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Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate Examination
Sample 2

Physics

Higher Level

2 hours 30 minutes

300 marks

Examination Number

Date of Birth

For example, 3rd February 2005 is entered as 03 02 05

Centre Stamp

v.2

Instructions

There are seven questions on this examination paper. Each question carries 50 marks.

Answer **Question 1** and any **five other** questions.

Write your Examination Number and your Day, Month and Year of Birth in the boxes on the front cover.

Write your answers in blue or black pen. You may use pencil for sketches, graphs and diagrams only.

This examination booklet will be scanned and your work will be presented to an examiner on screen. All of your work should be presented in the answer areas, or on the given graphs, or diagrams. Anything that you write outside of the answer areas may not be seen by the examiner.

You are not required to use all the space provided. There is space for extra work at the back of the booklet. If you need to use it, label any extra work clearly with the question number and part.

The superintendent will give you a copy of the *Formulae and Tables* booklet. You must return it at the end of the examination. You are not allowed to bring your own copy into the examination.

Data from the *Formulae and Tables* booklet, including but not limited to fundamental physical constants, particle physics data and electrical circuit symbols should be used wherever necessary.

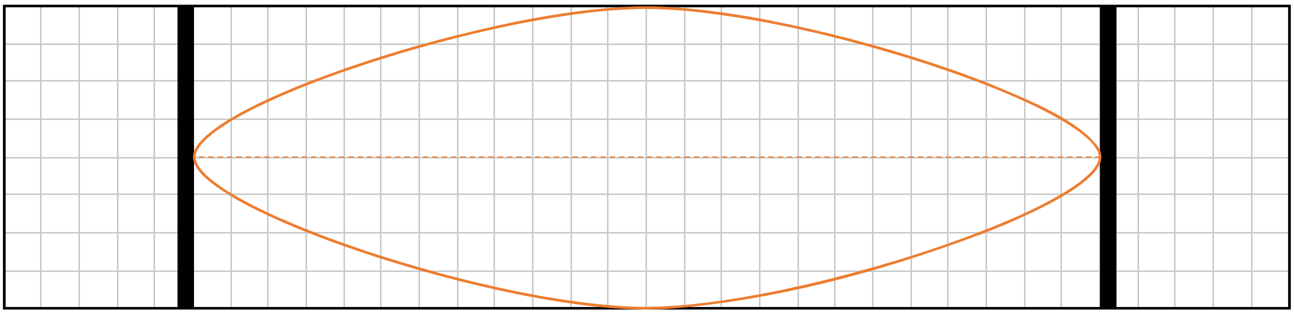
You may lose marks if your solutions do not include relevant supporting work.

You may lose marks if the appropriate units of measurement are not included, where relevant.

Write the make and model of your calculator(s) here:

Question 1

(a) The fundamental frequency of the stretched string shown is the loudest harmonic but a quieter second harmonic can also add to the quality of the note.



(i) Draw, on the diagram above, the string vibrating at a quieter second harmonic.

(ii) Identify which of the following expressions gives the magnitude of the new frequency of the stretched string when the following changes are made.
Draw a ✓ in one box only each time.

(a) The frequency of the stretched string has a magnitude f and only the length of the original stretched string is doubled.

$\frac{f}{4}$ ☐ $\frac{f}{\sqrt{2}}$ ☐ $\frac{f}{2}$ ☐ $\sqrt{2}f$ ☐ $2f$ ☐ $4f$ ☐

(b) The frequency of the stretched string has a magnitude f and only the mass per unit length of the original stretched string is doubled.

$\frac{f}{4}$ ☐ $\frac{f}{\sqrt{2}}$ ☐ $\frac{f}{2}$ ☐ $\sqrt{2}f$ ☐ $2f$ ☐ $4f$ ☐

(iii) While working with the formula for the fundamental frequency of a stretched string, where T is the tension and μ is the mass per unit length, a student concluded that the speed of the wave on the string, v, could be determined using the formula below.

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

Using unit analysis, evaluate the validity of the student's conclusion.

(b) A wind turbine is used to generate electrical power. The relationship between the power output of the wind turbine, P_{output} , and the velocity of the wind, v, is modelled below.

$$P_{output} \propto v^3$$

(i) The velocity of the wind increases by a factor of 2. Predict the change in P_{output}.
Assume all other variables are constant.

(ii) Draw a ✓ in one box only to complete the statement. Justify your answer.

Compared to the average kinetic energy of the wind before passing through the wind turbine, the kinetic energy of the wind after passing through is

lower ☐ the same ☐ varying ☐ higher ☐

Justification

(c) The diameter of a wire is being measured. A student reads a value of 0.3 mm when using a vernier callipers, with 0.1 mm graduations.
In an effort to improve the measurement the student reads a value of 0.34 mm by using a micrometer screw gauge, with 0.01 mm graduations.

(i) Calculate the reduction in percentage error.

(ii) Is the student certain to have improved the reading's accuracy, precision or both?
Draw a ✓ in one box only.

accuracy ☐ precision ☐ both ☐

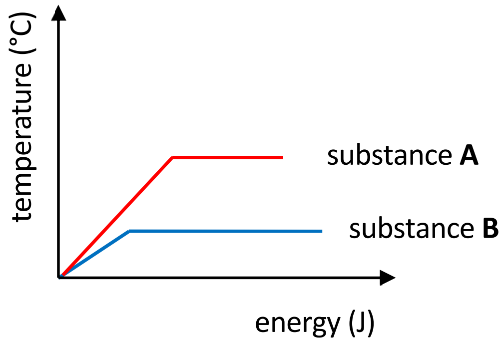
(d) All matter around us is made up of elementary particles. These particles occur in two basic types called quarks and leptons. Each group consists of six particles, which are related in pairs, or "generations". The lightest and most stable particles make up the first generation, whereas the heavier and less stable particles belong to the second and third generations. The six quarks are paired in three generations – the "up quark" and the "down quark" form the first generation, followed by the "charm quark" and "strange quark", then the "top quark" and "bottom quark".

Adapted from an article at home.cern/science/physics/standard-model

(i) Suggest a reason that protons are made from up and down quarks only.

(ii) Using the *Formulae and Tables* booklet, or otherwise, explain how the quark model can be used to predict the charge on the proton.

(e) The graph shows the temperature changes for 1 kg of two different substances, **A** and **B,** as they gain heat energy. Both samples were solid before the heat was added and liquid at the end.



(i) **(a)** Explain what is meant by specific heat capacity.

(b) Explain what is meant by specific latent heat.

(ii) Draw a ✓ in one box each time.

(a) Compare the specific heat capacity values of **A** (c_A), and **B** (c_B). Justify your answer.

c_A is higher ☐ c_B is higher ☐ both are the same ☐

Justification

(b) Compare the specific latent heat values of **A** (l_A), and **B** (l_B). Justify your answer.

l_A is higher ☐ l_B is higher ☐ both are the same ☐

Justification

(iii) 25 g of ice at 0 °C gains 15 kJ of heat energy. Calculate the final temperature of the melted ice.

specific heat capacity of water = 4180 J kg^{-1} K^{-1};
specific latent heat of fusion of ice = 3.3×10^5 J kg^{-1}.

(f) The following diagram shows the path taken by an electron • as it moves through space between a positive and a negative electrode.

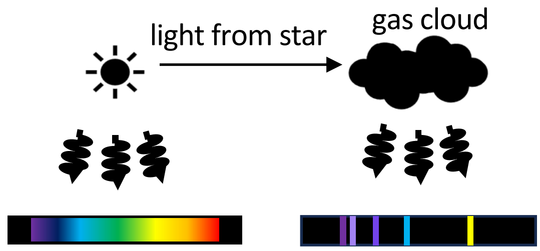
(i) Explain how the electron experiences a force without contacting the positive or negative electrodes.

(ii) On the diagram, label each electrode as positive + or negative –.

(iii) The potential difference between the electrodes is increased. On the diagram, draw and label the path that the electron would now take as it moves between the plates.

Question 2

(a) The diagram shows a star emitting a continuous spectrum of visible light. Light from a star can be absorbed and re-emitted from a stellar gas cloud to produce an emission line spectrum as shown.



(i) Explain, with the aid of a labelled diagram, how a line spectrum is produced.

(ii) Explain how spectra produced from stellar gas clouds can be used to identify the elements that the cloud is composed of.

Astronomers can observe gas clouds with telescopes, and use the line spectra observed to determine if a gas cloud is moving towards or away from the Earth.

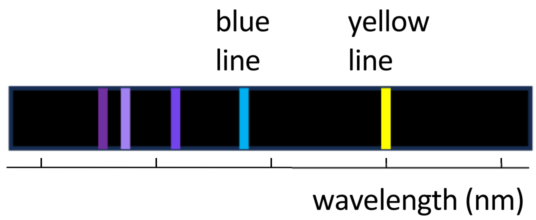
A shift in the line spectrum observed from the gas cloud is described by the Doppler effect.

(iii) Explain what is meant by the Doppler effect.

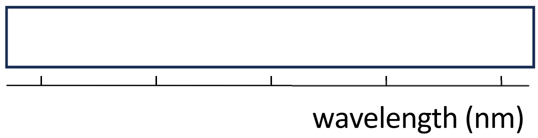
The image below represents the line spectrum, observed in the laboratory, of elements found in a stellar cloud.

(iv) Draw labelled lines in the box provided to approximate the new positions of the yellow and blue spectral lines if the cloud were moving away from Earth.

line spectrum (stationary source)

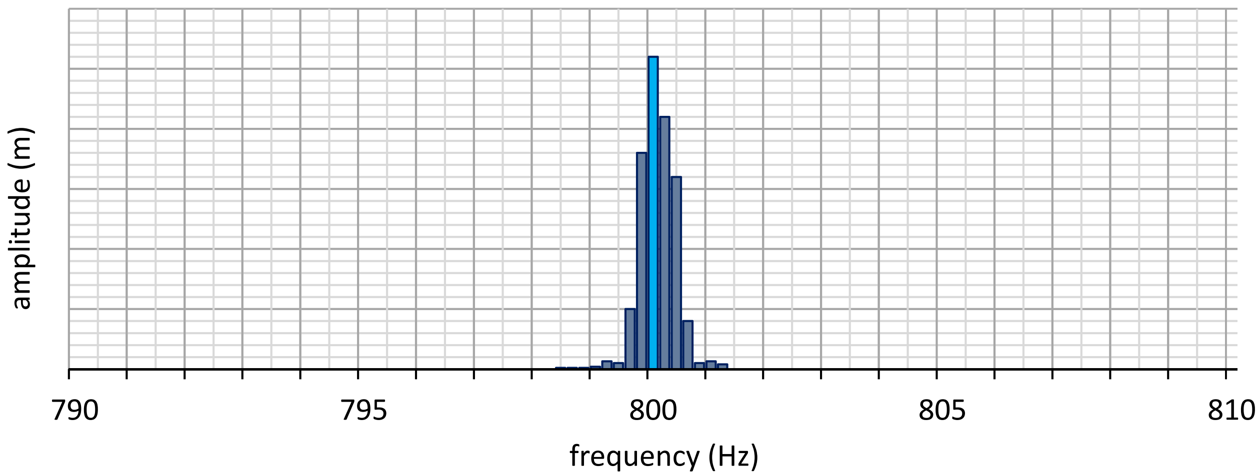


line spectrum (source moving away)



(b) Students conducting research on the Doppler effect in the lab used a speaker that was set to emit a frequency of 800 Hz. They recorded and analysed the sound using a datalogger and audio software. The graph below shows the amplitude obtained versus the frequency output.

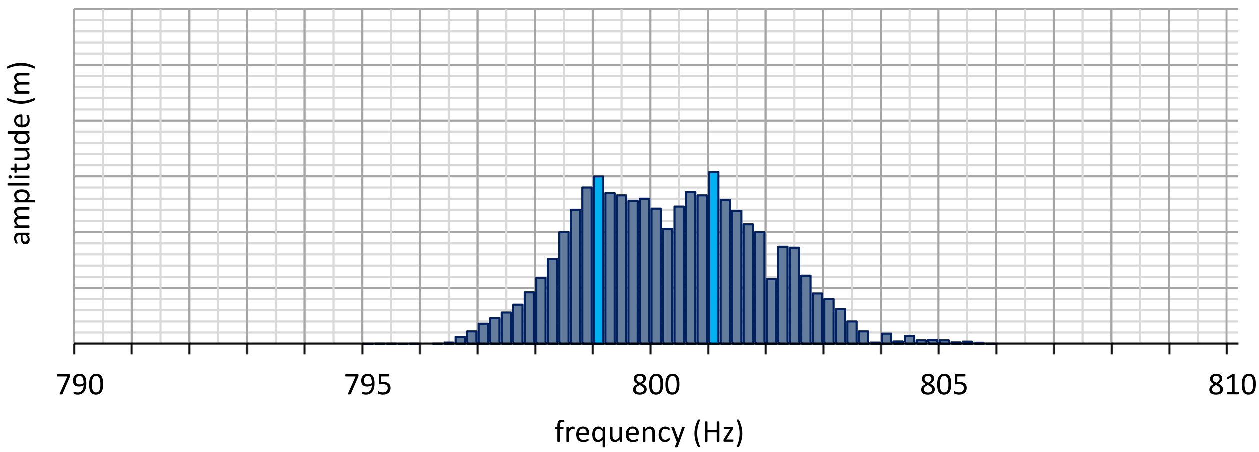
Stationary speaker



The student then attached the speaker to a string and rotated it in a circle at a constant speed while it was still set to give a frequency of 800 Hz. The circular path was horizontal and pointed directly towards and away from the microphone as shown in the diagram. The sound was recorded as before.

The data from the moving source was analysed and the following graph produced.

Speaker moving in a circle at constant speed



(i) Draw a ✓ in one box only to complete the statement.

For an observer of the investigation, sitting by the microphone, it appears that the frequency is

lower ☐ the same ☐ varying ☐ higher ☐

Another student suggests that a more accurate title for the second graph would be "Speaker moving in a circle at constant velocity".

(ii) Would you change the title? Justify your answer.

Answer

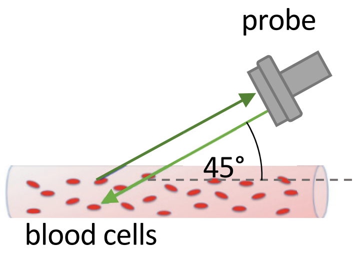
Justification

(iii) Given that the speed of sound in air is 340 m s^{-1}, use the data to calculate an approximate value for the speed of the speaker as it was rotated in a circle.

(iv) The mass of the speaker was 200 g and the radius of the circle was 80 cm.

Calculate the tension in the string as the speaker was rotated in a circle.

(c) The Doppler effect can also be used to monitor blood flow. The diagram shows an ultrasonic wave being transmitted at a frequency of 6500.0 kHz from a probe into the body during a medical investigation.
The observed frequency of the ultrasound waves change as they reflect from the moving blood cells.
The probe detects the frequency of the reflected waves.



The following formula can be used to mathematically model the velocity of the blood cells.

$$\Delta f = \frac{2fv\cos\theta}{c}$$

where

Δf = change in frequency

f = frequency of transmitted wave

v = velocity of the blood cells

c = speed of ultrasound

θ = angle between the transmitted wave and the blood flow

During the investigation, the frequency of the reflected wave was recorded as 6502.4 kHz.

(i) Calculate the velocity of the blood cells flowing during this examination.

speed of ultrasound = 1540 m s^{-1}

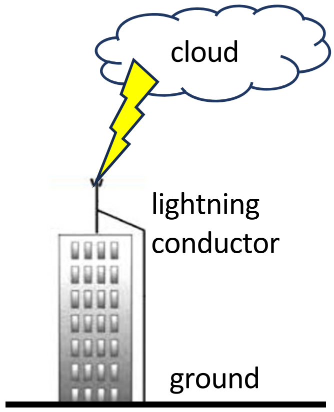
(ii) State one advantage and one disadvantage of using ultrasound in medical imaging when compared to the use of X-rays.

Advantage

Disadvantage

Question 3

(a) A lightning conductor is a grounded metal pole that is attached to tall buildings. It is designed to be struck by lightning and to protect the buildings by carrying charge from clouds to the ground.



(i) A cloud is negatively charged. Explain, with reference to free electrons, how a neutral lightning conductor becomes charged as the cloud comes near.
A labelled diagram may help your answer.

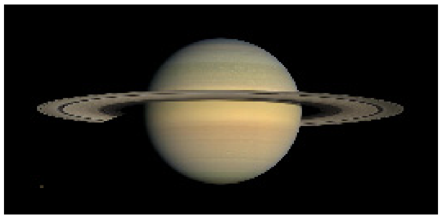
(ii) The diagram below models the cloud as a negative point charge and the lightning conductor as a positive point charge.
Sketch the electric field around these two point charges.

(iii) Lightning strikes the lightning conductor. A very large current of 25 kA passes through the lightning conductor for 4.2×10^{-4} s as it flows to ground.
Calculate the number of electrons transferred to ground in this time.

(iv) The lightning conductor is 28 m long and made from copper which has a resistivity of 1.7×10^{-8} Ω m. The conductor has a cross-sectional area of 50 mm^2.
Calculate the resistance of the lightning conductor.

(v) Calculate the minimum electrical energy stored in the cloud that produced the lightning.

(b) Saturn, the second-largest planet in our solar system, is orbited by at least 83 moons. A group of students researched the orbits of these moons to try to verify Kepler's 3rd law.



Kepler's 3rd law can be modelled by the equation $T^2 = \frac{4\pi^2 R^3}{GM}$.

The table below shows the period of orbit T and the radius of orbit R for three of Saturn's moons.

Name of Moon	**Period of orbit T (s)**	**Radius of orbit R (m)**
Mimas	8.14×10^4	1.85×10^8
Enceladus	1.18×10^5	2.37×10^8
Dione	2.36×10^5	3.77×10^8

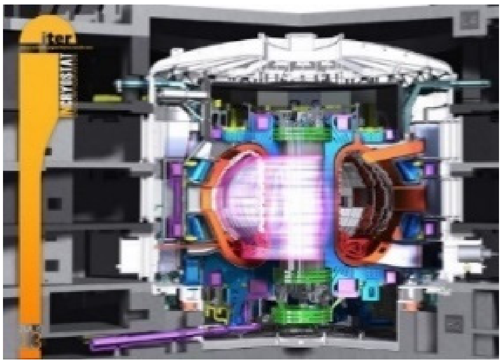
(i) Use the data in the table to verify Kepler's 3rd law.

(ii) Calculate an average value for the mass of Saturn.

(iii) Given that the mass of Saturn is 5.683×10^{26} kg, calculate the percentage error in your calculated value for the mass of Saturn.

(iv) State one assumption made when working with the model $T^2 = \frac{4\pi^2 R^3}{GM}$ that may account for the error.

Question 4



(a) The ITER project involves over 30 nations collaborating to build the world's largest tokamak, a magnetic fusion device. Scientists predict a shift from mining radioactive isotopes of uranium for nuclear fission reactors to sourcing hydrogen isotopes from seawater to run fusion reactors.

(i) State one similarity and one difference between nuclear fission and nuclear fusion.

Similarity

Difference

The table below shows some data on a fission and a fusion reaction.

	Fission reaction	Fusion reaction
Reaction	${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{139}_{56}Ba + {}^{94}_{36}Kr + \boxed{}$	${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$
Energy produced in each reaction	171 MeV	

(ii) Neutrons are also emitted in the fission reaction.
Complete the unfinished fission reaction in the table.

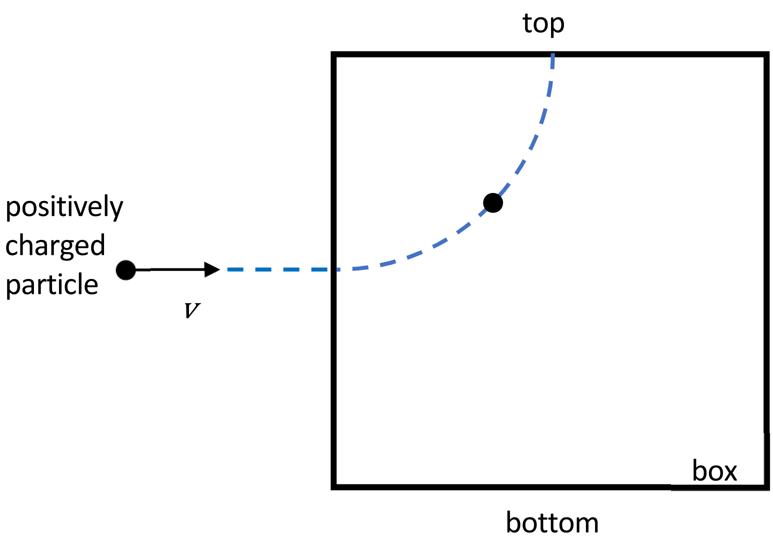
(iii) Calculate the energy produced when a single hydrogen–2 nucleus undergoes fusion with another hydrogen–2 nucleus as shown in the table.
Give your answer in megaelectronvolts (MeV).
You should refer to pages 46, 47 and 83 of the *Formulae and Tables* booklet when answering this question.

The energy produced in each fission reaction is 171 MeV. 2 g of hydrogen–2 contains the same number of nuclei as 235 g of uranium–235.

(iv) Identify, by calculation, which fuel produces more energy per gram when they undergo the nuclear reactions shown.

(v) State an ethical factor that should be considered when choosing between nuclear fission reactors and nuclear fusion reactors.

The tokamak uses magnetic fields to control the direction of charged particles. The following diagram models a positively charged particle, with constant velocity v, entering an area with a magnetic field (inside the box). The path of the particle ● is deflected as shown in the diagram as a dashed line.



(vi) Using the diagram above, determine the direction of the magnetic field that is inside the box. Draw a ✓ to identify your answer.

Direction	✓
towards the top of the box	
towards the bottom of the box	
towards the left-hand side of the box	
towards the right-hand side of the box	
into the page	
out of the page	

(vii) Draw labelled vector arrows, on the diagram above, to represent the direction of

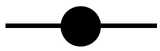
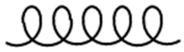
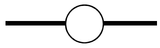
(a) the force F on the charged particle ● when it is in the magnetic field,

(b) the velocity v of the charged particle ● when it is in the magnetic field.

(b) Fundamental particles and their interactions are currently described by the standard model of matter. Fundamental particles can be divided into two categories – fermions and bosons.

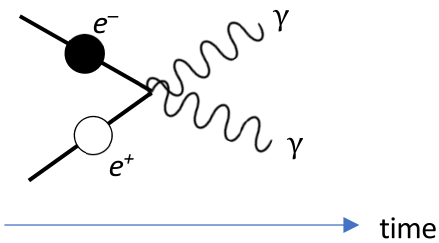
Diagrams can be used to model the interactions of fermions and bosons before, during and after an interaction, and to show how forces are communicated between the fundamental particles.

The following symbols are used.

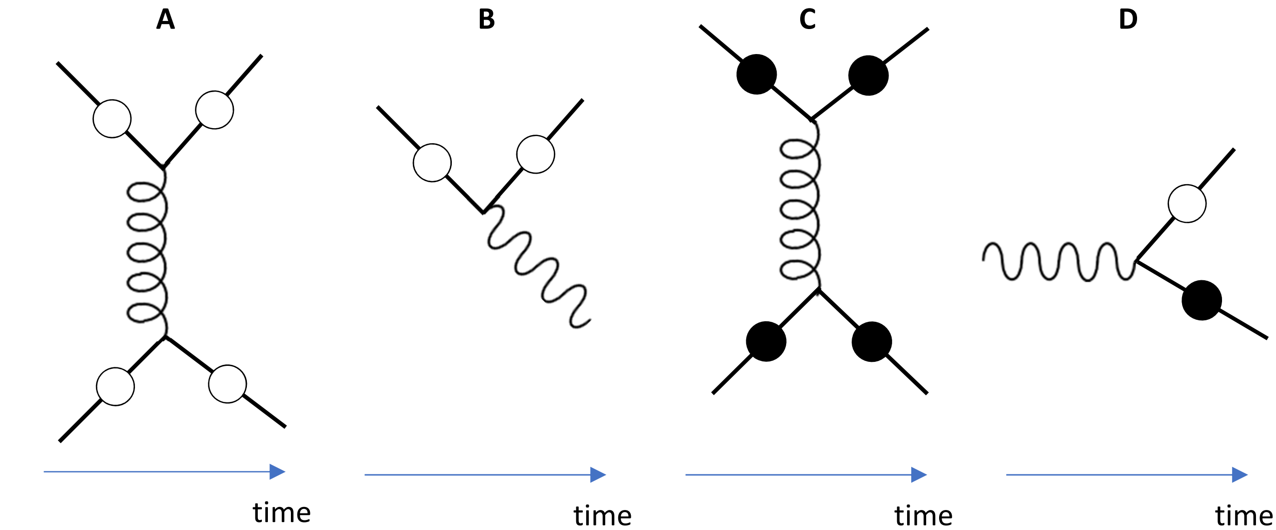
Fermions		**Bosons**	
	matter particle		photon (γ^0)
			gluon (g^0)
	anti-matter particle		Z^0 or W^+ or W^-

The diagrams below are read from left to right and junctions represent interactions.

Below is an example of pair annihilation, where an electron and a positron interact to produce two photons.

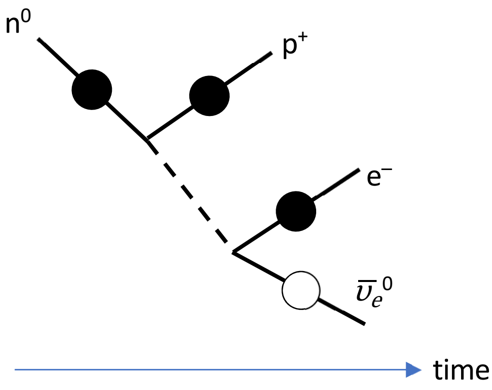


(i) Match the following diagrams to the descriptions below by writing **A**, **B**, **C** and **D** in the table.



Description	**A, B, C or D**
A photon produces a matter particle and an anti-matter particle.	
Two matter particles interact by a gluon and both matter particles travel on.	
Two anti-matter particles interact by a gluon and both anti-matter particles travel on.	
An anti-matter particle produces a photon and travels on.	

The following diagram shows a beta decay, where a neutron n^0 decays to form a proton p^+, an electron e^- and an anti-neutrino $\overline{\upsilon}_e^{\,0}$.



(ii) Write a nuclear equation to model the decay shown in the diagram above.

(iii) By analysing the diagram, or otherwise, predict what type of boson is involved in the radioactive decay. Justify your choice.

Prediction

Justification

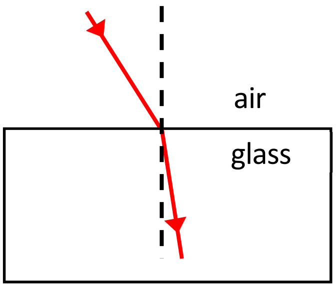
The presence of the neutrinos is very difficult to detect.

(iv) Using information in the diagram and/or in the *Formulae and Tables* booklet predict a reason that the neutrino is a difficult particle to detect.

Question 5

(i) Explain what is meant by refraction.

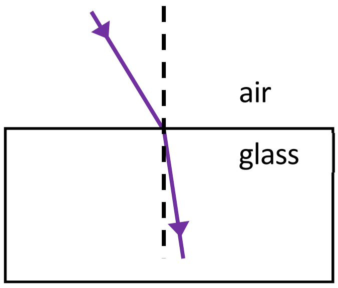
Red light is passed through a glass block, as shown in the diagram. The following information about the red light is given in the table to the right of the diagram.



frequency of red light	4.569×10^{14} Hz
wavelength of red light in air	656.0 nm
wavelength of red light in glass	450.2 nm
speed of red light in air	2.997×10^{8} m s^{-1}
speed of red light in glass	2.057×10^{8} m s^{-1}
refractive index of the glass for red light	

(ii) Calculate the refractive index of the glass for red light.
Write your answer to 4 significant figures.

Violet light is also passed through the glass block, as shown in the second diagram. The following information about the violet light is given in the table to the right of the diagram.



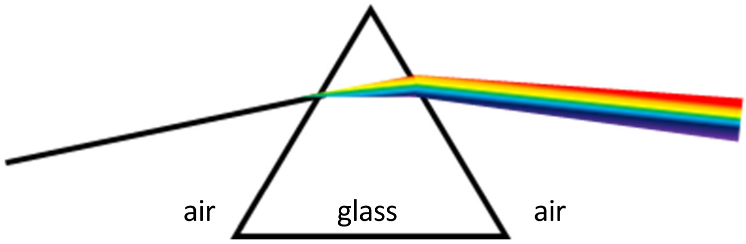
frequency of violet light	7.400×10^{14} Hz
wavelength of violet light in air	405.0 nm
wavelength of violet light in glass	
speed of light violet in air	2.997×10^{8} m s^{-1}
speed of violet light in glass	2.037×10^{8} m s^{-1}
refractive index of the glass for violet light	1.471

(iii) Calculate the wavelength of the violet light as it passes through the glass block.

A ray of red light travelling from air into the glass block with an angle of incidence of 25.00˚ makes an angle of refraction of 16.86˚.

(iv) A ray of violet light travels from air into the glass block with an angle of incidence of 25.00˚. Calculate the angle of refraction of the ray of violet light.

(v) Explain why the dispersion of white light occurs as it passes through a prism.



(vi) Explain what is meant by the term critical angle.

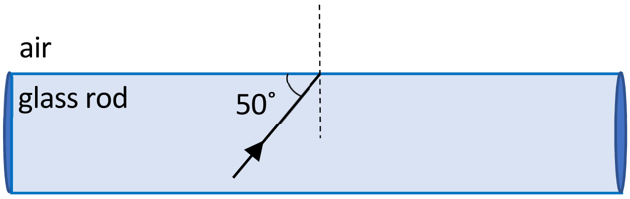
(vii) Compare the values of the critical angle for a ray of red light, C_{red}, and the critical angle for a ray of violet light, C_{violet}, when travelling from glass to air. Justify your answer.
Draw a ✓ in one box only.

C_{red} is higher ☐ C_{violet} is higher ☐ they are the same ☐

Justification

The diagram shows a ray of unpolarised light inside a glass rod. The critical angle for the light in the rod is 42˚.

(viii) Describe what happens to the ray of light incident on the side of the glass rod.
Draw a ✓ in the table to identify your answer.

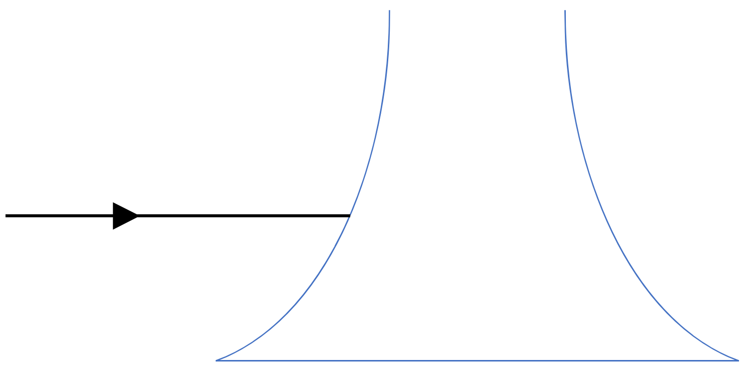


light is reflected	light is refracted	✓
no	no	
no	yes	
yes	no	
yes	yes	

(ix) Explain, with the aid of a labelled diagram, why light travels through an optical fibre.

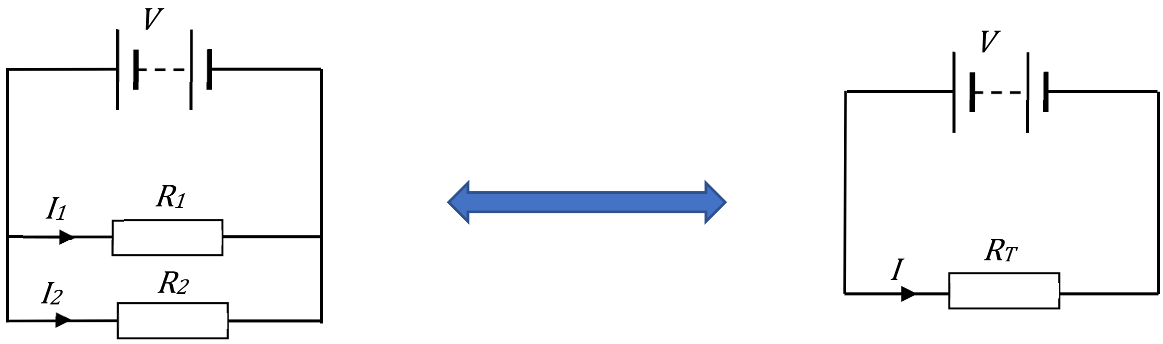
Another common application for the refraction of light is in the design and use of lenses.

(x) Complete the diagram below by drawing the path of the light ray as it travels through the lens and out the other side.



Question 6

The power supply in the two equivalent circuits shown below are identical. The combined resistance of R_1 and R_2 is equal to R_T.



(i) Explain what is meant by resistance.

(ii) Hence, or otherwise, derive the formula for the equivalent resistance of two resistors in parallel.

(iii) R_1 has a lower resistance value than R_2.

Draw a ✓ to identify if the following statements are always true, sometimes true or always false.

(a) The equivalent resistance of the two resistors in the parallel circuit is less than or equal to R_1.

always true ☐ sometimes true ☐ always false ☐

(b) The voltage drop across R_1 is less than the voltage drop across R_2. Justify your answer.

always true ☐ sometimes true ☐ always false ☐

Justification

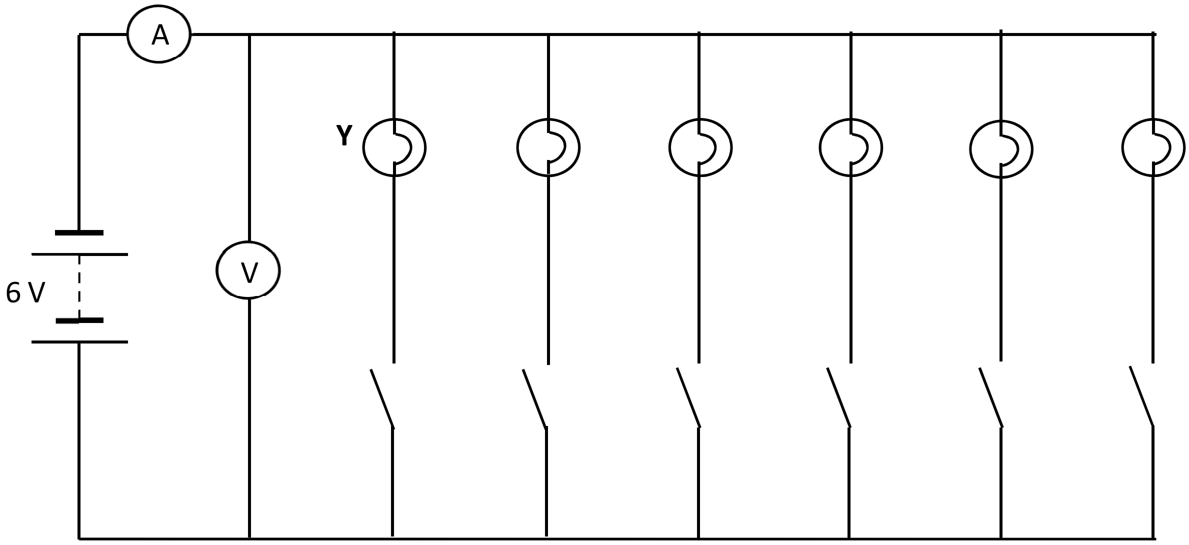
(iv) Using the same battery and resistors, the student converted the circuit to an arrangement with the resistors in series.

Draw a ✓ in one box to complete the following statement.

When compared to the current through resistor R_2, the current through resistor R_1 is

lower ☐ the same ☐ varying ☐ higher ☐

A student carried out an experiment to investigate the relationship between the current I flowing through and the voltage V across a filament bulb.
They built the circuit below to determine how the current, voltage and power varied in a parallel circuit as they varied the number of bulbs that were switched on.



The data were recorded in the following table.

Number of bulbs switched on	Total current (A)
1	0.075
2	0.145
3	0.210
4	0.273
5	0.325
6	0.360

They measured the resistance of each bulb to be 80 Ω using an ohmmeter.

(v) **(a)** Calculate the equivalent resistance of three 80 Ω resistors connected in parallel.

(b) Use the data given to calculate the total resistance in the circuit when three of the switches are closed.

(c) Compare this total resistance to the equivalent resistance of three 80 Ω resistors connected in parallel. Explain your answer.

(vi) Determine the current flowing through bulb **Y** when all 6 switches are closed.

(vii) Another student observing the experiment makes the following statement.

"Connecting the six bulbs in parallel will use the energy provided by the battery more quickly than if the bulbs were connected in series."

Do you agree with this student? Justify your answer.

agree ☐ disagree ☐

Justification

Question 7

(i) State the law of conservation of momentum.

(ii) State the law of conservation of energy.

A group of students completed an experiment to investigate the velocity of a cart accelerating down a ramp on a slight incline. They recorded values for the time t taken to travel a displacement s.

(iii) Draw a labelled diagram of the apparatus that could be used to collect the primary data recorded by the students.

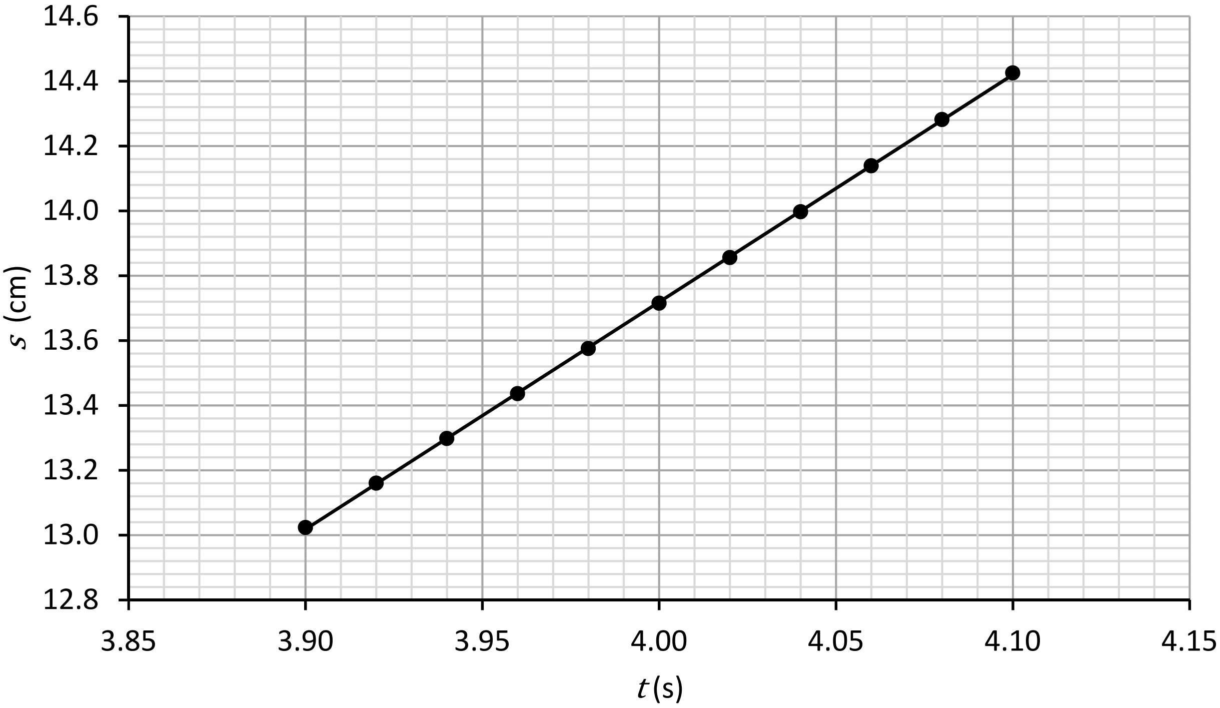
(iv) Describe how values for time t and displacement s could be measured.

The following data were recorded.

t (s)	0.98	1.80	2.74	3.59	4.80	5.75
s (cm)	0.42	2.34	6.05	11.55	18.70	28.29

(v) Draw a graph of the data to show displacement s against time t.

The following graph shows the displacement s against time t over the time interval t = 3.90 s to t = 4.10 s.

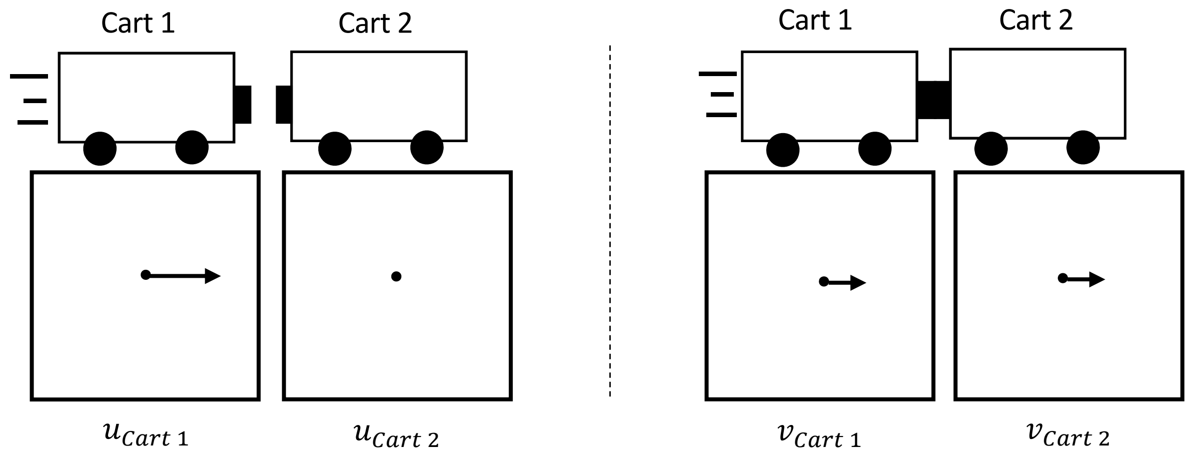


(vi) Explain why this graph appears to represent a different type of motion to the data in the table.

(vii) Use the graph provided to calculate the average velocity of the cart over the time interval t = 3.90 s to t = 4.10 s.

The group of students then added a second cart and adjusted their setup to investigate the principle of conservation of momentum.

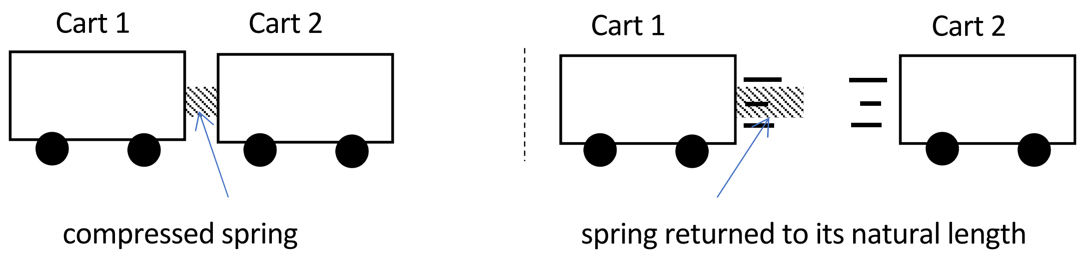
They drew the following diagrams to model the carts' velocities before and after a collision. After the collision the two carts move off together as shown.



The vector diagrams above illustrate that before the collision Cart 1 had an initial velocity, $u_{Cart\ 1}$, and collided with Cart 2, which was at rest, and that after the collision Cart 1 had a final velocity, $v_{Cart\ 1}$, and Cart 2 had a final velocity, $v_{Cart\ 2}$.

(viii) Using these vector diagrams, draw vectors in the boxes below to represent the change in velocity of Cart 1, $\Delta v_{Cart\ 1}$, and the change in velocity of Cart 2, $\Delta v_{Cart\ 2}$, after the collision.

Another student, investigating the law of conservation of energy, connected the carts together using a compressed spring. The carts were initially at rest. The force provided by the spring returning to its normal length changes the momentum of each cart.



The compressed spring has a spring constant of 11 N m^{-1} and is compressed by 3 cm. The total mass of cart 1 and the spring is recorded as 330 g and the mass of cart 2 is recorded as 295 g.

Assume that there are no other external forces, and that energy and momentum are conserved.

(ix) Calculate the velocities of each cart due to the force of the spring.

Page for extra work.

Label any extra work clearly with the question number and part.

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Acknowledgements

Images

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Leaving Certificate Examination – Higher Level

Physics

Sample 2

2 hours 30 minutes