

Question 1

5. A student performed a single experiment to (a) verify Joule's law, and (b) determine the specific heat capacity of olive oil.

An electrical heating coil of resistance 8.5Ω was immersed in 350 g of olive oil which was at room temperature. A current I was allowed to flow through the coil for three minutes and the final temperature θ of the oil was determined.

This process was repeated for six different values of I .

The following data were recorded.

Room temperature = 17.0°C

I (A)	1.0	2.0	3.0	3.5	4.0	4.5
θ ($^\circ\text{C}$)	19.2	26.1	36.6	44.4	53.1	62.1

- (i) Draw a labelled diagram of how the apparatus was arranged in this experiment.

heating coil [3]

power supply / battery [3]

ammeter in series [3]

thermometer [3]

[-1 if no label present on diagram]

- (ii) How was the mass of the olive oil determined?

subtract mass of empty calorimeter from mass of full calorimeter / tare mass of empty calorimeter before adding oil [3]

- (iii) Draw a suitable graph to verify Joule's law.

values for I^2 [3]

I^2 (A^2)	1.0	4.0	9.0	12.25	16.0	20.25
$\Delta\theta$ (K)	2.2	9.1	19.6	27.4	36.1	45.1

labelled axes [3]

correct points plotted [3]

line of best fit [3]

- (iv) Calculate the slope of your graph.

slope formula [3]

$m = 0.447$ [no units required] [3]

- (v) Hence calculate the specific heat capacity of olive oil.

$mc\Delta\theta / I^2Rt$ [4]

$(0.447)(8.5)(180)/0.35 = 1954 \text{ J kg}^{-1} \text{ K}^{-1}$ [3]

Question 2

2. In an experiment to determine the focal length f of a concave mirror, a student first found an approximate value for the focal length. She then measured the image distance v for a series of object distances u .

The following data were recorded.

u (cm)	20.0	30.0	40.0
v (cm)	66.3	31.1	25.2

- (i) How did the student find an approximate value for f ?
focus the image of a distant object on a screen [6]
measure the distance from the screen to the mirror [3]
- (ii) Why did the student find an approximate value for f ?
object must be outside focal point / to get an image on the screen / to check answer [3]
- (iii) Draw a labelled diagram of the apparatus used in this experiment.
 Show u and v on your diagram.
object, screen, mirror [3]
 u shown [3]
 v shown [3]
- (iv) Describe how the student determined and measured v .
move object/screen/mirror [3]
until a (sharp) image is formed on the screen [3]
measure v with a metre stick [3]
- (v) Use all of the data to calculate f .
 $1/u + 1/v = 1/f$ [2]
substitution for u and v (once) [2]
first calculation of f [2]
two further calculations for f [2 × 1]
average of values for $f = 15.4$ cm [2]

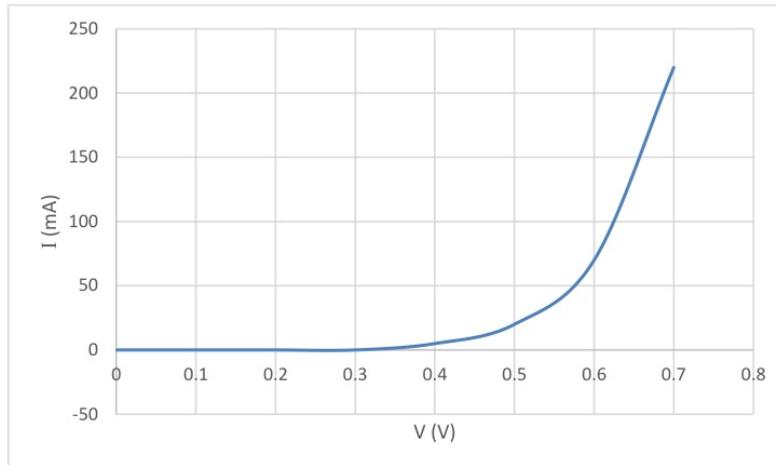
Question 3

5. A student investigated the variation of current I with potential difference V for a semiconductor diode in forward bias.

The following data were recorded.

V (V)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
I (mA)	0	0	0	0	5	20	70	220

- (i) Draw a circuit diagram for this experiment with the diode in forward bias.
- source of voltage** [3]
 - diode in forward bias** [3]
 - voltmeter across the diode** [3]
 - (milli)ammeter in series** [3]
- (ii) Draw a suitable graph to show the relationship between I and V for a diode in forward bias.
- labelled axes** [3]
 - 6 points plotted** [3]
 - curve with good fit** [3]



- (iii) Is Ohm's law obeyed for this diode? Justify your answer.
- no** [3]
 - not a straight line** [3]

The student then investigated the variation of current I with potential difference V for a diode in reverse bias. Several adjustments were made to the circuit.

- (iv) Draw a circuit diagram for this experiment with the diode in reverse bias.
- diode in reverse bias** [3]
 - voltmeter across the diode and (micro)ammeter** [3]
- (v) Sketch a graph to show the relationship between I and V for a diode in reverse bias.
- axes labelled** [3]
 - correct shape** [4]

Question 4

12. Answer **either** part (a) or part (b).

(a) In 1932 Ernest Walton and John Cockcroft verified experimentally Einstein's equation that relates mass and energy. They accelerated protons through a potential difference of 70 kV before allowing them to collide with lithium metal.

(i) Draw a labelled diagram of their apparatus.

hydrogen discharge tube [3]

linear accelerator with voltage applied correctly [3]

target [at 45°] [3]

screen/scintillations/microscope [3]

(ii) Write a nuclear equation for the interaction between a proton and a nucleus of lithium-7.



[−3 for each additional incorrect species]

The mass of the ${}^1\text{H}$ nuclide is given on page 83 of the *Formulae and Tables* booklet as 1.007825 u.

(iii) Convert this mass to kg. (Give your answer to six decimal places.)

$$(1.007825)(1.6605402 \times 10^{-27}) = 1.673534 \times 10^{-27} \text{ [kg]} \quad [3]$$

(iv) Explain the discrepancy between the value you have calculated and the value given for the mass of the proton on page 47 of the *Formulae and Tables* booklet.

the nuclide mass [on page 83] contains the mass of the electron [3]

Calculate

(v) the kinetic energy of the proton as it collided with the metal,

$$E = qV \quad [3]$$

$$(1.60217653 \times 10^{-19})(70000) = 1.12152357 \times 10^{-14} \text{ J} \quad [3]$$

(vi) the mass lost (in kg) during the interaction,

$$7.016005 + 1.007825 - 2(4.002603) = 0.018624 \text{ [u]} \quad [3]$$

$$(0.018624)(1.6605402 \times 10^{-27}) = 3.09259007 \times 10^{-29} \text{ [kg]} \quad [3]$$

(vii) the energy produced (in J) during the interaction,

$$E = mc^2 \quad [3]$$

$$(3.09259007 \times 10^{-29})(2.99792458 \times 10^8)^2 = 2.77948134 \times 10^{-12} \text{ [J]} \quad [3]$$

(viii) the speed of the alpha particles formed during the interaction.

$$E = \frac{1}{2}mv^2 \quad [3]$$

$$v = 2.05 \times 10^7 \text{ m s}^{-1} \quad [3]$$

(ix) A proton may be classified as a *hadron*. Explain why.

it experiences the strong force / it is composed of quarks [3]

(x) A proton may also be classified as a *baryon*. Explain why.

baryons are composed of three quarks [2]

(b) A moving-coil galvanometer is a device for detecting and measuring electric current.

(i) What is electric current?

the flow of charge [3]

(ii) Draw a labelled diagram of a moving-coil galvanometer.

magnet [3]

coil [3]

[soft] iron core [3]

scale and pointer [3]

[−1 if no label present on diagram]

(iii) Describe, with the aid of your diagram, the principle of operation of a moving-coil galvanometer.

current in coil [3]

force/torque [3]

- deflection of pointer** [3]
- (iv) Draw a circuit diagram to demonstrate how a galvanometer can be converted into an ammeter.
- [low resistance] resistor/shunt** [3]
in parallel with galvanometer [3]
- (v) Draw a circuit diagram to demonstrate how a galvanometer can be converted into an ohmmeter.
- variable resistor in series with galvanometer** [3]
power supply [3]
- A resistor called a multiplier is used to convert a galvanometer into a voltmeter.
- (vi) A galvanometer has a full scale deflection of 50 mA and a resistance of 0.7Ω . Calculate the resistance of the multiplier used when this galvanometer is converted into a voltmeter which can read up to 10 V.
- $V = IR$** [3]
- $10 \div 0.05 = 200 [\Omega]$** // **$10 - (0.05 \times 0.7) = 9.965 [V]$** [3]
- $200 - 0.7 = 199.3 \Omega$** // **$9.965 \div 0.05 = 199.3 \Omega$** [3]
- A loudspeaker also contains a moving coil.
- (vii) Explain, with the aid of a labelled diagram, how a loudspeaker produces sound.
- current in the coil** [3]
creates a magnetic field [3]
force produced from the interaction between the two magnetic fields [3]
cone vibrates [to produce sound] [2]
- [-1 if no label present on diagram]*

Question 5

13. (i) Diffraction is one of the wave properties of light. What is meant by diffraction?
spreading [of a wave]
around an obstacle / through a gap **[4 + 3]**
- (ii) (a) Draw a labelled diagram of an experiment to demonstrate the wave nature of light.
light source **[2]**
diffraction grating **[2]**
screen/spectrometer **[2]**
[-1 if no label present on diagram]
- (b) What is observed in this experiment?
series of fringes **[4]**
- (c) How do the observations demonstrate the wave nature of light?
interference **[4]**
- (iii) The eyepiece lens of Huygens' telescope was a converging lens arranged so as to produce a virtual image. Draw a ray diagram to show how a converging lens can produce a virtual image.
converging lens **[2]**
object inside focal point **[2]**
apparent intersection of rays to form virtual image **[3]**
- (iv) The pendulum of Huygens' clock oscillated with a period of 2 s. Calculate the length of this pendulum.
 $T = 2\pi\sqrt{l/g}$ **[4]**
 $l = 0.993 \text{ m}$ **[3]**
- Titan orbits Saturn every 15.9 Earth days. The surface of Titan is $1.16 \times 10^9 \text{ m}$ above the surface of Saturn.
- (v) Calculate
- (a) the mass of Saturn,
 $T^2 = 4\pi^2 R^3 / GM$
 $R = 1.16 \times 10^9 + 58200000 + 2570000 = 1.22 \times 10^9 \text{ [m] or}$
 $T = 15.9 \times 24 \times 60 \times 60 = 1373760 \text{ [s]}$
 $M = 4\pi^2(1.22 \times 10^9)^3 / (6.6742 \times 10^{-11} \times 1373760^2) = 5.7 \times 10^{26} \text{ kg}$ **[6 + 3 + 3]**
- (b) the acceleration due to gravity on the surface of Saturn,
 $g = GM/d^2$ **[3]**
 $g = (6.6742 \times 10^{-11} \times 5.7 \times 10^{26}) / (58200000)^2 = 11.2 \text{ m s}^{-2}$ **[3]**
- (c) the period that Huygens' clock would have on the surface of Saturn.
 $T = 2\pi\sqrt{0.993/11.2} = 1.87 \text{ s}$ **[3]**

Question 6

7. A spring of natural length 150 mm obeys Hooke's law. When an object of mass 200 g is attached to it, the length of the spring increases to 185 mm.

(i) State Hooke's law.

extension *// F = -kx* [2]

proportional to force *// notation* [2]

(ii) Calculate the elastic constant of the spring.

$F = -kx$ [2]

$(0.2)(9.8) = k(0.185 - 0.15)$ [2]

$k = 56 \text{ N m}^{-1}$ [2]

The object is pulled down until the spring has a length of 200 mm. The object is then released. It moves with simple harmonic motion.

(iii) Calculate the period of oscillation of the object.

$T = 2\pi/\omega$ [3]

$\omega = \sqrt{k/m}$ or $\omega = \sqrt{280} = 16.73 \text{ [s}^{-1}\text{]}$ [3]

$T = 2\pi/16.73 = 0.375 \text{ s}$ [3]

(iv) Calculate the maximum acceleration of the object.

$a = -\omega^2x$ [3]

$a_{max.} = (280)(0.2 - 0.185) = 4.2 \text{ m s}^{-2}$ [3]

(v) What is the speed of the body when it has maximum acceleration?

zero [3]

The object is now detached from the spring and attached to the end of a string of fixed length 11 cm. It is made to rotate in a vertical circle with constant angular velocity and with a period of 0.5 s.

(vi) Derive an expression for the linear velocity of an object moving in circular motion in terms of its angular velocity and the radius of the circle.

$\theta = s/r$ [3]

$v = s/t = r\theta/t$ [3]

$\omega = \theta/t$ so $v = r\omega$ [3]

[accept $v = r\omega$ as partial answer for 3]

(vii) Calculate (a) the angular velocity, (b) the linear velocity of the object.

(a) $T = 2\pi/\omega$ [3]

$\omega = 2\pi/0.5 = 12.57 \text{ rad s}^{-1}$ [3]

(b) $v = 0.11 \times 12.57 = 1.38 \text{ m s}^{-1}$ [3]

(viii) Calculate the minimum tension in the string.

$F_c = m\omega^2 / F_c = mv^2/r$ [3]

$T_{min.} = (0.2 \times 0.11 \times 12.56^2) - (0.2 \times 9.8) = 3.47 - 1.96 = 1.51 \text{ N}$ [3]

(ix) Draw a labelled diagram of the forces acting on the object when the string has its minimum tension.

weight acting downwards [2]

tension acting downwards [2]

[-2 for each additional incorrect force; ignore references to centripetal force]

[-1 if no label present on diagram]

Question 7

14.

(a) Ireland's Fittest Family is a competition where families compete across a range of different fitness challenges. These challenges exemplify many physics principles in action.

(i) State the law of conservation of energy.
energy cannot be created or destroyed [4]

A man is competing in a race where participants are required to slide from a raised horizontal platform down a 2.4 m long slide. The slide is at an angle of 32° to the horizontal from the platform. The end of the slide is a vertical distance of 90 cm above the water.

(ii) Calculate the height of the platform above the surface of the water.
slide height = 2.4 sin 32° (= 1.27 m) [3]
total height = 1.27 + 0.9 = 2.17 m [3]

(iii) The man starts from rest. Calculate his velocity as he enters the water. Assume that there is no friction on the slide.
 $mgh = \frac{1}{2}mv^2$ [3]
 $v = 6.52 \text{ m s}^{-1}$ [3]

(iv) Draw a force diagram for the man
 (a) as he slides down the slide,
weight down [3]
normal reaction perpendicular to surface [3]
 (b) when he is floating in the water.
weight down [3]
upward force equal in size [3]

[-3 for additional/incorrect forces]

(b) Ra-224 is an unstable nucleus of radium.

(i) Ra-224 decays by releasing an alpha-particle. Write a nuclear equation for this decay.

$${}_{88}^{224}\text{Ra} \rightarrow {}_2^4\text{He} + {}_{86}^{220}\text{Rn}$$
 [7 × 1]

[-3 for additional incorrect species]

(ii) A sample of Ra-224 decays to form Pb-208, an isotope of lead.

(a) How many alpha-particles are released?
4
 (b) How many beta-particles are released?
2 [4 + 2]

Ra-224 has a half-life of 3.6 days.

(iii) Explain what is meant by the term half-life.
the time taken [3]
for half of the nuclei to decay [3]

[-1 for incorrect reference to atoms]

(iv) Calculate the total number of alpha-particles emitted per second by a sample of Ra-224 containing 4.7×10^{14} atoms.

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ [3]
 $A = \lambda N$ [3]
 $A = 1.05 \times 10^9 \text{ (Bq)}$ [3]

(c) (i) What is meant by thermionic emission?
emission of electrons [3]
from the surface of a hot metal [3]

(ii) Draw a labelled diagram of a cathode ray tube.
heating coil [2]
voltage across cathode and anode [2]
labelled vacuum [2]
one other detail [2]

A high-speed electron that strikes the screen of an oscilloscope produces the green light that is seen.

- (iii) Calculate the minimum voltage required across the tube to give an electron a velocity of $2.7 \times 10^7 \text{ m s}^{-1}$.
- $E_k = \frac{1}{2}mv^2$ or $W = qV$ [3]
- $qV = \frac{1}{2}mv^2$ [3]
- $V = 2072 \text{ V}$ [3]
- (iv) How does the photoelectric effect differ from thermionic emission?
(energy needed) to release the electron is provided by light [5]

(d) A spectrometer can be used to measure the wavelength of light.

- (i) Draw a labelled diagram of a spectrometer.
labelled collimator, table, telescope, other detail [2 + 2 + 2 + 2]

Green light of wavelength 530 nm is passed through a diffraction grating with 400 lines per mm.

- (ii) Calculate the angle of separation between the second order images.
- $d = \frac{1}{\text{number of lines per metre}}$ [3]
- $n\lambda = d\sin\theta$ [3]
- $\theta = 25.1$ [3]
- angle of separation = 50.2°** [3]
- (iii) Identify a different colour of light that could be used to produce a greater angle of separation.
red / orange / yellow [4]
- (iv) Explain how the number of lines per mm on a diffraction grating affects the angle of separation.
increased number of lines per mm means increased angle [4]

Question 8

6. Answer any **eight** of the following parts, (a), (b), (c), etc.
- (a) An airplane starts from rest on a runway and reaches a velocity of 290 km hour^{-1} in 33 s. Calculate the acceleration of the airplane in terms of g , the acceleration due to gravity.
- $v = 80.56 \text{ (m s}^{-1}\text{)}$** [2]
 $v = u + at$ [2]
 $a = 2.44 \text{ (m s}^{-2}\text{)}$ [2]
 $a = 0.25 g$ [1]
- (b) Explain the term solar constant.
- (solar) energy falling normally on the Earth** [3]
per second [2]
per m^2 [2]
- (c) A converging lens of focal length 15 cm is placed in combination with a diverging lens of focal length 5 cm. Calculate the power of the combination.
- $P = 1/f$; $P_T = P_1 + P_2$** [3 + 2]
 $P_T = -13.33 \text{ m}^{-1}$ [2]
- (d) Uranus has a mass of $8.7 \times 10^{25} \text{ kg}$ and a radius of 25 400 km. Calculate the acceleration due to gravity on Uranus.
- $g = GM/d^2$** [4]
 $g = 8.99 \text{ m s}^{-2}$ [3]
- (e) Draw a diagram to show how a ray of light can be turned through 90° using a $45^\circ\text{--}90^\circ\text{--}45^\circ$ prism.
- ray entering normally at one short face** [2]
ray exiting at the other short face [2]
total internal reflection [3]
- (f) State one application of stress polarisation.
- e.g. to identify weaknesses in plastics** [7]
- (g) What is meant by potential difference?
- work done** // formula [4]
per unit charge (moved between two points) // notation [3]
- (h) Calculate the power output of a resistor of resistance 3.4Ω when a potential difference of 55 V is maintained across it.
- $P = VI$; $V = IR$** [3 + 2]
 $P = 889.7 \text{ W}$ [2]
- (i) The peak voltage of an a.c. supply is 311 V. Calculate its rms voltage.
- $V_{rms} = V_{peak}/\sqrt{2}$** [4]
 $V_{rms} = 219.9 \text{ V}$ [3]
- (j) A proton experiences a force of $4.59 \times 10^{-16} \text{ N}$ when it moves with velocity v perpendicular to a magnetic field of flux density 18.5 mT. Calculate v .
- $F = qvB$** [4]
 $v = 1.55 \times 10^5 \text{ m s}^{-1}$ [3]

- (k) Explain what is meant by a chain reaction in nuclear fission.
- neutrons** [4]
from one reaction initiate subsequent reactions / cause a self-sustaining reaction [3]
- (l) The equation to describe an emission line spectrum is $hf = E_2 - E_1$. Explain what each of the symbols in this equation stands for.

h = Planck constant

[2]

f = frequency

[2]

E_2 = higher energy; E_1 = lower energy

[2 + 1]