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 8.5 Ω 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 (°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 J kg^{-1} K^{-1} **[3]**

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]**

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]**

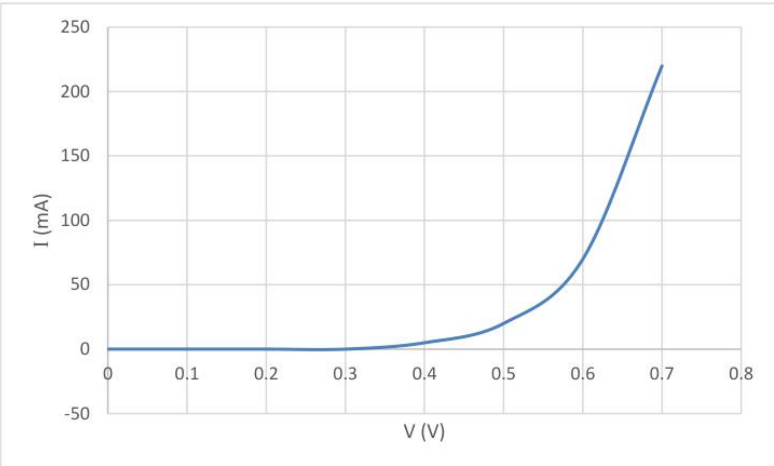
(milli)ammeter in series **[3]**

(*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]**

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.

$^{7}_{3}Li + ^{1}_{1}p \rightarrow 2^{4}_{2}He$ **[9 × 1]**

[–3 for each additional incorrect species]

The mass of the ^{1}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 × 10^{-27}) = 1.673534 × 10^{-27} [kg] **[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 **[3]**

(1.60217653 × 10^{-19})(70000) = 1.12152357 × 10^{-14} J **[3]**

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

7.016005 + 1.007825 – 2(4.002603) = 0.018624 [u] **[3]**

(0.018624)(1.6605402 × 10^{-27}) = 3.09259007 × 10^{-29} [kg] **[3]**

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

$E = mc^2$ **[3]**

(3.09259007 × 10^{-29})(2.99792458 × 10^{8})^2 = 2.77948134 × 10^{-12} [J] **[3]**

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

$E = ½mv^2$ **[3]**

v = 2.05 × 10^{7} m s^{-1} **[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 0.7 Ω. 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 ÷ 0.05 = 200 [Ω] **// 10 – (0.05 × 0.7) = 9.965 [V]** **[3]**

200 – 0.7 = 199.3 Ω **// 9.965 ÷ 0.05 = 199.3 Ω** **[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]

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]**

$l = 0.993$ m **[3]**

Titan orbits Saturn every 15.9 Earth days. The surface of Titan is 1.16×10^9 m above the surface of Saturn.

(v) Calculate

(*a*) the mass of Saturn,

$T^2 = 4\pi^2R^3/GM$

$R = 1.16 \times 10^9 + 58200000 + 2570000 = 1.22 \times 10^9$ [m] *or*

$T = 15.9 \times 24 \times 60 \times 60 = 1373760$ [s]

$M = 4\pi^2(1.22 \times 10^9)^3/(6.6742 \times 10^{-11} \times 1373760^2) = 5.7 \times 10^{26}$ kg **[6 + 3 + 3]**

(*b*) the acceleration due to gravity on the surface of Saturn,

$g = GM/d^2$ **[3]**

$g = (6.6742 \times 10^{-11} \times 5.7 \times 10^{26})/(58200000)^2 = 11.2$ m s^{-2} **[3]**

(*c*) the period that Huygens' clock would have on the surface of Saturn.

$T = 2\pi\sqrt{(0.993/11.2)} = 1.87$ s **[3]**

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]**

$\omega = \sqrt{(k/m)}$ <u>or</u> $\omega = \sqrt{280} = 16.73\ [\text{s}^{-1}]$ **[3]**

$T = 2\pi/16.73 = 0.375$ s **[3]**

(*iv*) Calculate the maximum acceleration of the object.

$a = -\omega^2 x$ **[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.

$F_C = mr\omega^2$ / $F_C = mv^2/r$ **[3]**

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

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.

$^{224}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{220}_{86}\text{Rn}$ **[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]**

$A = 1.05 \times 10^9$ **(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 $2.7 \times 10^7 \text{ m s}^{-1}$

$E_k = ½mv^2$ or $W = qV$ **[3]**

$qV = ½mv^2$ **[3]**

V = 2072 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]**

θ **= 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]**

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 (m s^{-1}) **[2]**

$v = u + at$ **[2]**

a = 2.44 (m s^{-2}) **[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 m^{-1} **[2]**

(*d*) Uranus has a mass of 8.7 × 10^{25} kg and a radius of 25 400 km. Calculate the acceleration due to gravity on Uranus.

$g = GM/d^2$ **[4]**

g = 8.99 m s^{-2} **[3]**

(*e*) Draw a diagram to show how a ray of light can be turned through 90° using a 45°–90°–45° 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 3.4 Ω when a potential difference of 55 V is maintained across it.

$P = VI$; $V = IR$ **[3 + 2]**

P = 889.7 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 V **[3]**

(*j*) A proton experiences a force of 4.59 × 10^{-16} 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 × 10^5 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]**