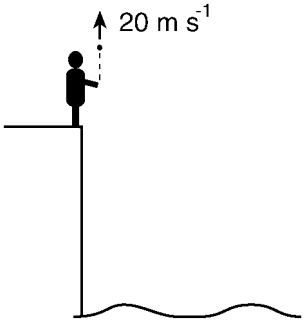
MECHANICS AND PROPERTIES OF MATTER

1. A stone is thrown vertically upwards with a speed of 20 m s^{-1} from the edge of a cliff as shown in the diagram below. It lands with a speed of 50 m s^{-1} at the bottom of the cliff. The effect of air resistance on the stone may be neglected.



(a) What is the speed of the stone at its highest point from the top of the cliff? 1

(b) What is the total time the stone is in the air? 2

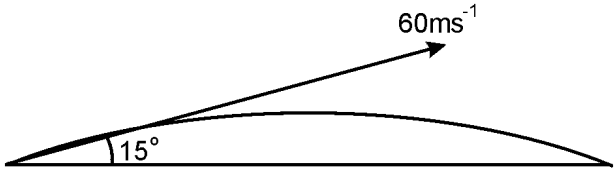
(c) Draw a graph to show how the velocity of the stone varies with time from the instant of projection until it reaches the ground. Numerical values are required on the axes of your graph. 2

(d) How high above the top of the cliff did the ball reach? 2

(e) How high is the cliff? 2

(9)

2. An arrow is fired at a speed of 60 m s^{-1} at 15^{o} above the horizontal so that it follows the path as shown in the diagram below.



The effect of air resistance on the arrow may be neglected.
Calculate the:

(a) horizontal component of the initial velocity of the arrow 1

(b) vertical component of the initial velocity of the arrow 1

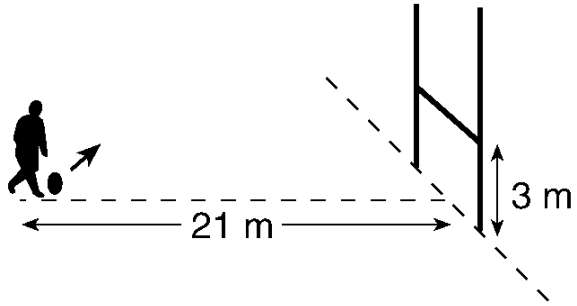
(c) total time of flight of the arrow 2

(d) maximum height reached by the arrow 2

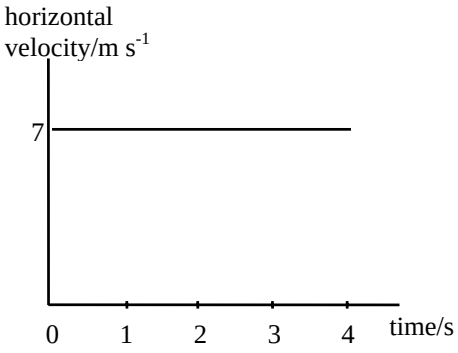
(e) total horizontal distance travelled by the arrow. 2

(8)

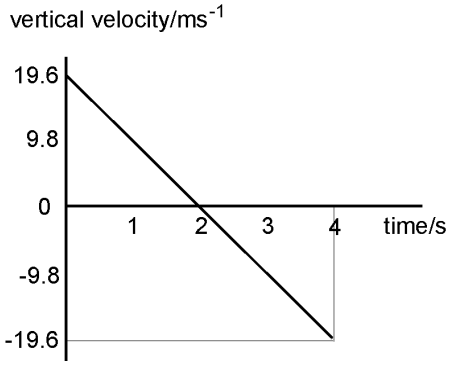
3. During a game of rugby, a ball is kicked in the direction of the posts as shown in the diagram below.
The initial velocity of the ball is v m s^{-1} and it is kicked at an angle to the horizontal as shown.
The horizontal distance of the ball from the base of the posts is 21 m. The height of the horizontal bar of the posts is 3 m.



Graph (i) below shows how the horizontal velocity of the ball varies with time.
Graph (ii) below shows how the vertical velocity of the ball varies with time.



Graph (i)



Graph (ii)

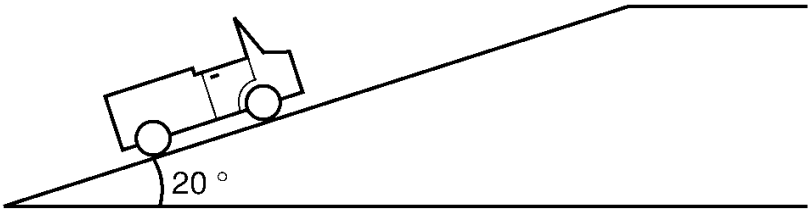
The effect of air resistance on the ball may be neglected.

(a) What is the time taken for the ball to reach the plane of the posts? 2

(b) Did the ball clear the horizontal bar of the posts? You must justify your answer. 3

(c) What was the magnitude and direction of the initial velocity of the ball? 3
(8)

4. A 600 kg jeep is accelerating at 2 m s^{-2} up a slope as shown in the diagram below.



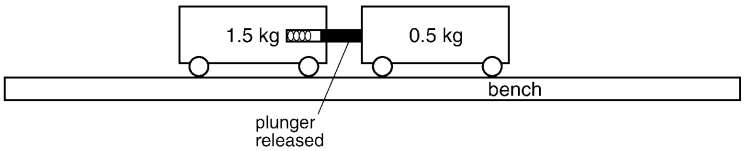
The slope is inclined at an angle of 20^{o} to the horizontal. A constant frictional force of 1500 N acts on the jeep down the slope.

(a) (i) Calculate the size of the unbalanced force acting on the jeep when it is accelerating up the slope.
(ii) Calculate the size of the force acting up the slope on the jeep at this time. 5

(b) At the top of the slope the jeep moves horizontally with a constant speed of 12 m s^{-1}. The frictional force remains constant at 1500 N.
What is the forward force on the jeep. Explain your answer. 2
(7)

5. (a) State the law of conservation of linear momentum as it applies to a collision between two objects moving in a straight line. 1

(b) Two trolleys of mass 0.5 kg and 1.5 kg respectively are placed in contact with one another on a smooth horizontal bench as shown below.



The trolleys are pushed apart by the release of a spring loaded plunger which is attached to the 1.5 kg trolley.

(i) The 1.5 kg trolley moves off at 0.40 m s^{-1}.
Calculate the speed of the 0.5 kg trolley.

(ii) The spring loaded plunger was in contact with the 1.5 kg trolley for 50 ms.
Calculate the average force exerted by the plunger on the 1.5 kg trolley.

(iii) Describe a method which would allow the time of contact between the plunger and the 1.5 kg trolley to be measured. 7
(8)

6. Two students Donna and Billy are investigating collisions between 'curling stones' at an ice rink. Billy releases his stone, of mass 15 kg, so that it collides head on with Donna's stone, of mass 12 kg, which is travelling in the opposite direction.

The speeds of the stones before and after collision are given in the table below.

	speed before collision/m s^{-1}	speed after collision/m s^{-1}
Donna's stone	0.6	*v*
Billy's stone	0.8	0

(a) Calculate the speed, *v*, of Donna's stone after the collision. 2

(b) Show by calculation whether the collision is elastic or inelastic. 4

(c) (i) During the collision the stones are in contact for 0.05 s. Calculate the average force exerted by Billy's stone on Donna's stone during the collision.

(ii) What is the average force exerted by Donna's stone on Billy's stone during the collision? 4

(10)

7. Two identical cars X and Y are crashed at 14 m s^{-1} into a wall as part of a car safety test.
Car X carries a dummy of mass 75 kg. The dummy is restrained by a seatbelt. The dummy is brought to rest by the seatbelt in a time of 35 ms.
Car Y carries an identical dummy that is not restrained by a seatbelt.

(a) Calculate the average force exerted by the seatbelt on the dummy in car X. 3

(b) The dummy in car Y is brought to rest in a time of 15 ms due to collision with the steering wheel.

(i) What is the impulse on the dummy in car Y during this time?

(ii) Which dummy is more likely to be damaged as a result of the crash You must explain your answer. 3

(6)

8. A block of mass 3 kg is suspended from a Newton balance.

(a) The balance is attached to the ceiling of a lift as shown in Figure (i) opposite.

The lift starts from rest and accelerates upwards at 2.4 m s^{-2} for 3 seconds. It then travels at a constant speed for 7 s, before decelerating at 1.8 m s^{-2} to stop at its destination.

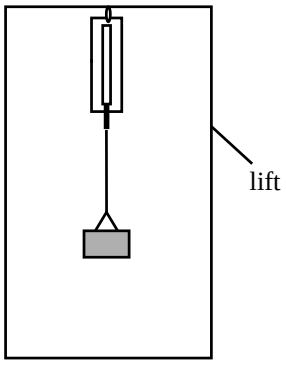


Figure (i)

(i) Sketch the acceleration time graph for the entire journey. You must show numerical values on **each** axis.

(ii) Calculate the reading on the balance at each of these three stages of the journey. 5

(b) The block and Newton balance are removed from the lift. The block is lowered into a container of water to a depth as shown in Figure (ii) below.

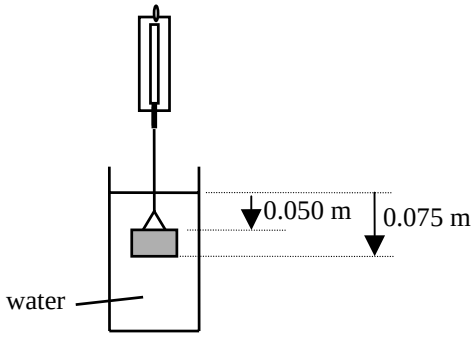


Figure (ii)

(i) Calculate the pressure on the top surface of the block **due to the water**.

(ii) Calculate the pressure on the bottom surface of the block **due to the water**.

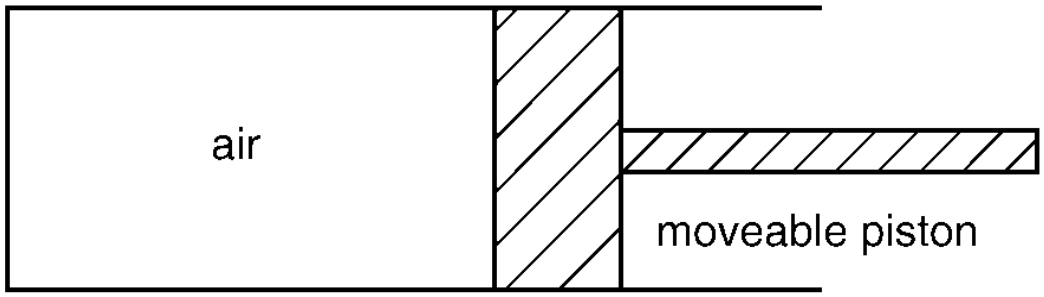
(iii) The top and bottom surfaces of the block are squares 0.15 m by 0.15 m. Calculate the buoyancy force on the block.

(iv) When the block is under the water at the depth shown, what is the reading on the Newton balance?

(v) The block is slowly lowered further into the water.
Will the reading on the Newton balance increase, decrease or remain the same? You must justify your answer. 9

(14)

9. A 1 kg sample of air is contained in a gas tight cylinder as shown in the diagram below. The cylinder has a moveable piston.
The sample of air is at a temperature of 0 ^{o}C and under a pressure of 101 kPa.



(a) The density of air at 0 ^{o}C and a pressure of 100 kPa is 1.28 kg m^{-3}.
Calculate the volume of air in the cylinder. 3

(b) The air in the cylinder is now heated to a temperature of 70 ^{o}C. The pressure of the air is kept constant at 101 kPa.

(i) Calculate the new volume of the air in the cylinder.

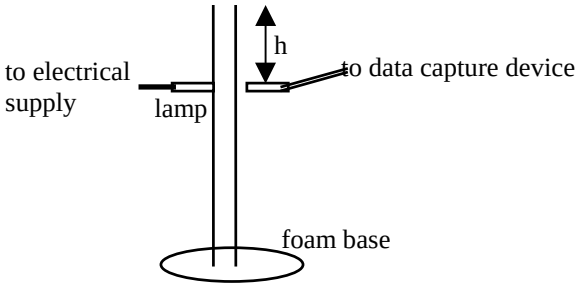
(ii) What is the density of the air in the cylinder when the temperature of the air is 70 ^{o}C and pressure of the air is 101 kPa? 4
(7)

10. (a) Use the kinetic theory of a gas to explain why the pressure of a fixed mass of gas increases as the temperature of the gas increases. 2

(b) Two students wish to investigate the relationship between the pressure and temperature of a fixed mass of gas.
Describe a suitable experiment which they could carry out.

Your description should include:
(i) a labelled sketch of the apparatus
(ii) a statement of any measurements taken
(iii) a clear indication of how these measurements could be used to show the relationship between pressure and temperature
(iv) a statement of the relationship between pressure and temperature including any conditions which apply. 7
(9)

11. Some students are carrying out an experiment to measure the acceleration due to gravity. A light gate can be placed at a variable distance *h* below the top of a plastic tube as shown in the diagram below.



The student drops a small steel ball down the tube on to a foam base at the bottom of the tube.

(a) The steel ball is released from rest at the top of the tube. The data capture device displays the velocity at the distance *h*.
Describe how the students can use this apparatus to obtain a mean value for the acceleration due to gravity. Your answer should include details of:

(i) the readings you would take
(ii) how the readings taken are used to calculate a value for the acceleration due to gravity
(iii) how a mean value for the acceleration due to gravity is obtained and how an uncertainty in the final result can be obtained. 5

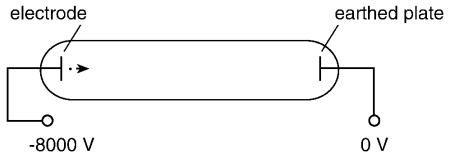
(b) Another group of students using the same apparatus, place the light gate near to the bottom of the tube. They release the ball from rest and the data capture device records the velocity at this distance *h*.

A value for the acceleration due to gravity is then calculated. Will this measured value be larger than, equal to, or smaller than the accepted value? You must justify your answer. 2

(7)

ELECTRICITY AND ELECTRONICS

12. Electrons at the surface of an electrode are accelerated from rest towards an earthed plate in an evacuated tube as shown in the diagram below. The electrode is at a potential of -8000 V.



(a) What is the potential difference between the electrode and the earthed plate? 1

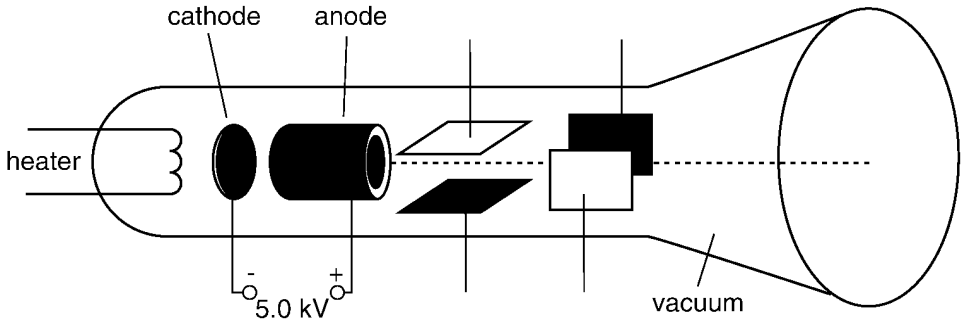
(b) Calculate the speed of an electron just before it reaches the earthed plate. 2

(c) How many electrons would need to arrive at the earthed plate so that a charge of 1 μC is transferred between the electrode and the plate? 2

(d) A charge of 1 μC is transferred between the electrode and the plate in 1 minute. What is the current in the vacuum tube? 2

(7)

13. The diagram below shows a cathode ray tube used in an oscilloscope.



The electrons which are emitted from the cathode, start from rest.
The electrons are accelerated towards the anode through a p.d. of 5.0 kV.

(a) Show that the speed of an electron is 4.2×10^7 m s^{-1} when it reaches the anode. 2

(b) The current in the tube is 10 mA.
How many electrons pass through the tube in one second?

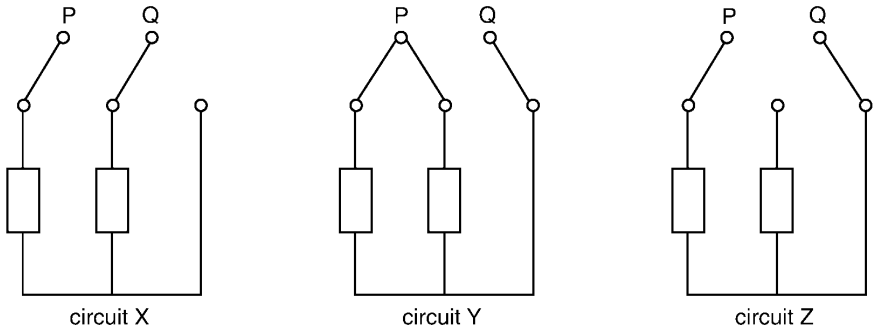
(c) After leaving the anode, the electrons travel at a constant speed of 4.2×10^7 m s^{-1} towards the screen. The electrons are brought to rest and hit the screen in an area of 1.5×10^{-6} m^2.

(i) What is the magnitude of the change in momentum of the electrons in one second?

(ii) Show that the pressure exerted by the electrons on the screen is 1.6 Pa. 7

(9)

14. The heating element of a ring of an electric cooker consists of two equal resistors each of 65 Ω. A selector switch on the cooker enables the resistors to be connected to the mains supply as shown in the circuits X, Y and Z.
The heating ring can produce LOW, MEDIUM and HIGH heat.



The terminals P and Q are connected to the mains supply of 230 V r.m.s.

(a) What is the peak voltage of the a.c. supply? 2

(b) Calculate the resistance between P and Q in:
(i) circuit X
(ii) circuit Y
(iii) circuit Z. 3

(c) Which of the circuits would be used to produce HIGH heat in the heating ring? Explain your answer. 2
(7)

15. The e.m.f. of a car battery is 12.6 V. When the car's rear screen heater of resistance 30.0 Ω is switched on, the p.d. across the battery is 12.0 V.

(a) (i) Calculate the current in the rear screen heater.

(ii) Calculate the internal resistance of the battery. 4

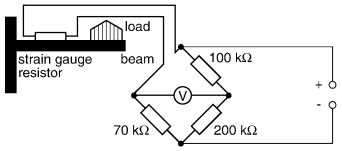
(b) A car mechanic accidentally drops a spanner of resistance zero ohms across the terminals of the battery and short circuits it.

(i) What is the p.d. across the battery terminals under these conditions?

(ii) Calculate the current in the battery as a result of the short circuit.

(iii) Calculate the power produced in the battery during the short circuit. 5
(9)

16. The Wheatstone bridge circuit shown below is used to measure the bending of a beam using a strain gauge resistor R_g. The strain gauge resistor has a resistance of 35 kΩ when there is a load of 2.0 N on the beam. The bridge circuit is balanced under these conditions.



The strain gauge increases its resistance by 5 Ω for each 0.1 N of load that is added to the beam. The Wheatstone bridge produces an out of balance voltage of +0.5 mV for each 10 Ω increase in resistance of the strain gauge resistor.

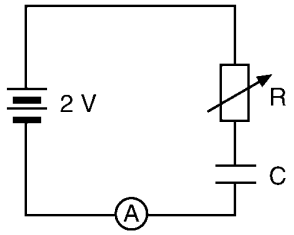
(a) Calculate the out of balance voltage for a load of 2.1 N on the beam. 2

(b) Calculate the out of balance voltage for a load of 1.5 N on the beam. 2

(c) For loads in the range 1.5 N to 2.5 N, draw a labelled sketch graph of the out of balance voltage (y-axis) against load (x-axis). 2

(6)

17. A technician carries out an experiment to measure the capacitance of a capacitor C.
The capacitor, initially uncharged, is charged up to 2 V using the circuit below.



The charging current is kept constant at 0.20 mA during the charging process by adjusting the resistance of R. The capacitor is fully charged in 10 seconds.

(a) Explain whether the resistance of R is increased or decreased during the charging period. 1

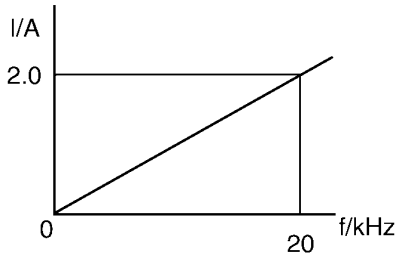
(b) What is the charge supplied to the capacitor? 2

(c) Calculate the capacitance of the capacitor. 2

(d) The capacitor is then used in a circuit where it is connected across a 10 V supply. Calculate:
(i) the charge stored on the capacitor
(ii) the energy stored on the capacitor. 4

(9)

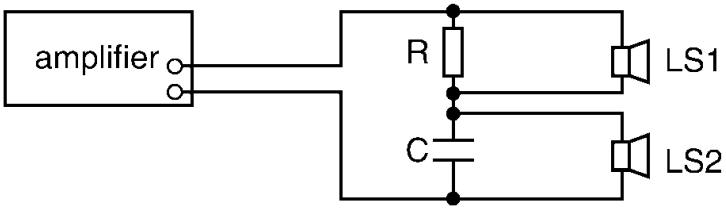
18. (a) An audio engineer obtains the results shown on the graph below. The graph shows how the current in a circuit containing an 8 μF capacitor varies with frequency. The output of the electrical supply is 2 V r.m.s.



Describe an experiment to obtain such a graph. Your answer should include the following:

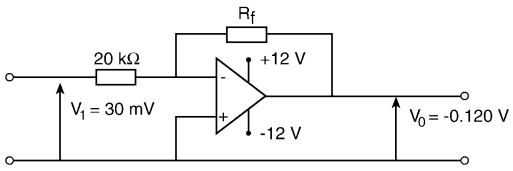
(i) a circuit diagram of the apparatus required
(ii) a statement of the variables measured and controlled
(iii) a description of how the measurements were taken
(iv) conclusions which can be drawn from the graph. 5

(b) An engineer has two loudspeakers, LS1 and LS2, to connect to an audio amplifier. One of the speakers is designed so that it is able to produce low frequency sounds.
The engineer connects the loudspeakers to the amplifier using the circuit shown below.



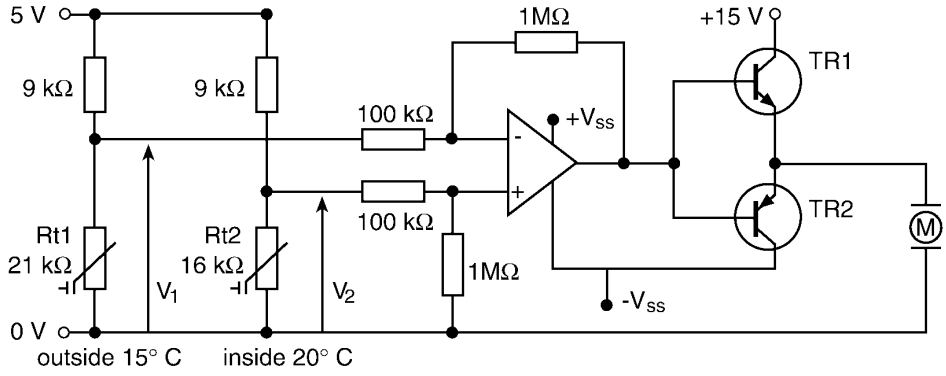
Which of the loudspeakers, LS1 or LS2, is intended to emit low frequency sounds. You must explain your answer. 2
(7)

19. An op-amp with a ±12 volt supply is set up as shown in the diagram below. The op-amp produces an output voltage of -0.120 V.



(a) In what mode is the op-amp being used? 1
(b) Calculate the value of the feedback resistor R_f. 2
(c) What is the output voltage obtained from the op-amp when V_1 is set at 4.0 V? 3
(6)

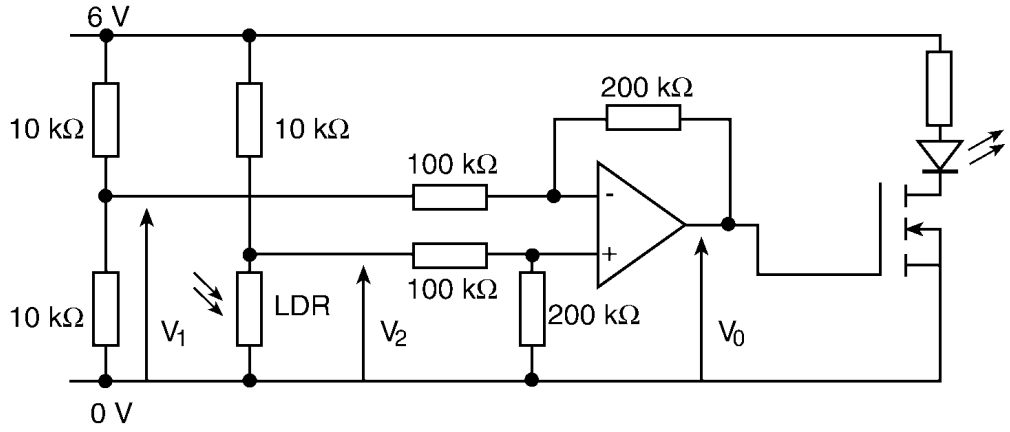
20. The circuit shown below is designed to control the opening and closing of a window in a room. The operation of the circuit depends on the temperature of the air in the room compared to the outside air temperature. If the temperature outside the room is higher than the temperature inside then a positive output voltage from the op-amp opens the window. If the temperature outside the room is lower than the room temperature then the negative output voltage from the op-amp closes the window.



R_{t1} and R_{t2} are identical thermistors.
R_{t1} senses the outside temperature and R_{t2} senses the inside temperature.

(a) In what mode is the op-amp being used? 1
(b) State the equation relating the input voltages V_1 and V_2 to the output voltage V_0. 1
(c) Using the values shown on the diagram calculate the two input voltages V_1 and V_2 to the op-amp. 3
(d) Calculate the output voltage from the op-amp. 2
(e) On a certain day the temperature of the room was 15 ^oC and the outside temperature 20 ^oC. What would the output voltage be on this day? Does this agree with the original specification of the circuit? 2
(f) What is the purpose of the two transistors TR1 and TR2? 1
(10)

21. The following circuit is designed to switch on a light emitting diode (LED) automatically.



The LED switches on when the light intensity sensed by the light dependent resistor (LDR) falls below a certain level.

(a) In what mode is the op-amp operating? 1

(b) Write down an expression for the output voltage V_0 of this op-amp in terms of the input voltages V_1 and V_2. 1

(c) Describe how the charge carriers in the LED enable light to be produced by the LED. 2

(d) Between the hours 20.00 and 22.00 in the evening the light intensity decreases. The table below shows the value of the resistance of the LDR at these different times of the day.

Time of day	*resistance of LDR / kΩ*
20.00	5
21.00	10
22.00	20

(i) Copy and complete the table to show the values of V_1, V_2, and V_0 at the times indicated.

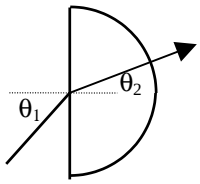
Time of day	V_1/volt	V_2/volt	V_0/volt
20.00	3	2	
21.00	3		
22.00			2

(ii) Explain why the LED is only switched on after 21.00. 5

(9)

RADIATION AND MATTER

22. Two students are studying the refraction of monochromatic light. A ray of monochromatic light enters a semicircular glass block at the midpoint of its straight side, as shown in the diagram below.



The students use a protractor to measure a range of values for θ_1 and θ_2.
The measurements are given in the table below.

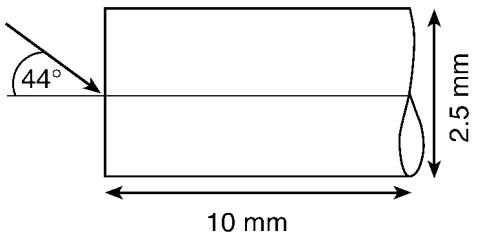
θ_1 / degrees	30	40	50	60	70
θ_2 / degrees	19	24	30	34	37

(a) Use **all** the measurements to obtain a mean value for the refractive index n of the glass. Express your answer in the form: n = value ± uncertainty.
You must show how you obtained the uncertainty. 5

(b) State one way in which this experiment could be improved to obtain a more accurate estimate of the refractive index. 1

(6)

23. A green ray of light of frequency 600 THz enters an optical fibre at an angle of 44^o to the axis of the fibre as shown below.
The refractive index of the optical fibre for green light is 1.4.



(a) Calculate the angle that the refracted ray makes with the axis of the fibre. 2

(b) Calculate the speed of the light in the fibre. 2

(c) Calculate the wavelength of the light in the fibre. 2

(d) Calculate the critical angle of the light in the fibre. 2

(e) Make a scale diagram of the optical fibre (scale 1 mm to 1 cm).
Use the scale diagram to show accurately how the ray of light travels along this 10 mm section of fibre. 2

(10)

24. Monochromatic light of wavelength 500 nm is shone on a grating with 2000 lines/cm. The light diffracts to give a maximum intensity at an angle θ to the normal from the grating.

(a) What colour of light is being used? 1

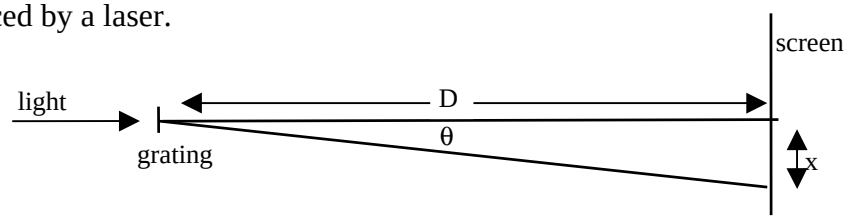
(b) What is the distance between the lines on the grating? 1

(c) Calculate the angle θ for the second maximum of interference produced. 2

(d) What effect would each of the following have on the angle θ?
(i) decreasing the frequency of the light.
(ii) using light of a shorter wavelength
(iii) increasing the brightness of the light
(iv) widening the grating spacing. 4

(8)

25. A grating is used in an experiment to measure the wavelength of the light produced by a laser.



The grating used has 2500 lines per cm with a manufacturer's claim of an uncertainty of ±0.5%.
The distance *D* from the grating to the screen is measured as (2.37 ± 0.01) m.
The distance x from the central spot to the first maximum of intensity is measured to be (38 ± 1) cm.

(a) Calculate the grating spacing *d*. 1

(b) Tabulate measurements of *d*, *x* and *D* together with their percentage uncertainties. 2

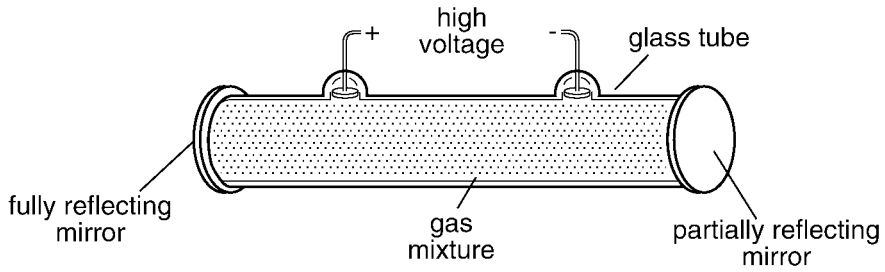
(c) Calculate a value for the angle θ. 1

(d) Determine a value in metres for the wavelength λ of the laser light used. Express your answer as λ = value ± uncertainty. 3

(e) State one way of improving the accuracy of the experiment. You must explain how this improvement affects the uncertainty in the measured value for λ. 2

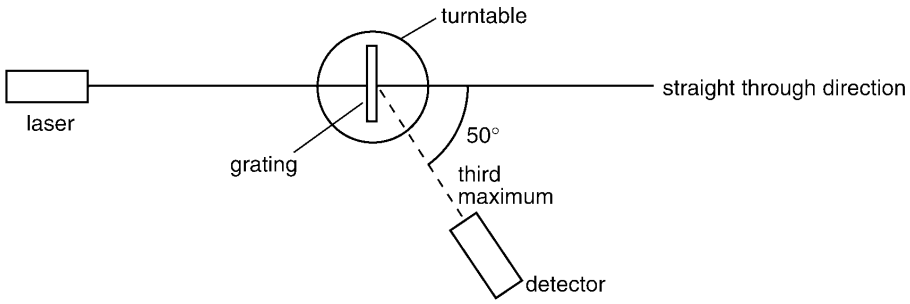
(9)

26. (a) The diagram below shows a simplified view of a laser tube that is used in a gas laser.



(i) Explain the purpose of each mirror in the laser tube.
(ii) The beam of light from the laser tube is very intense. Give **two** reasons for this. 4

(b) Light from a laser is directed at a grating as shown below.



The grating has 400 000 lines per metre.
The third maximum is detected at an angle of 50^o as shown.
Calculate the wavelength of the laser light. 3
(7)

27. Sodium has a threshold frequency of 440 THz. A 2 cm x 4 cm surface of clean sodium is illuminated with radiation of frequency 600 THz. 6×10^8 photons are incident every second on the sodium surface.

(a) Calculate the energy of each incident photon of radiation. 2

(b) Determine the power provided by the radiation at the sodium surface. 2

(c) Calculate the intensity of the radiation at the surface of the sodium. 2

(d) Calculate the maximum kinetic energy of an electron released from the sodium surface. 2
(8)

28. (a) In describing photoelectric emission the following terms *photoelectron* and *work function* are used. Explain the meaning of the terms *photoelectron* and *work function*. 2

(b) A source of monochromatic radiation has a power of 30 W. The source emits radiation of frequency 6.0×10^{14} Hz.

(i) Calculate the energy of one photon of the radiation emitted by the source.

(ii) How many photons are emitted by the source in one second? 4

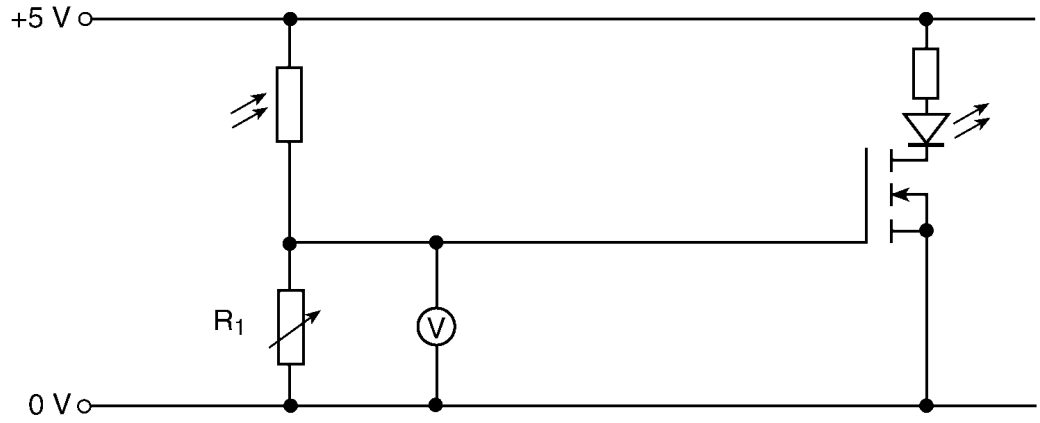
(c) The power of the source is reduced to 10 W.

(i) Explain the effect that this will have on the energy of an emitted photon.

(ii) What effect does reducing the power have on the number of photons emitted in one second. 2

(8)

29. A student designs the circuit shown below so that the LED will come on when the light intensity at the LDR rises to a certain value.



(a) (i) When the LDR is in darkness R_1 is set to a value of 10 kΩ and the reading on the voltmeter is 0.40 V.
Calculate the resistance of the LDR in darkness.

(ii) As the light intensity increases the reading on the voltmeter increases. When the light intensity reaches a certain value the LED comes on. Explain how the action of the n-channel enhancement MOSFET enables the LED to produce light. 4

(b) When the LED is lit it emits light of wavelength 510 nm.

(i) What is the colour of the light emitted by the LED?

(ii) Calculate the energy of one photon of radiation emitted by the LED. 4

(8)

30. Nuclear reactions can involve the release of energy.

(a) When plutonium $^{239}_{94}\text{Pu}$ captures a fast neutron, tellurium $^{137}_{x}\text{Te}$ and molybdenum $^{y}_{42}\text{Mo}$ and 3 neutrons are produced. Energy is released. The following statement represents this reaction.

$$^{239}_{94}\text{Pu} + {}^{1}_{0}\text{n} \rightarrow {}^{137}_{x}\text{Te} + {}^{y}_{42}\text{Mo} + 3 \text{ neutrons} + \text{energy}$$

(i) Determine the values of *x* and *y* in the above statement.

(ii) What is the name given to this type of nuclear reaction ?

(iii) Explain how energy is produced in this nuclear reaction. 4

(b) A nuclear reaction which occurs in the Sun produces helium $^{4}_{2}\text{He}$. The reaction is represented by the statement below.

$$^{3}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$$

(i) What is the name given to this type of nuclear reaction?

(ii) The symbols $^{3}_{1}\text{H}$ and $^{2}_{1}\text{H}$ both represent hydrogen nuclei. What is the name given to two such nuclei which have the same atomic number?

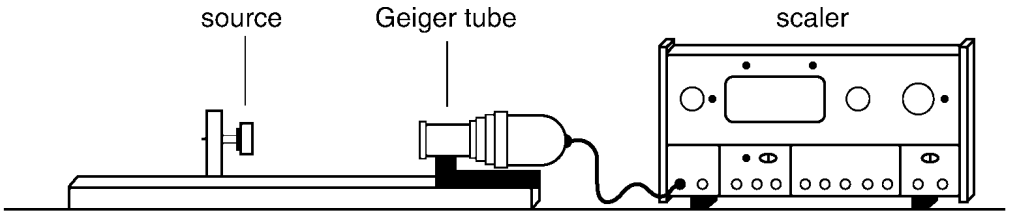
(iii) The masses of the nuclei involved in the nuclear reaction are given below.

nuclei	$^{3}_{1}\text{H}$	$^{2}_{1}\text{H}$	$^{4}_{2}\text{He}$	$^{1}_{0}\text{n}$
mass of nuclei / kg	5.004×10^{-27}	3.342×10^{-27}	6.642×10^{-27}	1.675×10^{-27}

Calculate the energy released when one nucleus of helium $^{4}_{2}\text{He}$ is formed. 5

(9)

31. A Geiger-Müller tube is connected to a scaler in order to measure the background count rate. This is measured to be 31 counts per minute (cpm). The Geiger-Müller tube is placed at different distances from a small source of gamma radiation as shown below.



The following results are obtained for the total count rate at various distances from the gamma ray source.

Distance from source / cm	5	10	15	20
Total count rate / cpm	1671	443	213	134
Corrected count rate / cpm				

(a) (i) Copy the above table. Complete the table, giving the corrected count rate at each distance from the source.

(ii) Use **all** the data from your completed table to establish the relationship between the corrected count rate and distance from the gamma ray source. 4

(b) The gamma ray source is to be used in an experiment to study the movement of mud in a model of a river estuary. A physicist involved in the experiment handles the source with very long tongs. In addition the experiment is completed as quickly as possible after removing the source from its container. The physicist does this to minimise the dose equivalent received from the gamma source.

(i) State **two** factors that affect the risk of biological harm from an exposure to radiation.

(ii) Explain how the action taken by the physicist causes the dose equivalent received to be as small as possible. 4

(8)