Please check the examination details below before entering your candidate information

Candidate surname	Other names
StemUp Model Solution	

Pearson Edexcel Level 3 GCE

Centre Number	Candidate Number

Friday 5 June 2020

Afternoon (Time: 2 hours 30 minutes)	Paper Reference **9PH0/03**

Physics

Advanced

Paper 3: General and Practical Principles in Physics

You must have: Ruler	Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*

Information

- The total mark for this paper is 120.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- In questions marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- You may use a scientific calculator.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- You are advised to show your working in calculations including units where appropriate.

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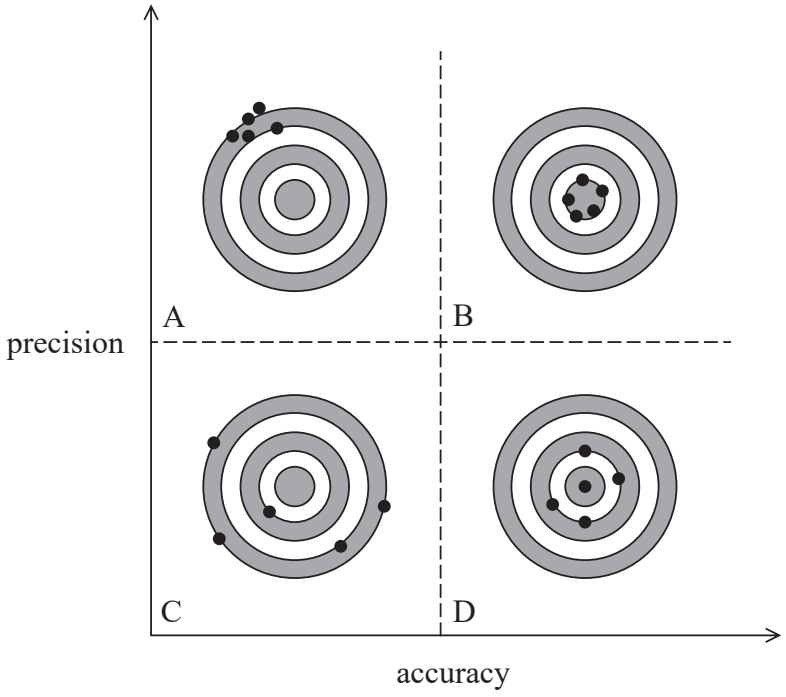
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Answer ALL questions in the spaces provided.

1 A teacher is explaining the differences between accuracy and precision to her students. She draws the following diagram, which shows different degrees of accuracy and precision. The circles represent targets A, B, C and D and the dots represent arrows hitting the targets.



Explain how targets A, B, C and D represent differing degrees of accuracy and precision.

(4)

High precision means a small spread of values (the arrows are close together). High accuracy means the values are close to the true value (the centre of the target).

A is precise but not accurate: there is a small spread but it is displaced from the centre of the target.

B is both accurate and precise: there is a small spread centred on the target.

C is neither accurate nor precise: there is a large spread displaced from the centre.

D is accurate but not precise: there is a large spread but it is centred on the target.

(Total for Question 1 = 4 marks)

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2 A student released a ping pong ball in front of a metre rule and used a phone camera to record the motion of the ball as it fell. The phone camera captures 60 images per second, which may be played back one image at a time.

(a) The ball was dropped from a height such that it reached its terminal velocity as it passed the metre rule.

(i) Explain how the terminal velocity of the ball could be determined using the phone camera recording.

(4)

Play the recording back one image at a time and identify when the distance fallen between frames has become constant (terminal velocity reached).

Measure the distance fallen against the metre rule over a number of frames (e.g. 10 frames), or measure it between frames several times and calculate an average distance.

The time between frames is 1/60 s, so the time taken = number of frames × 1/60 s.

Terminal velocity = distance fallen ÷ time taken (v = s/t).

(ii) Explain how a systematic error could affect the value obtained for the terminal velocity.

(2)

There may be parallax error in reading the ball position against the metre rule, so the recorded distance may be greater than the actual distance.

So the calculated terminal velocity would be greater than the true value.

(b) This experiment could have been attempted using a stopwatch to measure the time as the ping pong ball fell.

Explain an advantage of using a phone camera rather than a stopwatch.

(2)

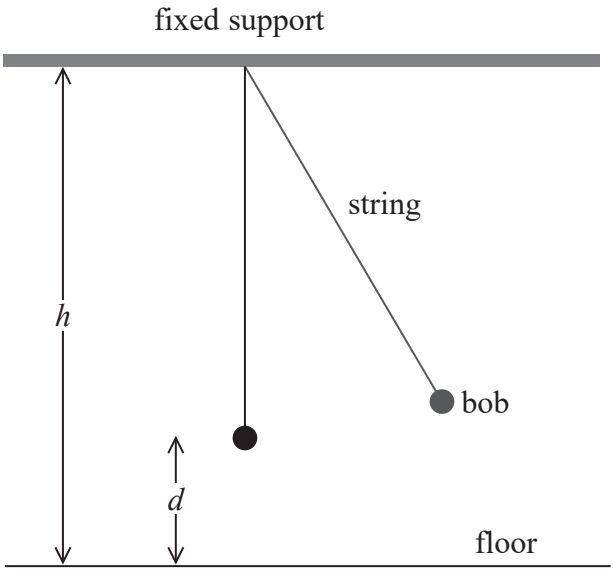
With a phone camera there are no reaction time errors when starting and stopping the stopwatch, and the recording can be replayed a number of times.

So the uncertainty in the measured times is reduced, giving a more accurate value for the velocity.

(Total for Question 2 = 8 marks)

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3 A student carried out an experiment with a pendulum hung from a fixed support. The fixed support was a distance h above floor level as shown.



As the student was unable to measure the length of the pendulum directly, she measured the distance d from the bob to the floor.

(a) To determine the period T of the pendulum, the student used the following method:

- release the bob from its highest position and start a stopwatch
- stop the stopwatch when the bob reaches the same position again.

Criticise the student's method for measuring the period.

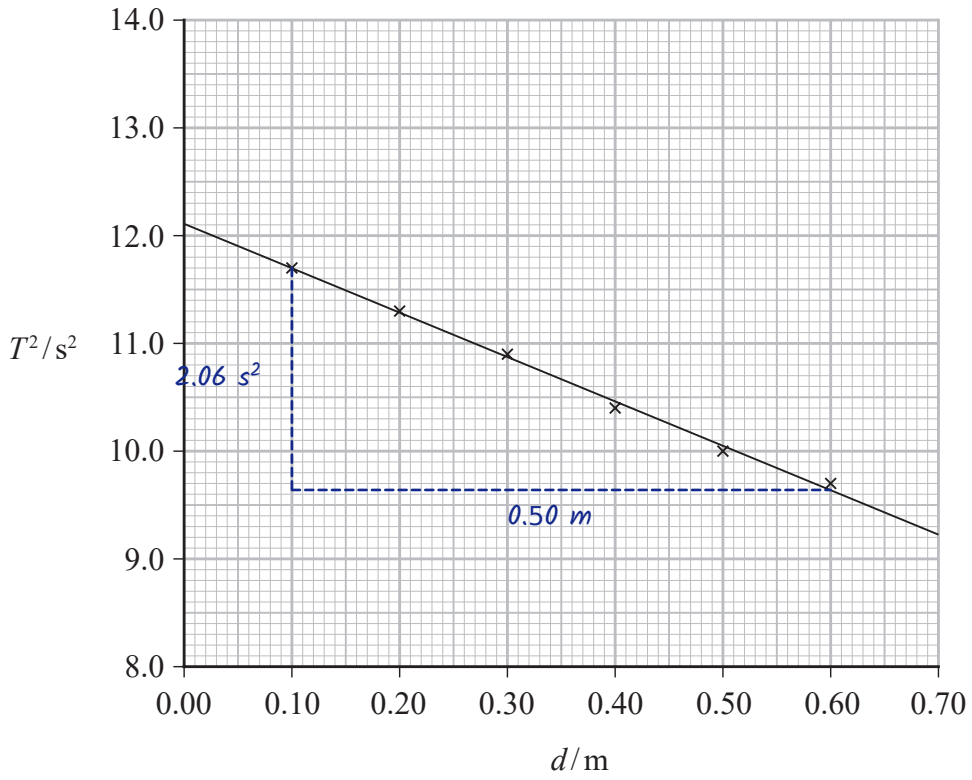
(2)

She only timed one oscillation: she should time several (e.g. 10) oscillations and divide by the number of oscillations.

She should time from the equilibrium position (where the bob moves fastest), using a fiducial marker as a reference point, not from the maximum displaced position.

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(b) The student used her data to plot a graph of T^2 against d as shown below.



Determine a value for the acceleration due to gravity g.

(5)

$T = 2\pi\sqrt{(l/g)}$, so $T^2 = (4\pi^2/g)\, l$, and the length of the pendulum $l = h - d$

$T^2 = (4\pi^2/g)(h - d)$, so $T^2 = -(4\pi^2/g)\, d + (4\pi^2/g)\, h$

This is $y = mx + c$, so the gradient of the graph $= -4\pi^2/g$

Gradient $= (9.64 - 11.70)\ s^2 \div (0.60 - 0.10)\ m = -4.12\ s^2\ m^{-1}$

$g = 4\pi^2 \div 4.12\ s^2\ m^{-1} = 9.6\ m\ s^{-2}$

$g =$ 9.6 m s^{-2}

(Total for Question 3 = 7 marks)

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*4 Radium is a radioactive element. The most common isotope of radium has a half-life of almost two thousand years. A sample of radium can remain at a higher temperature than its surroundings for a long period of time.

Explain how a sample of radium is able to release significant amounts of energy over a long period of time.

(6)

Radium nuclei are unstable and decay randomly. The rate of decay (activity) depends on the number of unstable nuclei in the sample: $A = \lambda N$.

Radium has a very large half-life (about 2000 years), so the decay constant λ is small and unstable nuclei remain present in the sample for a long time. A sample contains a very large number of nuclei, so decays keep occurring at a significant rate for a long period of time.

When a nucleus decays there is a small decrease in mass Δm (the binding energy per nucleon of the products is greater).

This mass is converted to energy according to $\Delta E = c^2 \Delta m$.

Δm is small but c^2 is very large, so a significant amount of energy is released in each decay.

The energy released by the decays becomes kinetic energy of the atoms in the sample, so the internal energy increases and the sample stays at a higher temperature than its surroundings.

(Total for Question 4 = 6 marks)

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5 The photograph shows a statue of Buddha in Sri Lanka, which is protected by a lightning conductor.



© Valery Shanin/123RF

(a) During a storm, a potential difference of 2.7 MV was generated between a cloud and the top of the lightning conductor on the statue. A flash of lightning passed between the cloud and the lightning conductor, producing a current of 25 kA for a time of 7.5 ms.

Calculate the energy transferred by the lightning strike.

(3)

$Q = It = 25 \times 10^3\ A \times 7.5 \times 10^{-3}\ s = 188\ C$

$W = QV = 188\ C \times 2.7 \times 10^6\ V = 5.1 \times 10^8\ J$

Energy transferred = $5.1 \times 10^8\ J$

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(b) The lightning conductor is a length of copper wire with a diameter of 1.2×10^{-2} m and a resistance of 4.3×10^{-3} Ω. It runs along the back of the statue from the base to a height of 1.5 m above the top of the statue.

A guidebook claims that the statue is over 30 m high.

Assess the validity of this claim.

resistivity of copper = 1.7×10^{-8} Ω m

(4)

$A = \pi d^2/4 = \pi \times (1.2 \times 10^{-2}\ m)^2 \div 4 = 1.13 \times 10^{-4}\ m^2$

$R = \rho l/A$, so $l = RA/\rho = (4.3 \times 10^{-3}\ \Omega \times 1.13 \times 10^{-4}\ m^2) \div 1.7 \times 10^{-8}\ \Omega\ m =$ 28.6 m

Height of statue = 28.6 m − 1.5 m = 27.1 m

27.1 m is less than 30 m, so the statue is not over 30 m high and the claim is not valid.

(c) Give a reason why the lightning conductor should be taller than the statue.

(1)

So that the lightning makes contact with the conductor rather than the statue.

(Total for Question 5 = 8 marks)

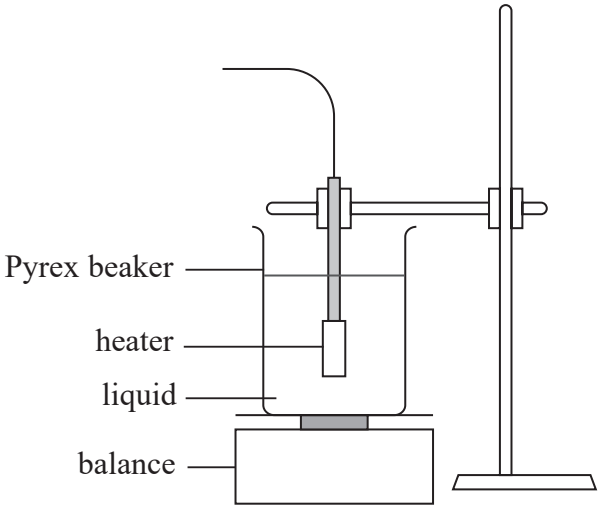
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6 A student determined the latent heat of vaporisation of a liquid using an electrical heater to boil the liquid in a Pyrex beaker.

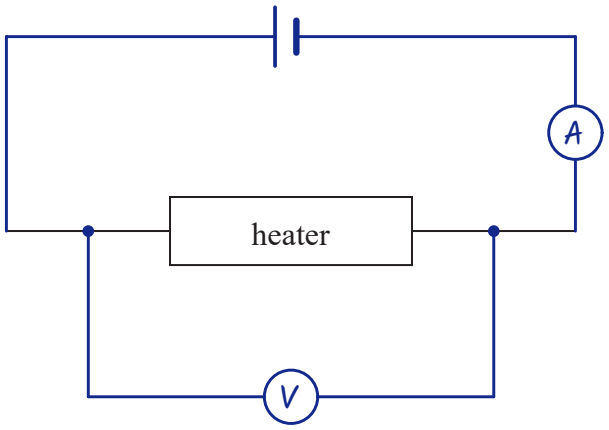
The apparatus used is shown below.



(a) She connected the heater into a circuit and took measurements of the potential difference V and the current I for the heater.

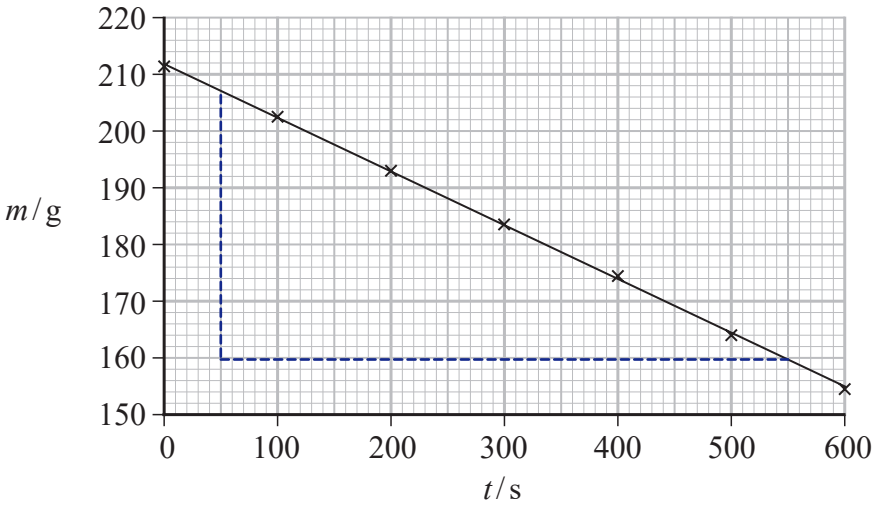
Complete the circuit diagram to show a suitable circuit.

(2)



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(b) The student monitored the mass of the beaker and the liquid m over the time t for which the liquid was boiling. Her results are plotted on the graph.



The student used her graph to determine a value for the latent heat of the liquid in the beaker. She concluded that the liquid was pure water.

Liquid	Latent heat of vaporisation / MJ kg^{-1}
Pure water	2.26
Weak salt water solution	2.10
Strong salt water solution	2.00

Comment on the validity of the student's conclusion.

$V = 20.5\,\text{V}$

$I = 10.5\,\text{A}$

(7)

Gradient = $\Delta m/\Delta t$

= $(206.3 - 159.7) \times 10^{-3}$ kg ÷ $(550 - 50)$ s = 9.33×10^{-5} kg s^{-1}

$P = VI = 20.5\ \text{V} \times 10.5\ \text{A} = 215\ \text{W}$

$\Delta E = L\Delta m$ and $P = \Delta E/\Delta t$, so $L = P \div (\Delta m/\Delta t) = 215\ \text{W} \div 9.33 \times 10^{-5}\ \text{kg s}^{-1} =$

$2.30 \times 10^{6}\ \text{J kg}^{-1}$

$2.30\ \text{MJ kg}^{-1}$ is closest to the value for pure water ($2.26\ \text{MJ kg}^{-1}$), which supports her conclusion.

But not all of the energy supplied is used to boil the liquid: thermal energy is transferred to the surroundings, so the true L is less than $2.30\ \text{MJ kg}^{-1}$. It could be a salt water solution (2.10 or $2.00\ \text{MJ kg}^{-1}$), so her conclusion is not valid.

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(c) Explain how this method might be modified to improve the accuracy of the student's conclusion.

(2)

Use lagging to insulate the beaker (and a lid) from the surroundings, so that a greater proportion of the energy supplied is used to boil the liquid (minimising heat loss to the surroundings).

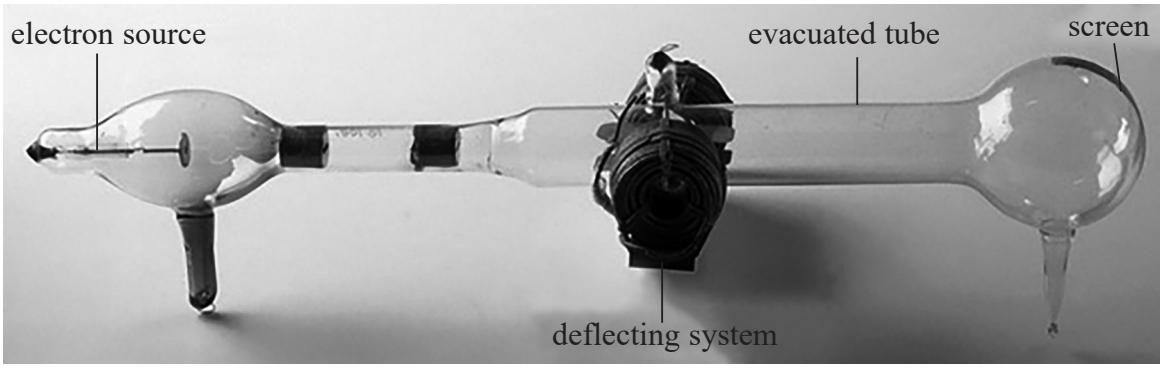
(Total for Question 6 = 11 marks)

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7 At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown.



© Science Museum London

Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

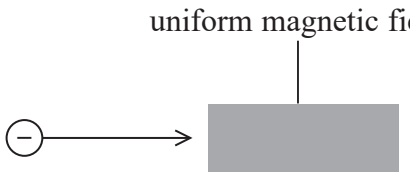
(a) Explain how electrons from the source become a beam of high-energy electrons.

(2)

The potential difference creates an electric field between the electrodes.

The electric field does work on the electrons (force accelerates them), increasing their kinetic energy.

(b) An electron is travelling left to right and enters a region of uniform magnetic field as shown below. The direction of the magnetic field is perpendicular to the direction of travel of the electron.



(i) The magnetic field deflects the electron in the direction up the page.

Explain the direction of the magnetic field that would produce this deflection.

(2)

The field is (perpendicularly) out of the page.

Electrons move to the right so conventional current is to the left; by Fleming's left-hand rule the force is perpendicular to the field and the current.

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(ii) Explain why the electron would travel in a circular path if no other forces acted on it.

(2)

The magnetic force on the electron is of constant magnitude and always perpendicular to its direction of motion, so it causes an acceleration towards the centre of a circle (a centripetal force).

(c) In a modern version of Thompson's experiment, a uniform electric field of electric field strength E is applied so that the electric and magnetic forces on the electrons are equal and in opposite directions.

(i) Show that for electrons to be undeflected their velocity must be given by

$$v = \frac{E}{B}$$

where B is the magnetic flux density of the magnetic field.

(2)

Magnetic force $F = Bev$ and electric force $F = eE$

Undeflected when the forces are equal: $Bev = eE$, so $v = E/B$

(ii) The beam is produced by accelerating electrons through a potential difference of 250 V. The electric field strength is $1.4 \times 10^4\,\text{V m}^{-1}$. The magnetic flux density is 1.5×10^{-3} T.

Calculate the value of the specific charge e/m for the electron using this data.

(3)

$v = E/B = 1.4 \times 10^4\ \text{V m}^{-1} \div 1.5 \times 10^{-3}\ \text{T} = 9.33 \times 10^6\ \text{m s}^{-1}$

$eV = \frac{1}{2}mv^2$ ($W = QV = E_k$), so $e/m = v^2/2V$

$e/m = (9.33 \times 10^6\ \text{m s}^{-1})^2 \div (2 \times 250\ \text{V}) = 1.7 \times 10^{11}\ \text{C kg}^{-1}$

$e/m =$ $1.7 \times 10^{11}\ \text{C kg}^{-1}$

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(d) In his original experiments, Thompson determined the specific charge of a range of particles. His results indicated that the specific charge of an electron is about 2000 times bigger than that for a hydrogen ion.

Deduce what conclusion can be made from this information.

(1)

The charge is the same size, so the hydrogen ion must be about 2000 times more massive than the electron.

(Total for Question 7 = 12 marks)

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8 A student investigated the rate at which a hot liquid transfers thermal energy to the surroundings. He placed hot water in a Pyrex beaker and measured the temperature of the water using a liquid-in-glass thermometer.

He obtained the following data for the temperature θ of the water at times t. He measured t using a stopwatch.

t / s	θ / °C	Δθ / °C	ln (Δθ / °C)
0	95	72	4.277
120	87	64	4.159
240	81	58	4.060
360	76	53	3.970
480	71	48	3.871

temperature of surroundings = 23 °C

Theory suggests that a liquid transfers internal energy to the surroundings at a rate proportional to the temperature difference $\Delta\theta$ between the liquid and the surroundings.

This leads to the expression

$$\Delta\theta = \Delta\theta_0 e^{-bt}$$

where b is a constant and $\Delta\theta_0$ is the initial temperature difference.

(a) Explain why a graph of ln $\Delta\theta$ against t should be a straight line.

(2)

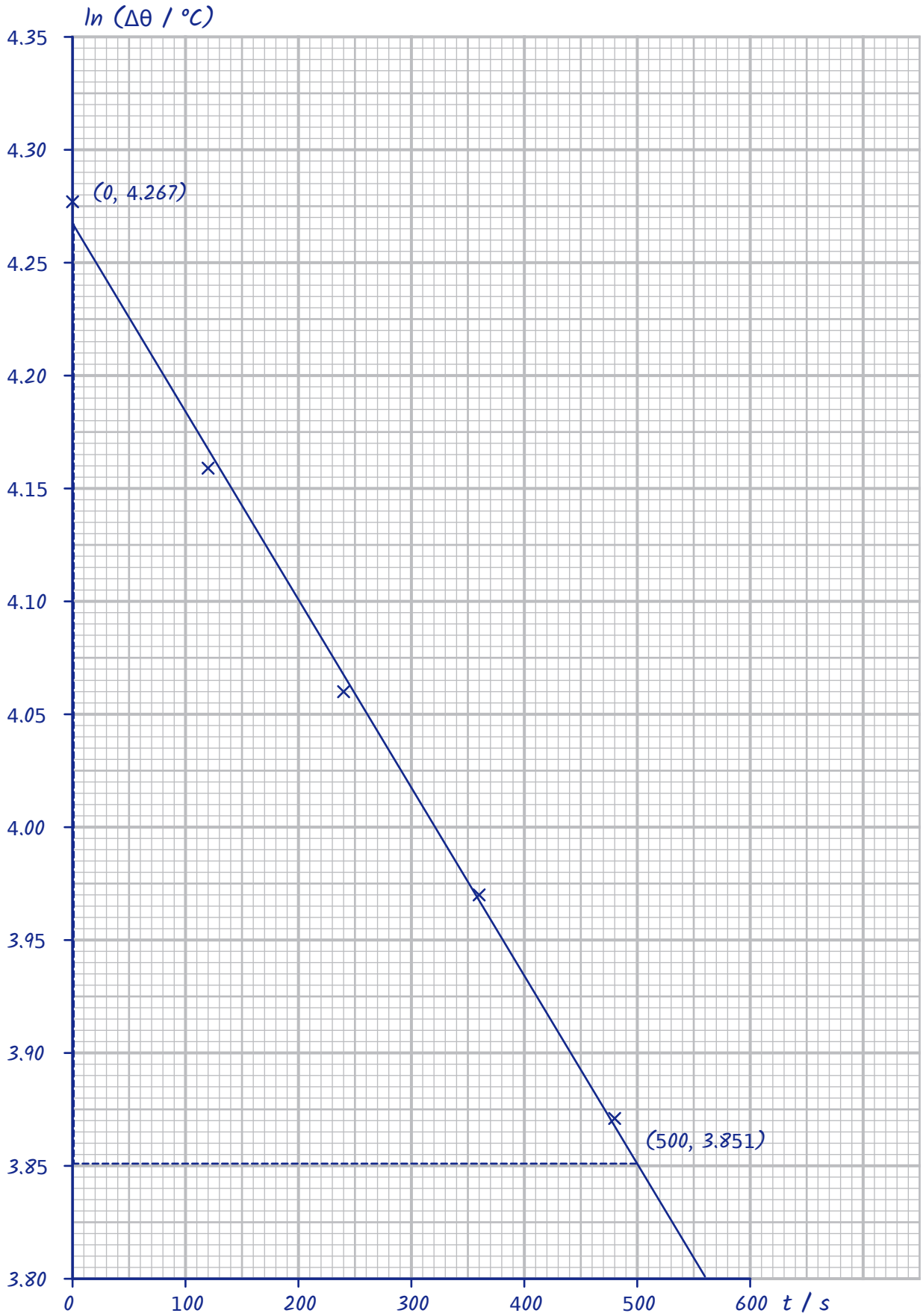
Taking logs: ln Δθ = ln $\Delta\theta_0$ − bt

Compare with y = mx + c: ln Δθ is y, t is x, so the graph is a straight line with gradient −b (constant) and intercept ln $\Delta\theta_0$.

(b) (i) Plot a graph of ln $\Delta\theta$ against t on the grid opposite.
Use the columns provided in the table to show any processed data.

(5)

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(ii) Determine the value of b.

(3)

Gradient from a large triangle on the line of best fit:

gradient = (3.851 − 4.267) ÷ (500 − 0) s = -8.3×10^{-4} s^{-1}

gradient = $-b$, so $b = 8.3 \times 10^{-4}$ s^{-1}

$b =$ 8.3×10^{-4} s^{-1}

(c) The student suggested that the experiment would have been more accurate if a temperature sensor and data logger had been used to collect the data.

Assess the validity of the student's suggestion.

(4)

Data loggers are useful when data changes over a very short (or very long) time scale, or when a number of quantities are measured simultaneously.

Here only the temperature is measured, and it changes slowly: readings were taken only every 120 s, so this is easily done by hand.

However, a liquid-in-glass thermometer takes longer to respond to temperature changes than a temperature sensor, and there may be parallax error in reading it.

Conclusion: as the temperature changes slowly, a data logger would make little difference to the accuracy, so the suggestion is only partly valid.

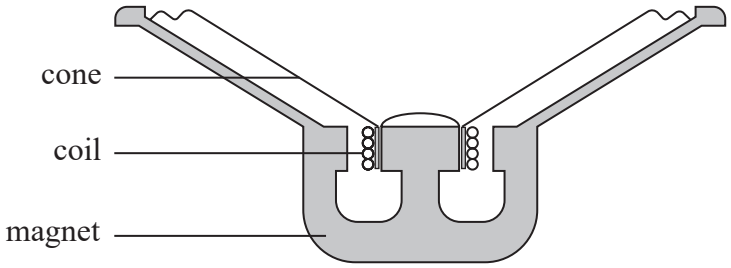
(Total for Question 8 = 14 marks)

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9 A simple loudspeaker consists of a cone, a coil of wire and a magnet. The cone and coil are attached to each other and are free to move. An alternating current in the coil causes the cone to oscillate. The loudspeaker is mounted in a wooden box. A cross-section through the loudspeaker is shown.



A student made the following observations:

- when an alternating potential difference (p.d.) is applied to the coil, the cone oscillates
- the frequency of oscillation is the same as the frequency of the p.d.
- at particular frequencies, the box vibrates with a large amplitude.

*(a) Explain these observations.

(6)

The alternating p.d. causes an alternating current in the coil.

The current-carrying coil is in the magnetic field of the magnet, so it experiences a force.

The current is alternating, so the force changes direction with the current, at the same frequency as the p.d.: the cone attached to the coil is driven to oscillate at the frequency of the p.d.

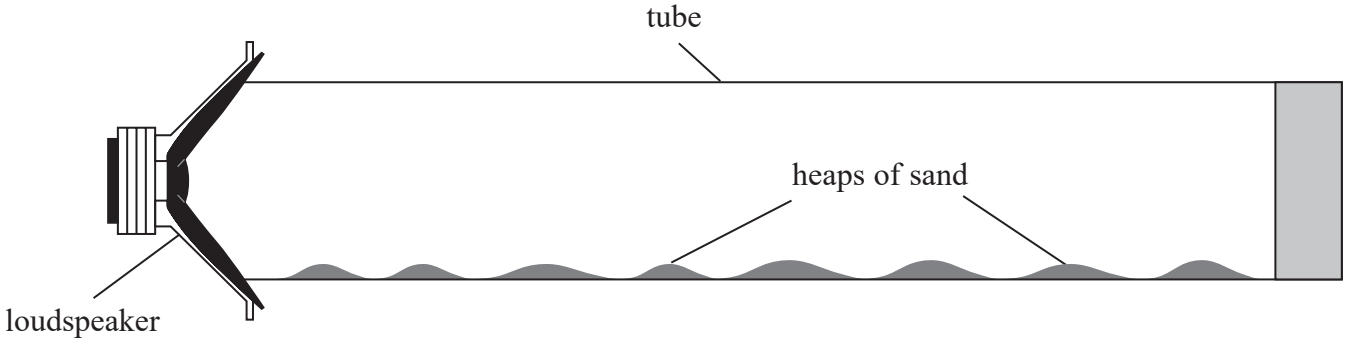
The loudspeaker forces the box (and the air in it) into oscillation.

At particular frequencies the driving frequency equals the natural frequency of oscillation of the box (and the air in the box).

Resonance occurs: maximum energy is transferred, so the amplitude of vibration of the box increases.

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(b) The student connected a signal generator to the loudspeaker, and placed the loudspeaker near to one end of a long tube containing sand. The student adjusted the signal generator until the sand collected in small heaps as shown.



(i) Explain why the sand collects in heaps.

(4)

Sound reflected from the end of the tube interferes with the incident sound, so a standing wave is set up in the tube.

Where constructive interference occurs (antinodes) the amplitude of vibration of the air is a maximum.

Where destructive interference occurs (nodes) the amplitude is zero (minimum).

The sand is displaced from the antinodes (maximum amplitude) and collects at the nodes (minimum amplitude).

(ii) The student determined the distance d between the centres of adjacent heaps.

Describe the procedure she should follow to determine an accurate value for d.

(3)

Use a metre rule to measure the distance across several heaps, from the centre of the first to the centre of e.g. the sixth heap (at least 3 heaps).

Divide by the number of gaps between the heaps (5 gaps here).

Repeat the measurement at different places along the tube and calculate an average.

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(iii) Assess whether the experimental data is consistent with a value for the speed of sound of 340 m s^{-1}.

signal generator frequency = 3.25 kHz.

d = 5.1 cm

(3)

Adjacent heaps are at nodes, $d = \lambda/2$, so $\lambda = 2d = 2 \times 5.1 \times 10^{-2}$ m = 0.102 m

$v = f\lambda = 3.25 \times 10^{3}$ Hz $\times$ 0.102 m = 332 m s^{-1} (330 m s^{-1})

332 m s^{-1} differs from 340 m s^{-1} by only about 2%, so the data is consistent with a speed of sound of 340 m s^{-1}.

(Total for Question 9 = 16 marks)

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10 A spring is made from loops of thick steel wire as shown.



There are two extra loops, one on each end of the spring.

(a) A student determined the length of steel used to make the spring by using vernier calipers to measure the width w of the spring.
The length of wire l on each loop is given by $l = \pi w$

The student obtained the following values for w.

w / mm	15.3	15.2	15.4	15.3

(i) Calculate l.

(3)

Mean $w = (15.3 + 15.2 + 15.4 + 15.3) \div 4 = 15.3$ mm

$l = \pi w = \pi \times 15.3$ mm $= 48.1$ mm

$l =$ 48.1 mm

(ii) Estimate the percentage uncertainty in your value for l.

(2)

Half range $= (15.4 - 15.2)$ mm $\div 2 = 0.1$ mm

% uncertainty $= (0.1$ mm $\div 15.3$ mm$) \times 100\% = 0.65\% = 0.7\%$

% uncertainty in $l =$ 0.7 %

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(iii) Calculate the total length L of wire used to make the spring.

(2)

16 coils + 2 extra end loops = 18 loops

$L = 18 \times 48.1\ mm = 866\ mm$

$L =$ 866 mm

(b) The student measured the diameter d of the steel wire and obtained a value of 2.52 mm.

(i) Explain which instrument he used to measure the diameter.

(2)

A micrometer screw gauge,

because the measured value (2.52 mm) shows a resolution of 0.01 mm.

(ii) Estimate the percentage uncertainty in the student's value for d.

(1)

$(0.005\ mm \div 2.52\ mm) \times 100\% = 0.2\%$

% uncertainty in $d =$ 0.2 %

(iii) The student used a balance to measure the mass m of the spring.
He obtained a value of 32.0 ± 0.5 g.

Estimate the percentage uncertainty in the mass of the spring.

(1)

$(0.5\ g \div 32.0\ g) \times 100\% = 1.6\%$

% uncertainty in $m =$ 1.6 %

(iv) The student calculated the density ρ of the steel using the equation

$$\rho = \frac{m}{V}$$

Calculate the percentage uncertainty in his value for the density of steel.

(1)

$0.7\% + 1.6\% + (2 \times 0.2\%) = 2.7\%$

% uncertainty in value for density of steel = 2.7 %

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(v) Determine whether the data collected leads to a value for the density of steel in agreement with the standard value.

density of steel = 7 800 kg m^{-3}

(4)

$V = L \times \pi d^2/4 = 0.866\ m \times \pi \times (2.52 \times 10^{-3}\ m)^2 \div 4 = 4.32 \times 10^{-6}\ m^3$

$\rho = m/V = 3.20 \times 10^{-2}\ kg \div 4.32 \times 10^{-6}\ m^3 = 7400\ kg\ m^{-3}$

Uncertainty in $\rho = 2.7\% \times 7400\ kg\ m^{-3} = \pm 200\ kg\ m^{-3}$

So the maximum density is 7600 kg m^{-3}, which is lower than the standard value of 7800 kg m^{-3}: the data does not agree with the standard value.

(Total for Question 10 = 16 marks)

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11 Solar panels consisting of combinations of photovoltaic cells use energy in the radiation received from the Sun to generate electricity.

(a) An advertisement for solar panels claims that the intensity of radiation from the Sun incident at the top of the Earth's atmosphere is more than 2 kW m^{-2}.

Assess the validity of this claim.

radius of Sun = 6.96×10^8 m

surface temperature of Sun = 5790 K

distance from Sun to Earth = 1.50×10^{11} m

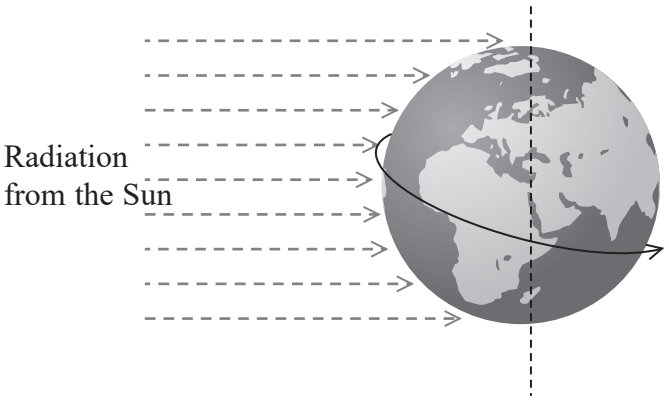
(4)

$L = 4\pi r^2 \sigma T^4 = 4\pi \times (6.96 \times 10^8\ m)^2 \times 5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4} \times (5790\ K)^4 = 3.88 \times 10^{26}\ W$

$I = L/4\pi d^2 = 3.88 \times 10^{26}\ W \div (4\pi \times (1.50 \times 10^{11}\ m)^2) = 1370\ W\ m^{-2} = 1.37\ kW\ m^{-2}$

$1.37\ kW\ m^{-2}$ is less than $2\ kW\ m^{-2}$, so the claim is not valid.

(b) The average intensity of radiation from the Sun incident at the Earth's surface over a 24-hour period has been determined to be 164 W m^{-2}.



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(i) The average intensity of radiation from the Sun at the Earth's surface is much less than the intensity incident at the top of the Earth's atmosphere.

Explain why.

(4)

Radiation is absorbed and scattered as it passes through the atmosphere.

Some radiation is reflected from the top of the atmosphere (and by clouds).

Only half of the Earth's surface has radiation from the Sun incident on it at any one instant (night), so the 24-hour average is lower.

The intensity of radiation normal to the surface is greater at the equator than at the poles, where the radiation arrives at an angle and is spread over a larger area.

(ii) It is claimed that the area of solar panels needed to generate 100 GW of power is about 0.5% of the surface area of the Earth.

Assess the validity of this claim.

radius of Earth = 6.4×10^6 m

typical efficiency of solar panels = 25%

(4)

Efficiency = useful power output ÷ total power input, so power input = 100×10^9 W ÷ 0.25

$I = P/A$, so $A = 100 \times 10^9$ W ÷ $(0.25 \times 164$ W $m^{-2}) = 2.44 \times 10^9$ m^2

Surface area of Earth = $4\pi r^2 = 4\pi \times (6.4 \times 10^6$ m$)^2 = 5.15 \times 10^{14}$ m^2

% needed = $(2.44 \times 10^9 \div 5.15 \times 10^{14}) \times 100\% = 0.0005\%$, much less than 0.5%, so the claim is not valid.

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(c) Scientists are developing a space station equipped with large solar panels. The space station would be located in a geostationary orbit. The space station would transfer energy to Earth as microwaves.

(i) A space station in a geostationary orbit is above the equator and has a period of 24 hours.

Explain one advantage of locating the space station in a geostationary orbit.

(2)

The space station would always be above the same point on the Earth's surface, so the receiving station on Earth can stay in contact with it at all times (a fixed receiving dish can be used to collect the microwaves continuously).

(ii) Calculate the height h of the space station above the equator when it is in a geostationary orbit.

mass of Earth = 6.00×10^{24} kg

24 hours = 8.64×10^{4} s

(4)

$GMm/r^2 = m\omega^2 r$ and $\omega = 2\pi/T$, so $r^3 = GMT^2/4\pi^2$

$r^3 = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2} \times 6.00 \times 10^{24}\ kg \times (8.64 \times 10^4\ s)^2 \div 4\pi^2$

$r^3 = 7.57 \times 10^{22}\ m^3$, so $r = 4.23 \times 10^7\ m$

$h = r - R_E = 4.23 \times 10^7\ m - 6.4 \times 10^6\ m = 3.6 \times 10^7\ m$

$h = 3.6 \times 10^7\ m$

(Total for Question 11 = 18 marks)

TOTAL FOR PAPER = 120 MARKS

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List of data, formulae and relationships

Acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$	
Coulomb law constant	$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19} \text{ C}$	
Electron mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$	
Electronvolt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	
Gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$	
Gravitational field strength	$g = 9.81 \text{ N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27} \text{ kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8} \text{ m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27} \text{ kg}$	

Mechanics

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

moment of force $= Fx$

Momentum

$$p = mv$$

Work, energy and power

$$\Delta W = F\Delta s$$

$$E_k = \tfrac{1}{2}mv^2$$

$$\Delta E_{grav} = mg\Delta h$$

$$P = \frac{E}{t}$$

$$P = \frac{W}{t}$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

Electric circuits

Potential difference

$$V = \frac{W}{Q}$$

Resistance

$$R = \frac{V}{I}$$

Electrical power and energy

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

Materials

Density

$$\rho = \frac{m}{V}$$

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$

$$E = \frac{\sigma}{\varepsilon}$$

Elastic strain energy

$$\Delta E_{\text{el}} = \tfrac{1}{2}F\Delta x$$

Waves and particle nature of light

Wave speed

$$v = f\lambda$$

Speed of a transverse wave on a string

$$v = \sqrt{\frac{T}{\mu}}$$

Intensity of radiation

$$I = \frac{P}{A}$$

Power of a lens

$$P = \frac{1}{f}$$

$$P = P_1 + P_2 + P_3 + \ldots$$

Thin lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Magnification for a lens

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

Diffraction grating

$$n\lambda = d \sin\theta$$

Refractive index

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n = \frac{c}{v}$$

Critical angle

$$\sin C = \frac{1}{n}$$

Photon model

$$E = hf$$

Einstein's photoelectric equation

$$hf = \phi + \tfrac{1}{2}mv^2_{\text{max}}$$

de Broglie wavelength

$$\lambda = \frac{h}{p}$$

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Further mechanics

Impulse

$$F\Delta t = \Delta p$$

Kinetic energy of a non-relativistic particle

$$E_k = \frac{p^2}{2m}$$

Motion in a circle

$$v = \omega r$$

$$T = \frac{2\pi}{\omega}$$

$$F = ma = \frac{mv^2}{r}$$

$$a = \frac{v^2}{r}$$

$$a = r\omega^2$$

$$F = mr\omega^2$$

Fields

Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Electric field strength

$$E = \frac{F}{Q}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in a capacitor

$$W = \tfrac{1}{2}QV$$

$$W = \tfrac{1}{2}CV^2$$

$$W = \tfrac{1}{2}\frac{Q^2}{C}$$

Capacitor discharge

$$Q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$$F = BIl \sin\theta$$

$$F = Bqv \sin\theta$$

Faraday's and Lenz's laws

$$\mathscr{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$$

Root-mean-square values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

Nuclear and particle physics

In a magnetic field

$$r = \frac{p}{BQ}$$

Thermodynamics

Heating

$$\Delta E = mc\Delta\theta$$

$$\Delta E = L\Delta m$$

Molecular kinetic theory

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

Ideal gas equation

$$pV = NkT$$

Stefan-Boltzmann law

$$L = \sigma AT^4$$

$$L = 4\pi r^2\sigma T^4$$

Wien's law

$$\lambda_{max}T = 2.898 \times 10^{-3}\ \text{m K}$$

Space

Intensity

$$I = \frac{L}{4\pi d^2}$$

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

Nuclear radiation

Mass-energy

$$\Delta E = c^2\Delta m$$

Radioactive decay

$$A = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{½}}$$

$$N = N_0\, e^{-\lambda t}$$

$$A = A_0\, e^{-\lambda t}$$

Gravitational fields

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field strength

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

Oscillations

Simple harmonic motion

$$F = -kx$$

$$a = -\omega^2 x$$

$$x = A\cos\omega t$$

$$v = -A\omega\sin\omega t$$

$$a = -A\omega^2\cos\omega t$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$\omega = 2\pi f$$

Simple harmonic oscillator

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

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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