eV 3

The star has an atmosphere of hydrogen gas
The star is moving away from us
at a speed of 3.6×10^7 m s^{-1} 3

[12]

90. Inflated balloon B C and AB ≈ twice AC on both diagrams 2

$\upsilon = Hd$ Terms defined **(1)**

Balloon represents universe **(1)**

A, B and C represent galaxies/stars **(1)**

Balloon expands, ABC appear to move apart, as do galaxies from us **(1)**

With $\upsilon \propto d$, i.e. furthest apart marks appear to have separated most **(1)** Max 4

Quality of written communication 1

[7]

91. Table:

Description	Type of wave	
A wave capable of causing photo-electric emission of electrons	Ultraviolet	**(1)**
A wave whose vibrations are parallel to the direction of propagation of the wave	Sound	**(1)**
A transverse wave of wavelength 5×10^{-6} m	Infrared	**(1)**
The wave of highest frequency	Ultraviolet	**(1)**

4

[4]

92. Calculation:
Use of $p = m\upsilon$ **(1)**
$2.1\% \times 3 \times 10^{8}$ m s^{-1} **(1)**
Wavelength = 6.3×10^{-14} m **(1)** 3

Discussion:
Electron mass < neutron mass — attempt recalculation using electron mass **(1)**
Hence $\lambda_e > \lambda_n$ — $\lambda_e = 1.15 \times 10^{-10}$ **(1)**

Electrons as λ_e ≈/closely atomic 'spacing'/'size' 3

[6]

93. Name:
Resonant/natural **(1)** 1

Calculation of mass:
$T = 2\pi \sqrt{(m/k)}$ [No mark]
Use of $T = 1/f$ **(1)**
Correct substitutions of k, T [Ignore × 10^{x}] **(1)**
Mass = 2.2×10^{-14} kg **(1)** 3

Assumption:
Motion is simple harmonic/no 'resistive' forces/ no damping/ ignore mass of nanotube/ [not weight] / obey's Hooke's law/does not pass elastic limit. **(1)** 1

[5]

94. Explanation:

- waves diffracted from each slit/each slit acts as a source
- these superpose/interfere **(1)**
- maxima/reinforcement – waves in phase/pd = $n\lambda$ **(1)**
  [or on a diagram][crest & crest] **(1)**
- minima/cancellation – waves in antiphase/pd = $(n+1/2)\lambda$ **(1)**
  [or on a diagram][crest and trough] [not just 'out of phase'] **(1)**
- phase or path difference changes as move around AB **(1)** Max 4

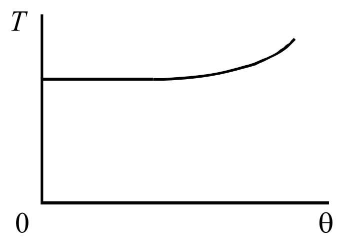
Determination of wavelength:
Use of wavelength = p.d. [incorrect use of xs/D 1/3 max] **(1)**
3 × (path difference. e.g.78 – 66 mm) **(1)**
= 36 mm[Range 30 – 42 mm] **(1)** 3

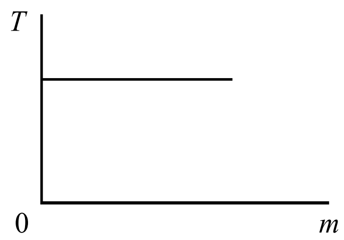
Explanation:
Less/No diffraction/spreading **(1)**
∴ waves will not superimpose/overlap as much **(1)** 2

Explanation:
Fixed phase relationship/constant phase difference **(1)**
Both waves derived from single source [transmitter ⇒] **(1)** 2

[11]

95. Graphs:





(2) 2

Description:
Time for a number of cycles ÷ by no. of cycles **(1)**
[accept swings]
Count from centre of swing/repeat timing and average/keep amplitude small **(1)**
Repeat for different lengths AND plot Graph of T v √l **(1)**
[allow for ratio method]
should be straight line through origin [consequent] **(1)**
[allow for ratio method] 4

Calculation (based on graph):
Attempt to find gradient **(1)**
Rate of change = 0.103 –0.106 $s^2\ m^{-1}$ **(1)**

Rate of change of l plus comment on answer:
9.6 m s^{-2} [1/their value above] [no ue] [ecf] **(1)**
close to/roughly/approx. acceleration of free fall/g **(1)**
[only if range 8.8 to 10.8 m s^{-2}] 4

[10]

96. Calculation:

$E = hc/\lambda$ [seen or implied] **(1)**
physically correct substitutions **(1)**
$\div 1.6 \times 10^{-19}$ eV J^{-1} **(1)**
5.78 eV **(1)** 4

Maximum kinetic energy:
3.52 eV [ecf but not if –ve.] **(1)**

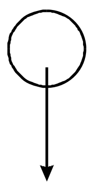
Stopping potential:
3.52 V [Allow e.c.f., but not signs] **(1)** 2

Annotated graph:
Position of S **(1)**
Cuts V axis between origin and existing graph **(1)**
Similar shape [*I* levels off up/below existing line] **(1)** 3

[9]

97. Discussion:
No equilibrium or there is a resultant force **(1)**
Direction changing or otherwise would move in a straight line (or off at an tangent) **(1)**
acceleration or velocity changing **(1)**
Force towards centre or centripetal **(1)**
The tension provides this force [consequent] **(1)**
[OR for last 2 marks: weight of ball acts downwards **(1)**
vertical component of tension balances it **(1)**] 5

Free-body diagram:



W/weight/*mg*/gravitational 'attraction' [not 'gravity'] **(1)** 1

[6]

98. Explanation:
Doppler shift:
change in frequency/wavelength **(1)**
due to motion of source/galaxy/observer **(1)**

Galaxies:
The shift of a spectral line **or** use formula to find *v*. **(1)**
'Red shift' ⇒ receding **or** 'Blue shift' ⇒ approaching **(1)**
Quality of written communication **(1)** 5

Graph:
Shape rough parabola; must hit time axis. **(1)** 1

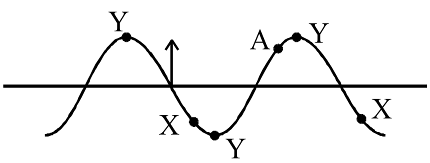
Experimental difficulties:
$\upsilon = Hd$[No mark]
d difficult to measure for distant galaxies **(1)**
Hence H is inaccurate/uncertain. [consequent] **(1)**
υ fairly accurately measured or H is squared so error bigger **(1)** 3

[9]

99. Wavelength
0.80 m **(1)**

Out of phase
Either X as in diagram below **(1)**

At rest
Y at crest or trough as in diagram below **(1)**



Direction of movement
Arrow at C up the page **(1)** 4

Time calculation **(1)**
Use of $t = \lambda/\upsilon$ **(1)**
0.25 s [ecf λ] 2

[6]

100. Inverse square law

Two (I,d), pairs read off graph **(1)**
Show Id^2 nearly the same for each or show I ratio = d $ratio^{-2}$ **(1)**

Amount of light absorbed
Negligible (or no) absorption **(1)** 3

Energy of photon
Use of $E = hc/\lambda$ **(1)**
3.2×10^{-19} [Minimum 2 significant figures] **(1)** 2

Number of photons
Use of graph to find I [at d = 0.2] [allow I = 0.25] **(1)**
Use of power (on pupil) = $\pi r^2 I$ [not r = 0.2 not 4π] [allow 6 mm] **(1)**
Use of number per second = power or intensity/photon energy **(1)**
2.6 to 2.8×10^{12} **(1)** 4

Why light intensity decreases
Fewer hit unit area (per second) OR **(1)**
Same **number** over a larger area. 1

[10]

101. <u>Simple harmonic motion</u>

Force/Acceleration proportional to displacement/ $a = \omega^2 x$ **(1)**
[define a and x but not ω]

In opposite direction to displacement/ towards a fixed point/towards equilibrium position/minus sign **(1)** 2

<u>Oscillation of mass</u>
Clarity of written communication **(1)**
Down: $T > W$ [W varying 0/3] **(1)**
Up: $T < W$ **(1)**
$T > W$ gives **resultant** force/acceleration UP **(1)**
[or equivalent argument for displaced up] 4

<u>Velocity-time graph</u>
Either Cosine graph [zigzag −1 here] **(1)**
Starting at positive maximum [if very poorly synchronised 0/2] **(1)** 2

<u>Maximum velocity of mass</u>
Period = 0.50 **or** amplitude = 0.07 **(1)**
Use of $f = I/T$ / Use of $x = x_0$ sin or cos (ωt) **(1)**
Use of $\upsilon_{max} = 2\pi f x_0$ **(1)**
0.88 m s^{-1} **(1)**

OR 4

υ_{max} = gradient at 0.50 s (or equivalent) **(1)**
Correct method for gradient **(1)**
Answer in range 0.8 to 1.0 m s^{-1} **(1)**
[Max 3 for gradient method]

[12]

102. <u>Electromagnetic waves experiment</u>

EITHER

'Lamp', 1 polaroid // LASER **(1)**
2^{nd} polaroid, suitable detector [e.g. eye, screen, LDR] **(1)**
Rotate one polaroid [consequent on 2 polaroids] [one if LASER] **(1)**
Varies [consequent] **(1)**

OR

Microwave transmitter (and grille) [not polaroid or grating] **(1)**
Receiver (or and grille) **(1)**
Rotate ANY [if 2 grilles; must rotate a grille] **(1)**
Varies [consequent] **(1)** 4

<u>Nature of waves</u>
ransverse **(1)** 1

[5]

103. Speed of electron
Selection of $\lambda = h/p$ and $p = m\upsilon$ **(1)**
$m = 9.11 \times 10^{-31}$ **(1)**
$7.2 - 7.3 \times 10^{6}$ m s^{-1} **(1)**

Kinetic energy
Use of $E_k = 1/2\, m\upsilon^2$ **(1)**
147 – 152 [ecf] **(1)** 5

High energy electron
Nucleus tiny/a lot smaller so λ very small **(1)**
υ or p very large [consequent] **(1)** 2

[7]

104. Calculation of fringe separation
Use of $\lambda = xs/D$ **(1)**
3.5 mm **(1)** 2

Fringe separation

(i) increases **(1)**

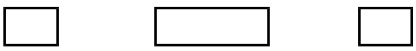
(ii) increases **(1)**

(iii) increases **(1)** 3

Diffraction pattern

EITHER

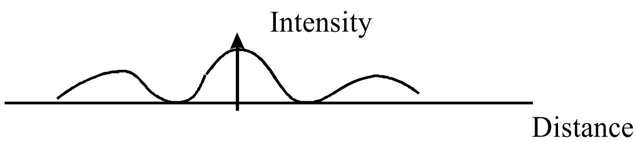
Sketch of pattern



Symmetrical pattern of maximum and minima [ignore intensity] **(1)**
Central max roughly 2 × width of others **(1)**
Middle brighter (shown or labelled) [consequent] **(1)**
[Single smear with intensity falling off 1/3]

OR

Graph of pattern:



Labelled axes and symmetrical curve of maxima and minima **(1)**
Central max roughly 2 × width of others [consequent on symmetry] **(1)**
Central max intensity higher than side max intensity [consequent] **(1)**
[Bell shape 1/3] 3

[8]

105. Planck constant
Realise that h is the gradient
Correct attempt to find gradient [but ignore unit errors here]
$h = (6.3 \text{ to } 6.9) \times 10^{-34}$ J s [No **bald** answers] 3

Work function

Use of hf_0 / use intercept on T axis/use of $\phi = hf - T$ **(1)**

$\phi = (3.4 \text{ to } 3.9) \times 10^{-19}$ J [-1 if –ve] [2.1 to 2.4 eV] **(1)** 2

Stopping potential

$T = 2.3 \times 10^{-19}$ //Use of $T = hf - \phi$ **(1)**

Use of V = their energy ÷ 1.6×10^{-19} **(1)**

V = 1.44 V // V = 1.1 – 1.8 V [ignore –ve sign] [ecf h] **(1)** 3

[8]

106. Table

Middle column:

Bq/Ci/decays s^{-1}/s^{-1} **(1)**

rad s^{-1}/degree s^{-1}/rev s^{-1}/rpm **(1)**

$yr^{-1}/days^{-1}/s^{-1}$/any velocity unit ÷ any distance unit **(1)**

Last column:

All s^{-1} **(1)** 4

107. Simple harmonic motion

Acceleration/force is proportional to *displacement* **(1)**

but in the opposite direction / towards equilibrium point /mean point **(1)** 2

Graph

Sine curve **(1)**

-ve [consequent] **(1)**

A and B / (i) and (ii) / a & x [beware a v x] **(1)** 3

Pendulum

Use of $T = 1/f$ **(1)**

Substitution of g and their T in correct equation **(1)**

l = 29 - 30 m [no ecf] **(1)** 3

[8]

108. Angular speed

Conversion of 91 into seconds – here or in a calculation **(1)**

Use of $T = 2\pi/\omega$ allow $T = 360/\omega$

ω = 1.15 – 1.20 × 10^{-3} rad s^{-1} /6.9 × 10^{-2} rad min^{-1} /0.066 deg s^{-1} **(1)** 3

Acceleration

Use of $a = r\omega^2$ / υ^2 / r **(1)**

Adding 6370 (km) to 210 (km)/ 6580 (km) **(1)**

a = 8.5 to 9.5 m s^{-2} [No e.c.f. for 210 missed but allow for ω in rad s^{-1}] **(1)** 3

Resultant force

Recall/Use of $F = ma$ **(1)**

F = 35 –39 N [Allow e.c.f their a above only] **(1)**

Towards (centre of the) Earth **(1)** 3

[9]

109. Table

Radio waves	Sound waves
Transverse	Longitudinal
Travel much faster than sound	Travel more slowly
(Can) travel in a vacuum	Cannot travel in a vacuum
Can be polarised	Not polarised
Electromagnetic	Pressure/Mechanical wave

Any three of the above Max 3

Assumption

Attempt to calculate area **(1)**

Intensity = 0.02 kW m^{-2} OR 20 W m^{-2} **(1)**

Efficiency at *collector* is 100%/beam perpendicular to *collector*

Power

Use of $I\ P/4\pi r^2$ **(1)**

Power = 3.3×10^{17} W [ecf their I]

No energy "lost" due to atmosphere (not surroundings) OR Inverse square applies to this situation **(1)**

More efficient method

Use a laser (maser) / reference to beaming/ray **(1)** 1

[10]

110. Ionisation energy

Use of $\times 1.6 \times 10^{-19}$

2.2×10^{-18}[No u.e.] **(1)** 2

Addition to diagram

(i) From 4 to 3 labelled *R* / *(i)* **(1)**

(ii) From 1 to 4 labelled *A* / *(ii)* **(1)** 2

Emission spectrum

Hydrogen *'excited'* in a discharge/thin tube/lamp [not bulb] **(1)**

Viewed through a diffraction grating/prism/spectrometer **(1)**

Appearance of emission spectrum

A series of lines / colours on a *dark* background [accept bands] **(1)** 3

Region of spectrum

Radio/microwave **(1)** 1

Speed of galaxy and deduction

$\Delta\lambda$ = 8 (mm) / 211 - 203 (mm) **(1)**

Use of 3×10^8 **(1)**

$\upsilon = 1.\ 1(4) \times 10^7\ ms^{-1}$ [No e.c.f.] **(1)**

Moving towards Earth (us) **(1)** 4

[12]

111. Photoelectric effect

Any two features and explanation from the following:

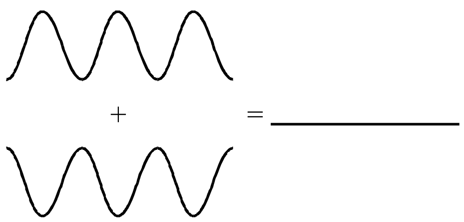
Feature:	Experiments show $k.e_{(max)} \propto f$, OR not intensity [Accept depends upon] **(1)**
Explanation: [Consequent]	Photon energy $\propto f$ **(1)**
	$k.e_{(max)} \propto$ intensity is a wave theory **(1)**
Feature:	Emission of photoelectrons immediate **(1)**
Explanation: [Consequent]	One photon releases one electron particle theory **(1)** Wave theory allows energy to "build up" **(1)**
Feature:	(Light) below a threshold frequency cannot release electrons **(1)**
Explanation: [Consequent]	Particle theory-*f* too low as not enough energy is released by photon to knock out an electron **(1)**
	Wave theory- if leave a low frequency beam on long enough, it will produce enough energy to release an electron **(1)**

[Max 5]

112. Explanation

Destructive interference / waves cancel out / waves (exactly) out of phase **(1)**

Sketch graphs similar to below [looking for crests & troughs] **(1)** 2



Path difference

$3\lambda/2$ **(1)**

Phase difference

3π / 9.42 **(1)** 2

Wavelength

Use of $\lambda = xs/D$ **(1)**

x = 1.8 or 1.9 (cm) **(1)**

6.00×10^{-7} m [No e.c.f.] **(1)** 3

Addition to graph

Smooth line / envelope +/- 4 [allow 1 pair of side maxima] **(1)**

Maximum at 0 original peak [consequent] **(1)** 2

[9]

113. How stationary waves could be produced on a string

Diagram showing:

String and arrangement to **apply** tension **(1)**

Vibration generator **and** signal generator **(1)** 3

Vary f / tension / length until wave appears **(1)**

Determination of speed of travelling waves

QOWC **(1)**

Determine node-node spacing; double to obtain λ **(1)**

Read f off signal generator / cro / use a calibrated strobe **(1)**

Use $\upsilon = f\lambda$ for υ **(1)** 4

[7]

114. Number of turns in slinky solenoid

n = 1 m ÷ 0.016 m = 62.5 /63 **(1)** 1

Magnetic field strength

$B = \mu_o n_I$

$= (4\pi \times 10^{-7}$ N $A^{-2})$ (62.5 m^{-1})(0.5 A) [Correct substitution] **(1)**

$= 3.9 \times 10^{-5}$ (T) **(1)** 2

Graph description

When the coils get closer together/when n increases

Then B (field) increases as pulse/compression passes (probe) **(1)** 2

Addition to graph

decrease in (magnetic field strength) as pulse passes **(1)**

decrease occurs over a *longer* time interval **(1)**

[Graphs with different starting values of B. max 1/2] 2

[7]

115. Angular speed

Use of $\omega = 2\pi/T$ 1

$\omega = 1.2 \times 10^{-3}$ [min 2 significant figures) [No ue as units given] 1

Free-body force diagram

Pull of Earth/Weight/mg/Gravitational Pull 1

Why satellite is accelerating

Resultant/Net/Unbalanced force on satellite must have an acceleration OR $\Sigma F = ma$. 1

Magnitude of acceleration

Use of $a = \omega^2 r$ OR $\upsilon^2 \div r$ 1

a = 9.36-9.42 OR 6.5 m s^{-2} 1

[Depends on which ω value used]

[6]

116. Table

Frequency/Hz	Relative amplitude	Waveform	
40	Low (no mark)	**None or small ‘wiggles’**	1
60	High (no mark)	(no mark)	
100	**Low**	**Similar to 40**	2
120	**High (accept medium)**	**3 nodes**	2
180	**High (accept medium)**	**4 nodes**	2

Answers above:
1 tick for 40 row
2 ticks for 100 row
2 ticks for 120 row
2 ticks for 180 row

Quality of written communication 1

The electrons act as standing/stationary waves/resonance 1

Any two from:

- Complete number of ‘waves’ in an orbit
- Probability of finding electron
- Higher number of ‘waves’ in a higher orbit/higher frequency
- Discreet energy levels of electron or atom Max 2

[11]

117. Electrons and photons

[Accept diagrams or words]

Electron as wave:

Observation
We observe a regular pattern
Accept dots; rings; circles [not fringes] 1

Explanation
Atomic/molecular spacing/gap in crystal ≈ (de Broglie) λ (of electrons) 1

Photon as particle:

Observation
No electrons emitted above a certain λ /below a *certain f*
OR Instantaneous emission of electrons 1

Explanation
Photon energy ∝ *f* /one photon collides with one electron /energy of photon quantised 1

Photon as wave:

Observation
Fringes seen /light & dark bands/pattern of max and min 1

Explanation
Waves can reinforce or cancel /superpose to produce fringes
OR diffraction at slits causes waves to overlap 1

[6]

118. Frequency of spectral line for calcium

Use of $c = f\lambda$ 1

$f = 7.63 \times 10^{14}$ Hz 1

Ultra violet 1

Line spectrum

(A series of) lines on a dark /white background 1

Wavelength of calcium line

Use of $\Delta\lambda = \upsilon/c \times 393$ nm 1

393 ± 18 – 19 (nm) 1

λ = 411–2 nm 1

Hubble constant

See $365 \times 24 \times 60 \times 60/3.2 \times 10^7$ 1

Use of 3×10^8 [$d = 9.5 \times 10^{24}$] 1

Use of $\upsilon = Hd$ 1

$H = 1.50 \times 10^{-18}$ [no ue as unit given] 1

Recessional velocity

$\upsilon = 5.72 \times 10^7$ (ms^{-1}) [No u.e.] 1

[12]

119. Monochromatic source

Single wavelength/frequency 1

Description of experiment

Record/have values/measure both I and d 1

More than 2 values (accept range) of I or d 1

Calculate Id^2 for their values and check it is constant/
plot I vs d^{-2} and obtain a straight line through the origin 1

Precaution: black out room/eliminate reflections/use large d 1

Maximum wavelength

Use of $E = hf$ 1

Use of $\lambda. = c/f$ 1

$\lambda = 5.5\text{-}6 \times 10^{-7}$ m 1

[8]

120. Diagrams (completion)

Spring stretched, i.e. mass below equilibrium point + “up” arrow 1

Both “a” arrows towards centre 1

Amplitude

Amplitude = 0.065 ± 0.003 m 1

Spring Constant

T = 0.57- 0.59 (s) 1

Use of $T = 2\pi\sqrt{(m/k)}$ 1

k = 45- 49 [Depends on T above] 1

$N\,m^{-1}$ OR $kg\,s^{-2}$ 1

[7]

121. <u>Wavefront</u>

Line/surface joining points in phase 1

<u>Addition to diagrams</u>

Wavefront spacing ≈ as for incident waves (min. 3 for each) 1

1st diagram: wavefronts nearly semicircular 1

2nd diagram: much less diffraction 1

<u>Reception</u>

L W has long**er** wavelength 1

so is more diffracted around <u>mountains</u> [consequent] 1

[6]

122. <u>Gradient</u>

Gradient = (1.80 -2.00) [Ignore × 10^n errors] 1

<u>Slit spacing</u>

$s = \lambda$/above 1

s = 0.31-0.32 mm [3.1 to 3.2 × 10^{-4} m] 1

<u>Addition to graph</u>

Line of half gradient [Within 2 squares below 6,6] 1

[4]

123. <u>Explanation</u>

Clarity of written communication **(1)**
Wave reflects off bench **(1)**
(Incident and reflected) waves superpose/stationary wave is formed **(1)**
Maxima or antinodes where waves in phase or constructive interference occurs **(1)**
Minima or nodes where waves exactly out of phase or destructive interference occurs **(1)** 5

<u>Speed of sound</u>

See a value between 5.0 and 5.6 (cm) **(1)**
Use of $\upsilon = f\lambda$ **(1)**
λ = 2 × spacing **(1)**
320 m s^{-1} to 360 m s^{-1} **(1)** 4

<u>Explanation of contrast</u>

As height increases, incident wave gets stronger, reflected wave weaker **(1)**
So cancellation is less effective [consequent mark] **(1)** 2

[11]

124. <u>Magnitude of *F*</u>

$F = m\upsilon^2 / r$ **(1)**
Towards the centre **(1)** 2

<u>Calculation</u>

(i) 9.07×10^3 N **(1)**

(ii) $R = mg - m\upsilon^2 / r$ **(1)**
Substitutions **(1)**
5.37×10^3 N

[Calculation of $m\upsilon^2 / r$ max 1] **(1)** 4

<u>Explanation</u>

Required centripetal force > *mg* (so cannot be provided) **(1)** 1

<u>Critical speed</u>
Use of $(m)g = (m)\upsilon^2 / r$ **(1)**
15.7 m s^{-1} **(1)** 2

<u>Apparently weightless</u>
This means no force exerted on/by surroundings OR *R* = 0 OR only force acting is weight **(1)**
When car takes off it is in free fall [consequent] **(1)** 2

[11]

125. <u>Simple harmonic motion</u>
Acceleration proportional to displacement (from equilibrium position/ point) **(1)**
and in opposite direction/directed towards equilibrium position / point) **(1)** 2

OR accept fully defined equation

<u>Oscillations</u>

$x_0 = 0.036$ m **(1)**

Period = 7.60 s/20 = 0.380 s **(1)**
f = 2.63 Hz **(1)** 3

<u>Displacement when *t* = 1.00 s</u>

x = (–)0.026 m **(1)** 1

<u>How and why motion differs from prediction</u>

Motion is damped/amplitude decreases with time **(1)**
(Because of) air resistance **(1)** 2

[8]

126. Oscillating, system

Diagram: suitable oscillator **(1)**
method of applying periodic force of variable frequency **(1)** 2

Natural frequency:

(With no periodic force) displace oscillator and let it oscillate (freely) **(1)**

Frequency of this motion is natural frequency **(1)**

Forced oscillation:

Their system is being forced to oscillate/vibrate at driver's frequency **(1)**

Resonance:

Vary the frequency **(1)**

Oscillator has large amplitude at / near natural frequency **(1)** 5

[7]

127. Separation

Use of $\lambda = xs/D$ or Use of $s = \lambda D/x$ **(1)**
0.30 mm/3.0×10^{-4} m **(1)** 2

Addition of line to diagram (intensity variation)

Similar pattern with larger fringe spacing **(1)** 1

Explanation

No, because wavelength difference very small/0.6 nm **(1)**

So fringe spacings almost equal/fringes nearly coincide/
$\Delta x = 3.0 \times 10^{-4}$ mm **(1)** 2

[5]

128. Ionisation energy

(10.4 eV) × (1.6×10^{-19} J eV^{-1}) **(1)**
(–) 1.66×10^{-18}(J) **(1)** 2

Kinetic energy

0.4 (eV) **(1)** 1

Transition

Use of $E = hc/\lambda$ **(1)**
3.9 (eV) **(1)**
Transition is from (–)1.6 eV to (–)5.5 eV 3

[6]

129. Deductions about incident radiations

(i) Radiations have same frequency/same wavelength/ same photon energy **(1)**

(ii) Intensity is greater in (a) than in (b) **(1)** 2

Sketch graph (c)

Line of similar shape, starting nearer the origin on negative V axis **(1)** — 1

Maximum speed

Use of $E = hf$ **(1)**
Subtract 7.2×10^{-19} (J) **(1)**
Equate to $\frac{1}{2} m\upsilon^2$ **(1)**
3.1×10^6 ms^{-1} **(1)** — 4

[7]

130. Red shift

Change in wavelength/frequency of the light **(1)**

Wavelength increased/frequency decreased **(1)** — 2

Explanation of how red shift is thought to occur

Galaxies moving away (from us) **(1)**

Shift is due to Doppler effect **(1)**

(Suggests) universe is expanding **(1)**

Evidence for Big Bang **(1)** — Max 3

[5]

131. Fringes

This wavelength/790 nm is in IR region / eye cannot detect this wavelength **(1)** — 1

Fringe separation

Use of $\lambda = sx/D$ [Ignore 10^X errors] **(1)**
$x = 4.0$ mm **(1)** — 2

How fringe separation could be increased
Increase ***D***/decrease ***s*** **(1)** — 1

[4]

132. Velocity of galaxy
Calculation of 7 or 11nm, **(1)**
Consistent values substituted in $\Delta\lambda/\lambda$ $\Delta\lambda$ must be 7 or 11 **(1)**
[Ignore 10^X errors]
5.0 or 5.12×10^6 ms^{-1} (consequent mark) **(1)**
Moving away from the Earth/Milky Way/us/observer **(1)** — 4

Estimation of distance of galaxy from Earth

Use of $\upsilon = Hd$ **(1)**
$d = 2.8\text{-}2.9 \times 10^{24}$ m [Allow e.c.f their υ above] **(1)** — 2

[6]

133. Explanation

Diffraction **(1)**
Molecular/atomic separation ≅ 1nm/de Broglie wavelength **(1)** 2

Kinetic energy

Use of $\lambda = h/mv$ **(1)**
Use of k.e. = $1/2mv^2$ OR $p^2/2m$ **(1)**
k.e. = 9.1-9.2 × 10^{-23} J [no ecf] **(1)** 3

Wave-particle duality

QOWC **(1)**
When a wave/particle behaves like / have properties /have characteristics of a particle/wave **(1)**

Neutron is a particle in the (α) nucleus / it has momentum / mass / can collide **(1)**

Neutrons diffract/interfere, a wave like property. **(1)** 4

[9]

134. Description + diagram

Diagram to show:
Microwave source/transmitter and detector (not microphone) **(1)**
Transmitter pointing at metal plate/second transmitter from same source **(1)**
Written work to include:
Move detector perpendicular to plate/to and fro between /accept ruler on diagram **(1)**
Maxima and minima detected/nodes and antinodes detected **(1)** 4
[Experiments with sound or light or double slit 0/4]

Observation

In phase/constructive interference → maximum/antinode **(1)**
Cancel out/out of phase/Antiphase/destructive interference → minimum /node **(1)** 2

How to measure wavelength of microwaves
Distance between adjacent maxima/antinodes = λ/2 **(1)**
Measure over a large number of antinodes or nodes **(1)** 2

[8]

135. Light intensity

Use of $I = P / 4\pi r^2$ r = 120 ignore powers of ten. P can be 6 W or 0.9 W **(1)**

I = 5 (W m^{-2}) **(1)**

Assumption: Light spreads out spherically / no light absorbed / point source / no other source / obeys inverse square law **(1)** 3

Incident photon energies

Use of $E = hf$ **(1)**

Use of $c = f\lambda$ [ignore × 10^X errors] **(1)**
÷ e **(1)**
For 320 nm E = 3.9 (eV) **and** 640 nm E = 1.9 (eV) **(1)** 4

Photocurrent readings

Work function of Al > 3.9 / energies of the incident photons
OR threshold frequency is greater than incident frequencies **(1)**

For Li (φ = 2.3 eV / f = 5.6 × 10^{14} Hz / λ = 540 nm hence) a photocurrent at 320 nm but not 640 nm **(1)**
If intensity × 5 then photocurrent × 5 **(1)** 3

Stopping Potential
KE_{max} = 4.00/3.88 –2.30 = 1.7/1.58 [ignore anything with only e] **(1)**
Vs = 1.7/1.58 V **(1)** 2

[12]

136. Gradient of graph

Gradient = 2.5 **(1)**
Unit s^{-2} or negative sign **(1)**
Frequency

$(2\pi f)^2$ = 2.5 [or above value] **(1)**
f= 0.25 Hz [ecf ONLY for gradient error] **(1)** 4

Period

T = 4 s ecf their f **(1)** 1

Acceleration against time graph

Any sinusoidal curve over at least two cycles **(1)**

Negative sine curve **(1)**

y axis scale showing a = 20 (mm s^{-2}) OR x axis scale showing T = 4(s) / their T 3

[8]

137. Speed of rim of drum

$v = r\omega$ or $v = 2\pi r/T$ [either used] **(1)**

$\omega = \dfrac{2\pi \times 800 \text{ rev min}^{-1}}{60 \text{ s}}$ OR $T = \dfrac{60\text{s}}{800 \text{ rev min}^{-1}}$ **(1)**

= 18.4 m s^{-1} [3 sf min.] (no ue) **(1)** 3

Acceleration

Use of $a = r\omega^2$ OR $a = v^2/r$ **(1)**
1.5×10^3 ms^{-2} **(1)** 2

Addition of arrow and explanation

Arrow labelled A towards centre of drum **(1)**
Push of drum on clothing/normal contact exerted by drum on clothing **(1)** 2
[Normal reaction accepted]

Arrow of path

Arrow labelled B tangential to drum, from P, in anticlockwise direction **(1)** 1

[8]

138. Wavelength and wave speed calculation

λ = 0.96 m **(1)**

seeing f = 2 their λ (f = 2.1 Hz) **(1)** 2

Qualitative description

(Coil) oscillates / vibrates **(1)**

With SHM / same frequency as wave (their value) **(1)**

Parallel to spring / direction of wave **(1)** 3

[5]

139. Simple harmonic motion

Small angle of displacement/small amplitude OR negligible damping **(1)** 1

Period T

11.44 s **(1)**

Length of pendulum

Use of $T = 2\pi\sqrt{(l/g)}$ [Correct substitution into correct formula] **(1)**

32.5 m [Allow e.c.f. from 5.72 s only $\rightarrow l$ = 8.1 m] **(1)** 3

[4]

140. <u>Resultant force</u>

Direction of travel changing **(1)**

Velocity changing/accelerating **(1)**

<u>Force</u> is towards centre of circle **(1)** 3

<u>Why no sharp bends</u>

Relate sharpness of bend to r **(1)**

Relate values of υ, r and F **(1)** 2

[e.g. if r large, υ can be large without force being too large/if r small, υ must be small to prevent force being too large]

<u>Bobsleigh</u>

$N\cos\theta = mg$ **(1)**

$N\sin\theta$ **(1)**

$= m\upsilon^2/r$ or ma **(1)**

Proof successfully completed [consequent on using correct formula] **(1)** 4

<u>Calculation of angle</u>

77 – 78° **(1)** 1

[10]

141. <u>Diagram</u>

Shown and labelled:

Suitable source – laser or filament lamp/light source/monochromatic **(1)**
source <u>plus</u> single slit

Double slit plus screen or travelling microscope [unless laser used] **(1)** 2

<u>Procedure</u>

<u>Measure</u> distance from slits to screen [or focus plane of microscope] **(1)**
<u>Measure</u> spacing between <u>centres</u> of bright [or dark] fringes **(1)**
Substitute in $\lambda = xs/D$ **(1)** 3

<u>Precaution</u>

(Measure) distance <u>across</u> several fringes and find average x
OR maximise D to give maximum x **(1)** 1

<u>Value of D</u>

Laser	1 – 10 m	
Filament lamp	1 – 2 m	
Travelling microscope	0.1 – 2 m **(1)**	1

[7]

142. Wavelength

0.30 m **(1)** 1

Letter A on graph

A at an antinode **(1)** 1

Wavespeed

Use of $\upsilon = f\lambda$ **(1)**

11(10.8) m s^{-1} **(1)** 2

[allow ecf λ = 0.15 m ie υ = 5.4 m s^{-1}]

Phase relationship

In phase **(1)** 1

Amplitude

2.5 mm **(1)** 1

[6]

143. Identification of waves described

Description	Letter
Red light	**B**
Waves used for mobile telephone communication	**C**
Radiation capable of ionising matter	**A**

Any ONE correct **(1)**

Other TWO correct **(1)** 2

How does graph confirm that frequency is inversely proportional

Straight line of gradient – 1 [OR in working indicate $-\lg\lambda = \lg\lambda^{-1}$] **(1)**
OR substitute 2 pair of values to calculate a constant ($f\lambda$ constant)

Electromagnetic waves

All travel at the same speed **(1)** 2

[4]

144. Intensity of electromagnetic wave

Power per unit area **(1)** 1

Table

Ratio	Value	Explanation	
E_A/E_B	3/2	Photon energy = hc/λ / inversely proportional to λ	**(1) (1)**
N_A/N_B	2/3	N inversely proportional to E	**(1) (1)**

[Each value, 1 mark; each explanation, 1 mark] 4

Definition of work function

Minimum energy needed to remove an electron **(1)** 1

Photon energies in each beam and deductions of metal

Use of hc/λ **(1)**
Divide by 1.6×10^{-19} **(1)**
$E_A = 4.14$ eV OR $E_B = 2.76$ eV [At least one correct] **(1)**
Magnesium **(1)**
[Allow e.c.f. from wrong photon energies, i.e. any metal(s) with work functions between the calculated energies]

[OR for photoenergies in J:
Use of hc/λ **(1)**
Multiply any Φ (from table) by 1.6×10^{-19} **(1)**
$E_A = 6.63 \times 10^{-19}$ J OR $E_B = 4.42 \times 10^{-19}$ J **(1)**
Magnesium **(1)**] 4

[10]

145. Diagram

One arrow straight down (from –3.84 to – 5.02) **(1)**
Two arrows down (from –3.84 to –4.53, then – 4.53 to – 5.02) **(1)** 2

Transition T

T from – 5.02 to – 1.85 upwards **(1)** 1

Kinetic energy values and explanation of what has happened to lithium atom in each case

0.92 eV **(1)**
Atom stays in –5.02 (eV) level/nothing happens to it **(1)**

0.43 eV **(1)**

Atom excited to – 4.53 (eV) level **(1)** 4

Full credit is given to candidates who take the k.e. of the electron to be 0.92 J after collision. Any TWO correct energies with correct statement.

[7]

146. (a) Hubble constant

Attempt to find gradient **(1)**
1.9×10^{-18} s^{-1} **(1)** 2

Distance of this galaxy from Earth

$\Delta\lambda = 37.3$ or see $(410 - 372.7)$ **(1)**

Use of $\Delta\lambda/\lambda = \upsilon/c$ **(1)**

Use of $\upsilon = Hd$ [$\upsilon = 3.0 \times 10^{7}$ m s^{-1}] **(1)**

1.6×10^{25} m **(1)** 4

[full ecf H = 2×10^{-18} $s^{-1} \rightarrow 1.5 \times 10^{25}$ m]

(b) Balloon – position of three dots

P, Q, R further apart on larger balloon **(1)**

Approximately similar triangles, i.e. approx. isosceles with base approximately ½ of long sides **(1)** 2

How balloon can be used to model expansion of Universe

Quality of written communication **(1)**

Dots represent galaxies **(1)**

Balloon inflation represents expanding universe **(1)**

Dots further apart move apart faster, (as with galaxies) **(1)** 4

[12]

147. (a) Resultant force required

The direction of speed OR velocity is changing **(1)**
There is an acceleration/rate of change in momentum **(1)** 2

(b) (i) Angular speed

Use of an angle divided by a time **(1)**
7.3×10^{-5} rad s^{-1} OR 0.26 rad h^{-1} OR 4.2×10^{-3} ^{o} s^{-1} OR 15^{o} h^{-1} **(1)** 2

(ii) Resultant force on student

Use of $F = mr\omega^2$ OR $v = r\omega$ with $F = \frac{mv^2}{r}$ **(1)**

2.0 N **(1)** 2

(iii) Scale reading

Evidence of contact force = mg − resultant force **(1)**
Weight of girl = 588 (N) OR 589 (N) OR 60×9.81 (N) **(1)**
Scale reading = 586 N OR 587 N [ecf their mg − their F] **(1)** 3

[9]

148. Table 6

Wavelength of light	in range 390 nm – 700 nm	**(1)**
Wavelength of gamma	$\leq 10^{-11}$ m	**(1)**
Source	(unstable) nuclei	**(1)**
Type of radiation	radio (waves)	**(1)**
Type of radiation	infra red	**(1)**
Source	Warm objects / hot objects / above 0 K	**(1)**

[6]

149. (a) Calculation of intensity

6.0% of 100 (W) is 6 (W) **(1)**
Use of $I = P/4\pi r^2$ **(1)**
Intensity = 7.6×10^{-2} W m^{-2} **(1)** 3
Average photon energy

(b) Average energy = $\dfrac{7.6\times10^{-2}\,(Wm^{-2})}{2.4\times10^{17}\,(m^{-2}s^{-1})}$ [ecf intensity] **(1)**

Correct use of 1.6×10^{-19} **(1)**
Average photon energy = 2.0 (eV) [full ecf for I = 1.27 W ie P = 100 W giving 33.3 (eV)] **(1)** 3

[6]

150. (a) Amplitude
Maximum distance/displacement
From the mean position / mid point / zero displacement line / equilibrium point **(1)** 1
[If shown on a diagram, at least one full wavelength must be shown, the displacement must be labelled "a" or "amplitude" and the zero displacement line must be labelled with one of the terms above.]

(b) Progressive wave

Displacement at A: 2.0 (cm) [accept 2] **(1)**
Displacement at B: 2.5 (cm) to 2.7 (cm) **(1)**
Displacement at C: 1.5 to 1.7 (cm) **(1)** 3

Diagram

[Minimum] one complete sinusoidal wavelength drawn **(1)**

Peak between A and B [accept on B but not on A] **(1)**

y = 0 (cm) at x = +2.6 cm with EITHER x = +6.2 cm OR x = − 1.0 cm **(1)** 3

[7]

151. (a) Transverse wave

(Line along which) particles/em field vectors oscillate/vibrate **(1)**
Perpendicular to **(1)**
Direction of travel or of propagation or of energy flow or velocity **(1)** 3

(b) Differences

Any two:

Standing waves	Progressive waves	
1. store energy	1. transfer energy **(1)**	
2. only AN points have max ampl/displ	2. all have the max ampl/displ **(1)**	
3. constant (relative) phase relationship	3. variable (relative) phase relationship **(1)**	Max 2

(c) (i) Droplets

Formed at nodes / no net displacement at these points **(1)** 1

(ii) Speed

Use of $\upsilon = f\lambda$ **(1)**
Evidence that wavelength is twice node–node distance **(1)**
Wavelength = 1.2 (cm) **(1)**
Frequency = 8.0 [8.2 / 8.16] Hz or s^{-1} only **(1)** 4

[10]

152. (a) (i) Diagram

Component ($mg\cos\theta$) correctly drawn – good alignment and approximately same length **(1)** 1

(ii) Diagram

Component ($mg\sin\theta$) correctly drawn, reasonably perpendicular to T to the left **(1)** 1

(iii) Acceleration

Use of $mg\sin\theta = ma$ [must see 9.8(1) (m s^{-2}) not 10 for this mark] **(1)**
a = 0.68 m s^{-2} [for this mark allow 0.69 m s^{-2} ie 10 m s^{-2} for g] **(1)** 2

(iv) Direction

Directed to O along arc/in same direction as $mg\sin\theta$/tangential to arc **(1)** 1

(b) Acceleration of free fall

See $T_2 = \frac{4\pi^2 l}{g}$ [or see numbers] **(1)**
Evidence of difference / $l_1 - l_2$ = 1.0 (m) **(1)**
Correct final rearrangement for g **(1)** 3

$$\left[g = \frac{4\pi^2 1.0(m)}{4.2^2(s^2) - 3.7^2(s^2)} \right]$$

[8]

153. (a) Electromagnetic Doppler effect

Change in the frequency/wavelength (of the light/radiation from a source) **(1)**
because of relative motion between source and observer **(1)** 2
[If giving specific examples must cover both possibilities of change in frequency and relative motion eg describe red shift and blue shift]

(b) Hubble's conclusions

Any two from:

- (Recession) velocity $\propto$ galaxy distance [NOT stars]
- Red shift due to a galaxy moving away from Earth/observer
- Deduction of the expanding Universe [not the Big Bang] **(1) (1)** 2

[only penalise lack of galaxy **once**]

(c) Minimum velocity

$\Delta\lambda$= 660 (nm) − 390 (nm) = 270 (nm) **(1)**

Their $\Delta\lambda$/ their short $\lambda = v/c$ **(1)**

Correct substitution of $c = 3 \times 10^8$ (m s^{-1}) **(1)**

Maximum velocity = 2.1×10^8 (m s^{-1}) **(1)** 4

(d) Critical mean density

Density is large enough to prevent Universe expanding for ever **(1)**
but not too big to cause a collapse/contraction of the Universe **(1)** 2

[10]

154. Photoelectric effect

(a) Explanation:

Particle theory: one photon (interacts with) one electron **(1)**

Wave theory allows energy to 'build up', i.e. time delay **(1)** 2

(b) Explanation:

Particle theory: *f* too low then not enough energy (is released by photon to knock out an electron) **(1)**

Wave theory: Any frequency beam will produce enough energy (to release an electron, i.e. should emit whatever the frequency) **(1)** 2

[4]

155. (a) Units

s^{-1} / km s^{-1} kpc^{-1} /km s^{-1} Mpc^{-1} **(1)** 1

(b) Estimate

See $d = vt$ or rearrangement **(1)**

Substitution in $v = Hd$ for v to give $t = 1/H$ **(1)**

[Substitute value of H to obtain t]

Assumption

Since the Big Bang/start of time **(1)**

(All) galaxies/galaxy is/are travelling at constant speed /no **(1)**
gravitational attractive forces / Universe expands at a constant rate

[*H* is constant scores max 1 for Assumption. Allow credit for the 4 marking points anywhere within (b)] 4

[5]

156. (a) Superposition of waves

The resultant displacement at (point where waves meet) **(1)**
is the (vector) addition of the individual displacements **(1)** 2
Displacement need only be seen once]
[May be done by diagram: 1 for indication of vector; 1 for indication of scale]

(b) (i) Diagram

Lamp, single and double slit / laser and double slit (and screen) **(1)**
[lamp or laser must be labelled]
s about 1 mm / s given in range 0.1 mm ≤ s ≤ 1 mm **(1)**
screen at a distance of > 1 m from slits **(1)** 3

(ii) Use of higher frequency

dots / fringe width decreases / fringes get closer together / colour of fringe moves towards blue end of spectrum **(1)** 1

(iii) Single slit used

[marks awarded for labelled diagram, intensity graph or text]

Central brighter fringe / side fringes less bright **(1)**
(symmetrical) fringes on either side **(1)**
Central maximum ~ twice the width of side fringes **(1)**

[no credit for simply stating "single slit diffraction occurs"] 3

[9]

157. (a) Definition SHM

Acceleration / force is (directly) proportional to displacement but in **(1)**
opposite direction / towards equilibrium point / mean point / midpoint **(1)** 2

(b) Graph

Curve **Y** / (i) sine curve **(1)**
initially – ve (consequent mark) **(1)**

Curve **Z** / (ii) cosine curve **(1)**
initially – ve (consequent mark) **(1)** 4

[Both graphs drawn without labels score 0/4]

(c) Calculations

(i) use of $T = 2\pi\sqrt{\frac{m}{k}}$ OR quote *f* formula **(1)**

Use of / = 1/*T* use of formula **(1)**
f = 2.0 **(1)** (Hz) *f* = 2.0 **(1)** (Hz) **(1)**

(ii) use of speed = $2\pi f x_0$ ***(1)***

$= 2\pi \times 2.01 \times 30 \times 10^{-3}$
$= 0.38 \text{ m s}^{-1}$ **(1)** 5

[11]

158. Frequency

(a) (i) $1.0(3) \times 10^{10}$ Hz **(1)** 1

Electromagnetic Spectrum

(ii) IR, microwave & radio in correct order above visible **(1)**
UV with either X rays / Gamma rays / both in correct order below visible **(1)**

(iii) Wavelength at boundary 1×10^{-8} m / 1×10^{-9} m **(1)** 3

Plane polarised

(b) (i) Vibrations/oscillations (of electric field/vector) **(1)**
In one direction/plane (of oscillation) **(1)** 2

Description

(ii) Diagram showing generator labelled transmitter/generator/source/emitter **(1)**
And suitable detector eg shows how signal is observed by using **(1)**
(micro)ammeter/cro/loudspeaker/computer with interface
[Ignore anything drawn between generator and detector but for each mark do not give credit if a grille etc is attached]

To detect max and min **(1)**
(Rotate through) 90° between max and min **(1)** 4

[10]

159. (a) Explanation

QOWC **(1)**

UV/red photon **(1)** 2

$E_{UV} > E_R$ / f_{uv} ***(1)***
$E_{UV} > \Phi$ / $f_{uv} > f_{TH}$ (so electron can break free) **(1)**
One photon absorbed by one electron **(1)**
Both metal plate and electron are negative or repel (each other) **(1)** max 2

(b) (i) Intensity red light increased

nothing / no discharge **(1)**

(ii) Intensity of UV increased

(Coulombmeter) discharges quicker **(1)** 2

(c) Max KE

Use of $E = hc/\lambda$ **(1)**
conversion of eV to J or vice versa i.e. appropriate use of 1.6×10^{-19} **(1)**
Subtraction $hc/\lambda - \Phi$ [must use same units] or use of full equation **(1)**
max KE = 2.2×10^{-19} J **(1)** 4

[Candidates may convert photon energy to eV leading to max KE = 1.4 eV]

[10]

160. (a) Definition of longitudinal wave
Oscillations OR particles (of medium) move **(1)**
Parallel to direction of wave propagation/travel / energy transfer **(1)** 2
2^{nd} mark consequent on 1^{st}]

(b) Collapsing tower
Resonance **(1)**
Frequency of quake = natural frequency of tower **(1)**
[Allow resonant frequency for natural frequency]
Max energy transfer **(1)**
Very large increase in amplitude of oscillation or maximum amplitude **(1)** max 3

[5]

161. (a) Radius of circular path

Correct use of $v = \frac{2\pi r}{T}$ (allow substitution of their T) **(1)**

Radius = 70 – 80 m (74.48 m) **(1)** 2

(b) Resultant force

$F = \frac{mv^2}{r}$ [seen or used] **(1)**

Force = 0.08 N (0.077 N) [Allow ecf of their radius.] **(1)**

Towards the centre of the circular path / towards hub. **(1)** 3

(c) Forces on the man

(i) Force P : Normal contact/reaction force / EM force / push of **(1)**
capsule or floor on man

Force Q : Pull of Earth on man / weight / gravitational pull **(1)** 2

(ii) Resultant force (to centre) **(1)**
(at A provided by) friction **(1)** 2

(iii) at B resultant provided (by force Q being greater than P) **(1)** 1

[10]

162. Explanation

There is a resultant (or net or unbalanced) force **(1)**

Plus any 3 of following:–

Direction of motion is changing **(1)**
Velocity is changing **(1)**
Velocity change implies acceleration **(1)**
Force produces acceleration by $F = ma$ (or N2) **(1)**
Force (or acceleration) is towards centre / there is a centripetal **(1)**
force (or acceleration) / no force (or acceleration) parallel to motion
No work done, so speed is constant **(1)** Max 3

[4]

163. (a) Time interval between wavefronts
1/50 or 0.02 s **(1)** 1

(b) (i) Time interval between slits
1/50 or 0.02 [No ue] **(1)** 1

(ii) Angular speed
Time for 1 revolution = 12 × previous answer / Angle between slits = 2π/12 / Frequency = 50/12 **(1)**
26.2 [3 sf minimum] or ecf from wrong time in (i) **(1)** 2
[No ue]

e.g. $\omega = 2\pi/(12 \times 0.02\text{ s})$
$= 26.2\text{ rad s}^{-1}$

(iii) Velocity of A
Use of $v = r\omega$ ***(1)***
3.9 m s^{-1} **(1)** 2

e.g. $v = 0.15\text{ m} \times 26\text{ rad s}^{-1}$
$= 3.9\text{ m s}^{-1}$
[No marks for using $v = 2\pi f x_0$]

(iv) Ratios
$\omega_A : \omega_B$ = 1 : 1 or 1 **(1)**
$v_A : v_B$ = 3 : 2 or 1.5 **(1)** 2
[Accept any correct numbers in either format]

[8]

164. (a) Experimental verification

QOWC **(1)**
Measure T using clock or motion sensor or video camera or digital **(1)**
camera [Don't accept light gates]
for a range of masses (or various masses) **(1)**
Plot T *vs* $m^{1/2}$ / Plot T^2 *vs* m / Plot log T vs log m / calculate $T/m^{1/2}$
or T^2/m **(1)**

Str line through origin / Str line through origin / Str line gradient **(1)**
0.5 / constant
One precaution **(1)**
e.g. Use fiducial (or reference) mark
Repeat and average
No permanent deformation of spring
Small amplitude or displacement
Measure at least 10T — Max 5

(b) Natural frequency

Use of $T = 2\pi\sqrt{\frac{m}{k}}$ **(1)**

Use of $T = \frac{1}{f}$ **(1)**

3.8 (Hz) [2sf minimum No ue] **(1)** — 3

e.g. $T = 2\pi\sqrt{(0.4 \text{ kg} / 230 \text{ N m}^{-1})}$
$= 0.262$ s
$f = 1 / 0.262$ s
$= 3.8$ Hz

(c) Explanations
Natural frequency:
Freq of free vibrations / freq of unforced vibrations / freq when it **(1)**
oscillates by itself (or of its own accord) / freq of oscillation if
mass is displaced
[Don't accept frequency at which it resonates, frequency at which
it oscillates naturally, frequency if no external forces]

Resonance:
When vibration is forced (or driven) at natural frequency **(1)**
Amplitude (or displacement or oscillation) is large
(or violent or increases) **(1)**
Amplitude is a maximum / large energy transfer **(1)** — 4

[Accept 4 Hz for natural frequency]

[12]

165. (a) (i) Typical values
Slit separation: 0.1 to 1.0 mm **(1)**
Distance: 0.5 to 10 m **(1)** — 2

(ii) Fringe separation
Correct measurement to give separation on grid **(1)**
i.e. 12 mm, or correct distance across stated number of fringes
Use of scale **(1)**
6 mm [Only award if first mark gained] **(1)** 3

OR (if they think "separation" means half *x*)
Correct measurement to give separation on grid **(1)**
i.e. 6 mm, or correct distance across stated number of fringes
Use of scale **(1)**
[2 marks max]

OR (if they use formula)
Use of $\lambda = xs/D$ **(1)**
[See 720 for λ, and any values for *(D, s)* except (9.6, 6)]
[1 mark max]

[No marks for using measurements off the apparatus diagram]

(b) Blue Fringes
5 equally spaced fringes centred at O [Ignore additional fringes] **(1)**
Fringe centres 8 mm apart on grid **(1)**
Bands and gaps equal width **(1)** 3
[Mark all points on diagram, ignoring working.]
[No marks if fringe pattern drawn is identical to the red one]

(c) Central fringe
White centre **(1)**
Red edge(s) / red furthest from centre **(1)** 2

[10]

166. (a) Solar Power
Use of $P = I\pi r^2$ [no component needed for this mark] **(1)**
Use of cos 40 or sin 50 (with *I or A*) **(1)**
2.2 [2 sf minimum. No ue] **(1)** 3

e.g. $P = 1.1 \times 10^3 \text{ W m}^{-2} \times \cos 40 \times \pi(29 \times 10^{-3} \text{ m})^2$
= 2.2 W

(b) Energy
Use of $E = Pt$ **(1)**
1.8×10^4 J/2.0×10^4J **(1)** 2

e.g. $E = 2.2\text{W} \times (2.5 \times 3600 \text{ s})$
$= 2.0 \times 10^4$ J

[5]

167. (a) Graph
Straight line with positive gradient **(1)**
Starting the straight line on a labelled positive f_0 **(1)**
[Curved graphs get 0/2. Straight line below axis loses mark 2
unless that bit is clearly a construction line.] 2

(b) Work function
From the y intercept **(1)**
[Accept if shown on graph]
OR Given by gradient × f_0 (or $h \times f_0$) [Provided that f_0 is marked on their graph, or they say how to get it from the graph]
OR Read f and E_k off graph and substitute into $E_k = hf - \varphi$
[Curved graph can get this mark only by use of hf_0 or equation methods.] 1

(c) Gradient
Gradient equals Planck constant **(1)** 1

[Curved graph can't get this mark]

[4]

168. (a) Wavelength
eV to J **(1)**
Use of $\Delta E = hf$ **(1)**
Use of $c = f\lambda$ **(1)**
1.8×10^{-11} [2 sf minimum. No ue] **(1)** 4

e.g. f =
$(-1.8 \text{ keV} - (-69.6 \text{ keV})) \times (10^3 \times 1.6 \times 10^{-19} \text{ J keV}^{-1}) / 6.6 \times 10^{-34} \text{ J s}$
$= 1.64 \times 10^{19}$ Hz
$\lambda = 3.00 \times 10^8 \text{ m s}^{-1}/1.64 \times 10^{19}\text{Hz}$
$= 1.8 \times 10^{-11}$ m

(b) Type
X rays [Accept gamma rays] **(1)** 1

[5]

169. (a) (i) Hubble constant
Use of $v = Hd$ or gradient = H **(1)**
Converts y to s i.e. × (365 × 24 × 60 × 60) **(1)**
Correct × by 'c' **(1)**
[Seeing 9.46×10^{15} gets previous two marks]
1.7 to 1.8×10^{-18} (s^{-1}) **(1)** 4

[No marks for a bald answer]

e.g. $H = 60 \times 10^6 \text{ m s}^{-1}$ /
$(3.6 \times 10^7 \text{ ly} \times 365 \times 24 \times 3600 \times 3 \times 10^8 \text{ m ly}^{-1})$
$= 1.8 \times 10^{-18} \text{ s}^{-1}$

(ii) Uncertainty
Distance / d **(1)** 1

(b) Age of Universe
States that $d = vt$ (any arrangement) **(1)**
Combines this with restated Hubble law (any arrangement) to give
$t = \frac{1}{H}$ **(1)** 2

(c) Recessional Speed

Red shift = 76 nm / 469 – 393 nm **(1)**

Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ **(1)**

5.8×10^7 m s^{-1} **(1)** 3

e.g. $v = 76 \times 10^{-9}$ m $\times 3 \times 10^8$ m s^{-1}/393×10^{-9} m
$= 5.8 \times 10^7$ ms^{-1}

(d) Average mass-energy density

Closed : high density/above critical density **(1)**
Then gravitational pull (or force or attraction) sufficient to cause
Big Crunch/pull everything back/stop expansion **(1)**
[NOT to hold the galaxies together]
OR equivalent argument for Open
[Don't accept mass for density in mark 1 or just "gravity" in mark 2] 2

[12]