Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2022

Marking Scheme

Physics

Higher Level

Note to teachers and students on the use of published marking schemes

Marking schemes published by the State Examinations Commission are not intended to be standalone documents. They are an essential resource for examiners who receive training in the correct interpretation and application of the scheme. This training involves, among other things, marking samples of student work and discussing the marks awarded, so as to clarify the correct application of the scheme. The work of examiners is subsequently monitored by Advising Examiners to ensure consistent and accurate application of the marking scheme. This process is overseen by the Chief Examiner, usually assisted by a Chief Advising Examiner. The Chief Examiner is the final authority regarding whether or not the marking scheme has been correctly applied to any piece of candidate work.

Marking schemes are working documents. While a draft marking scheme is prepared in advance of the examination, the scheme is not finalised until examiners have applied it to candidates' work and the feedback from all examiners has been collated and considered in light of the full range of responses of candidates, the overall level of difficulty of the examination and the need to maintain consistency in standards from year to year. This published document contains the finalised scheme, as it was applied to all candidates' work.

In the case of marking schemes that include model solutions or answers, it should be noted that these are not intended to be exhaustive. Variations and alternatives may also be acceptable. Examiners must consider all answers on their merits, and will have consulted with their Advising Examiners when in doubt.

Future Marking Schemes

Assumptions about future marking schemes on the basis of past schemes should be avoided. While the underlying assessment principles remain the same, the details of the marking of a particular type of question may change in the context of the contribution of that question to the overall examination in a given year. The Chief Examiner in any given year has the responsibility to determine how best to ensure the fair and accurate assessment of candidates' work and to ensure consistency in the standard of the assessment from year to year. Accordingly, aspects of the structure, detail and application of the marking scheme for a particular examination are subject to change from one year to the next without notice.

In considering this marking scheme the following points should be noted.

1. In many instances only key words are given – words that must appear in the correct context in the candidate's answer in order to merit the assigned marks.

2. Words, expressions or statements separated by a solidus, /, are alternatives which are equally acceptable.

3. Answers that are separated by a double solidus, //, are answers which are mutually exclusive. A partial answer from one side of the // may not be taken in conjunction with a partial answer from the other side.

4. The descriptions, methods and definitions in the scheme are not exhaustive and alternative valid answers are acceptable.

5. The detail required in any answer is determined by the context and manner in which the question is asked, and also by the number of marks assigned to the answer in the examination paper. Therefore, in any instance, it may vary from year to year.

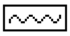
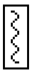
6. For omission of appropriate units (or for incorrect units) in final answers, one mark is deducted, unless otherwise indicated.

7. When drawing graphs, one mark is deducted for use of an inappropriate scale.

8. Each time an arithmetical slip occurs in a calculation, one mark is deducted.

9. A zero should only be recorded when the candidate has attempted the question but does not merit marks. If a candidate does not attempt a question (or part of) examiners should record NR.

10. Examiners are expected to annotate parts of the responses as directed at the marking conference. (See below.)

Symbol	Name	Use
✗	Cross	Incorrect element
✔	Tick	Correct element (0 marks)
✔ n	Tick_n	Correct element (n marks)
	Horizontal wavy line	To be noticed
	Vertical wavy line	Additional page
-1	−1	−1
^	^	Missing element

11. Bonus marks at the rate of 10% of the marks obtained will be given to a candidate who answers entirely through Irish and who obtains 75% or less of the total mark available (i.e. 228 marks or less). In calculating the bonus to be applied decimals are always rounded down, not up ¬ e.g., 4.5 becomes 4; 4.9 becomes 4, etc. See below for when a candidate is awarded more than 228 marks.

Marcanna Breise as ucht freagairt trí Ghaeilge

Léiríonn an tábla thíos an méid marcanna breise ba chóir a bhronnadh ar iarrthóirí a ghnóthaíonn níos mó ná 75% d'iomlán na marcanna.

N.B. Ba chóir marcanna de réir an ghnáthráta a bhronnadh ar iarrthóirí nach ngnóthaíonn níos mó ná 75% d'iomlán na marcanna don scrúdú. Ba chóir freisin an marc bónais sin **a shlánú síos**.

Tábla 304 @ 10%
Bain úsáid as an tábla seo i gcás na n-ábhar a bhfuil 304 marc san iomlán ag gabháil leo agus inarb é 10% gnáthráta an bhónais.

Bain úsáid as an ngnáthráta i gcás 228 marc agus faoina bhun sin. Os cionn an mharc sin, féach an tábla thíos.

Bunmharc	Marc Bónais
229 - 230	22
231 - 234	21
235 - 237	20
238 - 240	19
241 - 244	18
245 - 247	17
248 - 250	16
251 - 254	15
255 - 257	14
258 - 260	13
261 - 264	12
265 - 267	11

Bunmharc	Marc Bónais
268 - 270	10
271 - 274	9
275 - 277	8
278 - 280	7
281 - 284	6
285 - 287	5
288 - 290	4
291 - 294	3
295 - 297	2
298 - 300	1
301 - 304	0

1. A student used a metre stick to investigate the laws of equilibrium for a set of co-planar forces. He found that the weight of the metre stick was 1.2 N and that its centre of gravity was at the 50.6 cm position.

(*i*) Describe how the student determined (*a*) the centre of gravity and (*b*) the weight of the metre stick.

(*a*) suspended from a thread / balanced on a pivot **[3]**

(*b*) weighing scales / mass balance × *g* **[3]**

(*ii*) Why was it necessary to determine the centre of gravity of the metre stick?

to know where the weight acted / to calculate the moment *[state/imply]* **[4]**

He then applied vertical forces to the metre stick and adjusted them until the metre stick was horizontal and in equilibrium.

(*iii*) Indicate on a labelled diagram how these vertical forces were applied to the metre stick.

weights ***[for downward forces]*** **[2]**

newtonmeters / weights and pulleys ***[for upward forces]*** **[2]**

[–1 if no label present on diagram]

(*iv*) How was it ensured that the metre stick was in equilibrium?

not moving **[4]**

(*v*) What was the principal advantage of ensuring that the metre stick was horizontal?

distances read are perpendicular/correct / trigonometry not needed **[4]**

The following data were recorded.

Position on metre stick	22.5 cm	32.1 cm	72.2 cm	81.3 cm
Force (N)	2.85	2.00	3.00	3.40
Direction	upwards	downwards	downwards	upwards

(*vi*) Calculate the net moment about the 0 cm position.

(2 × 0.321) + (1.2 × 0.506) + (3 × 0.722) = 3.4152 [N m] **[3]**

(2.85 × 0.225) + (3.4 × 0.813) = 3.40545 [N m] **[3]**

3.4152 – 3.40545 = 0.00975 N m **[3]**

[–1 if incorrect fulcrum used]

[accept partial answer for 3, e.g. moment = force × distance, any moment calculated]

(*vii*) Calculate the net vertical force acting on the metre stick.

2.85 + 3.4 – 2 – 3 – 1.2 = 0.05 N [upwards] **[3]**

(*viii*) Explain how these results verify the laws of equilibrium.

net moment ≈ 0

net force ≈ 0 **[4 + 2]**

2. In an experiment to verify Boyle's law, a student measured the length *l* of a column of air of fixed mass and uniform diameter, at different values of air pressure *p*.

The following data were recorded.

l (cm)	15.0	20.0	25.0	30.0	35.0	40.0
p (kPa)	360	227	214	178	154	136

(*i*) State Boyle's law.

p is inversely proportional to V / pV = constant

for a fixed mass of gas at constant temperature **[4 + 2]**

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

means of measuring p **[3]**

means of measuring V or l **[3]**

means of changing p or V or l **[3]**

[–1 if no label present on diagram]

(*iii*) Why is it necessary for the column of air to have a uniform diameter?

so that V is proportional to l *[state/imply]* **[3]**

(*iv*) Draw a suitable graph to verify Boyle's law.

values for $1/l$ or $1/p$ **[3]**

$1/l$ (cm^{-1})	**0.067**	**0.05**	**0.04**	**0.033**	**0.029**	**0.025**
$1/p$ (kPa^{-1})	**0.0028**	**0.0044**	**0.0047**	**0.0056**	**0.0065**	**0.0074**

labelled axes **[3]**

correct points plotted **[3]**

line of best fit **[3]**

(*v*) Explain how your graph verifies Boyle's law.

straight line through origin **[3]**

One of the data points is inconsistent with the other data points.

(*vi*) Which of the data points is inconsistent with the others?

the second data point, i.e. when l = 20.0 cm **[3]**

(*vii*) How did you treat this data point when you drew your graph?

ignored it **[4]**

3. In an experiment to verify Snell's law, a student measured the angle of incidence *i* and the angle of refraction *r* for a ray of light as it passes from air into glass. This process was repeated for six different values of *i*.

The following data were recorded.

i (degrees)	30	40	50	60	70	80
r (degrees)	19	27	32	36	40	44

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

transparent block **[3]**

ray box / laser / pins **[3]**

detail e.g. paper, ruler, protractor **[3]**

[–1 if no label present on diagram]

(*ii*) Describe how the student determined the angle of refraction.

draw incident/emergent ray

draw refracted ray

draw normal [at point of incidence]

measure angle with protractor **[*any* 3 × 3]**

(*iii*) Draw a suitable graph to verify Snell's law.

values for sin *i* and sin *r* **[3]**

sin *i*	**0.5**	**0.64**	**0.77**	**0.87**	**0.94**	**0.98**
sin *r*	**0.33**	**0.45**	**0.53**	**0.59**	**0.64**	**0.69**

labelled axes **[3]**

correct points plotted **[3]**

line of best fit **[3]**

(*iv*) Use your graph to calculate the refractive index of the glass.

slope formula **[3]**

***n* = 1.4** **[3]**

(*v*) What would be observed if the angle of incidence was zero degrees?

no refraction / ray travels straight through **[4]**

4. In an experiment to determine the speed of sound in air a student measured the length l of a column of air when it was vibrating at its fundamental frequency f. This process was repeated for six different values of f.

The following data were recorded.

f (Hz)	256	288	320	341	384	480
l (cm)	29.2	25.5	22.6	20.9	18.1	13.7

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

tube **[3]**

means of changing length **[3]**

means of measuring length **[3]**

tuning fork[s] **[3]**

[–1 if no label present on diagram]

(*ii*) How did the student determine the length of the column of air for a particular frequency?

hold [vibrating] tuning fork over the mouth of the pipe

change the length of the pipe

until [the loudest] sound is heard

measure length from closed end to open end of the pipe **[*any* 2 × 3]**

(*iii*) Draw a graph to show the relationship between l and $\frac{1}{f}$.

(Note: the line of best fit on your graph should **not** go through the origin.)

values for 1/*f* **[3]**

1/*f* (Hz^{-1})	**0.0039**	**0.0035**	**0.0031**	**0.0029**	**0.0026**	**0.0021**

labelled axes **[3]**

correct points plotted **[3]**

line of best fit **[3]**

(*iv*) Use your graph to calculate the speed of sound in air.

slope formula **[3]**

c = 4 × 85 = 340 m s^{-1} **[3]**

(*v*) Explain why the line of best fit on the graph does not go through the origin.

end correction term / wave exists above the opening of the pipe **[4]**

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]**

6. Answer any **eight** of the following parts, (*a*), (*b*), (*c*), etc.

(*a*) Iron has a density of 7.87 g cm^{-3}. An iron sphere has a mass of 500 g. Calculate the radius of the sphere in cm.

$\rho = m/V$ or $V = (4/3)\pi r^3$ **[3]**

V = 500/7.87 = 63.53 [cm^3] **[2]**

r = 2.475 [cm] **[2]**

(*b*) Calculate how many electronvolts are in a kilowatt-hour.

1 eV = 1.6 × 10^{-19} [J] **1 kW-hour = 1000(60)(60) = 3.6 × 10^6 [J]** **[3 + 2]**

3.6 × 10^6/1.6 × 10^{-19} = 2.25 × 10^{25} **[2]**

(*c*) Draw a labelled diagram to show the forces acting on a piece of wood floating at rest.

weight labelled [downwards] **buoyancy/upthrust labelled [upwards]** **[3 + 2]**

equal and opposite force vectors **[2]**

(*d*) State the thermometric property of (*i*) a thermocouple, (*ii*) a mercury thermometer.

(*i*) voltage/emf **(*ii*) height/length/volume** **[4 + 3]**

(*e*) Transverse waves can be polarised. Explain what is meant by polarisation.

oscillations/vibrations

in one plane **[4 + 3]**

(*f*) The sound intensity is 0.18 mW m^{-2} at a distance of 3 m in any direction from a source of sound. Calculate the power of the source.

$P = IA$ **[3]**

$A = 4\pi(3^2)$ = 113.1 [m^2] **[2]**

P = 0.02 W **[2]**

(*g*) Describe how an insulated metal sphere can be charged by induction using a nearby charged rod.

earth sphere [when rod is close] **[3]**

de-earth sphere [while rod is close] **[2]**

then remove rod **[2]**

[–2 for each additional incorrect step]

(*h*) A current-carrying wire of length 20 cm is placed in a magnetic field. When a current of 55 mA flows in the wire the maximum force it can experience is 130 μN. Calculate the magnetic flux density of the field.

$F = BIl$ **[4]**

$B = 0.00013/(0.2 \times 0.055) = 0.0118$ T **[3]**

(*i*) A tungsten cube of side 2 cm has a resistance of 2.8 μΩ. Calculate the resistivity of tungsten.

$\rho = RA/l$ **[4]**

$\rho = 0.0000028 \times 0.02 = 5.6 \times 10^{-8}\ \Omega$ m **[3]**

(*j*) Describe how the Bohr model of the atom explains emission line spectra.

[electron] falling from one energy level to another / $E_2 - E_1$ / ΔE

produces light of a [particular] frequency/wavelength/energy/colour/hf **[4 + 3]**

(*k*) What is thermionic emission? Where does it occur in an X-ray tube?

emission of electrons **[2]**

from a hot surface **[2]**

cathode **[3]**

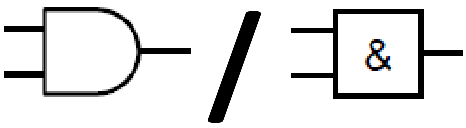
(*l*) Pair annihilation of an electron and a positron occurs in a positron emission tomography (PET) scanner. Write an equation for this annihilation.

$e^- + e^+$ / $2m_ec^2$

$= 2\gamma$ / $2hf$ **[4 + 3]**

or

Draw the symbol for an AND gate. Write out the truth table for an AND gate.



[3]

0	**0**	**0**
1	**0**	**0**
0	**1**	**0**
1	**1**	**1**

[4 × 1]

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]**

$k = 56\ \mathrm{N\ m^{-1}}$ **[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** $\omega = \sqrt{280} = 16.73\ [\mathrm{s^{-1}}]$ **[3]**

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

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

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

$a_{max.} = (280)(0.2 - 0.185) = 4.2\ \mathrm{m\ s^{-2}}$ **[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 = rω as partial answer for 3]

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

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

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

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

(*viii*) Calculate the minimum tension in the string.

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

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

8. Semiconductors are essential in many electrical devices.

(*i*) Distinguish between conductors, insulators and semiconductors.

conductors are good at allowing current to flow / high conductivity / low resistivity **[2]**

insulators are poor at allowing current to flow / low conductivity / high resistivity **[2]**

semiconductors are in-between **[2]**

Semiconductors can be converted into p-type semiconductors and n-type semiconductors by doping.

A p-n junction is used in a diode.

(*ii*) What is meant by doping?

addition of [a small amount of] impurity **[3]**

to increase conductivity / to decrease resistivity **[3]**

(*iii*) How does p-type doping differ from n-type doping?

p-type doping introduces [excess] holes / e.g. adding B **[3]**

n-type doping introduces [excess] electrons / e.g. adding P **[3]**

A depletion layer exists in a p-n junction.

(*iv*) Describe a depletion layer and explain how it forms.

insulating region / region with no free charge carriers **[3]**

between p-type and n-type semiconductors **[3]**

holes/electrons migrate **[3]**

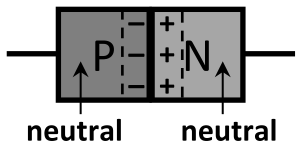
and combine/neutralise each other **[3]**

(*v*) Indicate on a diagram the sections of a p-n junction that are positively charged, negatively charged and neutral.

negatively charged in p-type close to the interface **[2]**

positively charged in n-type close to the interface **[2]**

neutral in remainder **[2]**



Associated with every diode is a voltage called its junction voltage. When a variable voltage is applied across a diode held in forward bias, the depletion layer breaks down as the junction voltage is reached.

(*vi*) Draw a circuit diagram to show this arrangement.

diode in forward bias **[3]**

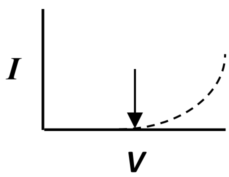
[variable] voltage source **[3]**

(*vii*) Sketch a graph to show the variation of current with voltage for this arrangement. Indicate the junction voltage on your graph.

axes labelled **[3]**

correct shape **[3]**

junction voltage indicated **[3]**



(*viii*) In many electric circuits a resistor is placed in series with a diode. Explain why this may be necessary.

to protect the diode / to limit the current / to prevent overheating **[5]**

9. (*a*) A metal sphere of diameter 5 cm holds a charge of –6 μC.

(*i*) Draw the electric field around the sphere.

radial shape of field **[3]**

direction of field towards centre **[3]**

(*ii*) Calculate the electric field strength at a distance of 3 cm from the surface of the sphere.

$F = q_1q_2/4\pi\varepsilon d^2$ **[3]**

$E = F/q$ **[3]**

$E = (6 \times 10^{-6})/(4\pi \times 8.854 \times 10^{-12} \times 0.055^2) = 1.78 \times 10^7$ **N C**$^{-1}$ **[3]**

(*b*) A device that is designed to store energy when it holds a specific charge is called a capacitor.

(*i*) Describe an experiment to demonstrate that a charged capacitor stores energy.

method to charge capacitor e.g. across battery **[4]**

method to discharge capacitor e.g. across bulb/buzzer **[4]**

observation **[4]**

A parallel-plate capacitor has a dielectric of permittivity *ε* and its plates have an area of overlap *A*. Voltage *V* is applied across the plates such that the capacitor stores energy *W*.

(*ii*) In terms of some or all of the symbols given, write an expression for (*a*) the charge on each plate of the capacitor, (*b*) the distance between the plates.

(*a*) $2W/V$ **[4]**

(*b*) $\varepsilon AV^2/2W$ **[4]**

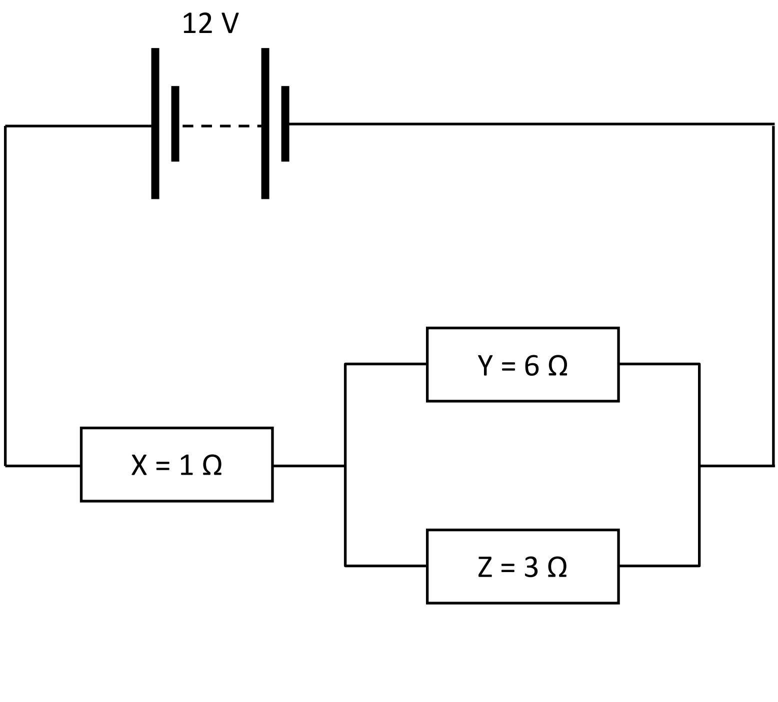
(*c*) (*i*) Derive an expression for the effective resistance of two resistors in parallel.

$I_T = I_1 + I_2$ **[3]**

$V/R_T = V/R_1 + V/R_2$ **[3]**

$1/R_T = 1/R_1 + 1/R_2$ **[3]**

Three resistors X, Y and Z are arranged in a circuit as shown below.



(*ii*) Calculate the current flowing (*a*) in resistor X, (*b*) in resistor Y.

(*a*) $R_{YZ} = 1/(1/6 + 1/3) = 2$ **[Ω]** **[3]**

$R_{XYZ} = 1 + 2 = 3$ **[Ω]** **[3]**

$I = 12/3 = 4$ **A** **[3]**

(*b*) **(4)(1/3) = 1.33 A** **[3]**

10. Americium–241, a radioactive substance, is the key component of smoke detectors, where its ionising ability is used to help detect smoke particles. It is produced from plutonium–239 in nuclear reactors.

(*i*) What is meant by (*a*) radioactivity, (*b*) ionisation?

(*a*) [spontaneous] emission of [one or more types of] radiation **[3]**

from a nucleus **[3]**

[–1 for "atom" instead of "nucleus"]

(*b*) removing/adding electron(s) from/to an atom / charging a particle **[3]**

A nucleus of plutonium–239 can absorb two neutrons to produce plutonium–241. This isotope of plutonium then undergoes beta decay to produce americium–241.

(*ii*) Write a nuclear equation for the conversion of plutonium–239 into plutonium–241.

$${}^{239}_{94}Pu + 2{}^{1}_{0}n \rightarrow {}^{241}_{94}Pu$$

[(5 × 1) + 1]

[–3 for each additional incorrect species]

(*iii*) Write a nuclear equation for the conversion of plutonium–241 into americium–241.

$${}^{241}_{94}Pu \rightarrow {}^{241}_{95}Am + {}^{0}_{-1}e$$

[7 × 1]

[–3 for each additional incorrect species]

At present, nuclear reactors are fission reactors. Nuclear fusion reactors are not yet viable.

(*iv*) Outline the differences between nuclear fission and nuclear fusion.

fission is splitting of a nucleus **[3]**

fusion is joining of [two] nuclei **[3]**

[–1 for "atom" instead of "nucleus" (once)]

Fission reactors usually contain moderators.

(*v*) What is the function of a moderator?

slows down neutrons / increases the rate of fission **[4]**

(*vi*) State one example of a moderator.

water / graphite / beryllium **[4]**

(*vii*) Why are nuclear fusion reactors not yet viable?

too much energy needed [to overcome electrostatic repulsion between nuclei] / scarcity of tritium **[3]**

Americium–241 undergoes alpha decay in a smoke detector. It has a half-life of 432 years. 241 g of americium–241 contains 6.0×10^{23} nuclei.

A typical smoke detector contains 0.29 μg of americium–241.

(*viii*) Why are the alpha particles produced in the detector not considered a health hazard?

easily stopped / not very penetrating / short range **[3]**

(*ix*) Calculate the decay constant for americium–241.

$T_{½} = (\ln 2)/\lambda$ **[3]**

$\lambda = 0.693/(432 \times 365 \times 24 \times 60 \times 60) = 5.09 \times 10^{-11}\ s^{-1}$ **[3]**

(*x*) Calculate the activity of the americium in the smoke detector.

$A = \lambda N$ **[3]**

0.29 μg has $(0.29 \times 10^{-6}/241)(6.0 \times 10^{23}) = 7.22 \times 10^{14}$ **[nuclei]** **[3]**

$(5.09 \times 10^{-11}) \times (7.22 \times 10^{14}) = 3.67 \times 10^{4}$ **Bq [or** s^{-1}**]** **[2]**

11. The Bronze Age began about 5000 years ago. Archaeologists use physics to help them understand the culture and technology of the Bronze Age.

During the Bronze Age in Ireland, a *fulacht fiadh* was used to heat water, perhaps to cook food. It contained an open pit which was filled with water. Stones were heated in a fire and the hot stones were placed into the water.

A particular *fulacht fiadh* contained 750 litres of water at an initial temperature of 4 °C. 50 stones were taken from the fire, at a temperature of 280 °C, and placed into the water. The stones had an average heat capacity of 8.5 kJ K^{-1} each.

(*i*) What is meant by (*a*) heat capacity, (*b*) specific heat capacity?

(*a*) energy to change the temperature of an object by 1 K ***// E/Δθ*** **[3]**

(*b*) energy to change the temperature of 1 kg of a material by 1 K [6 + 3] ***// E/mΔθ*** **[3]**

// notation [3]

(*ii*) Calculate the highest temperature the water could have reached.

mcΔθ

(750)(4180)(*x* – 4) *or* (50)(8500)(280 – *x*)

***x* = 36.95 °C** **[6 + 3 + 3]**

(*iii*) Suggest a way of improving the design of the *fulacht fiadh* to make it more efficient.

e.g. lid, fire closer to the water etc. **[3]**

The earliest harps and lyres were produced in the Bronze Age. Different strings in a lyre may have different lengths, different tensions and different diameters.

(*iv*) Draw a labelled diagram to represent a stretched string vibrating at its third harmonic.

node at both ends

three anti-nodes **[4 + 2]**

A 65 cm string of mass 0.21 g is stretched between two points of a lyre which are 34.1 cm apart. It is required to vibrate at a fundamental frequency of 440 Hz.

(*v*) Calculate the tension that is applied to the string.

$f = (1/2l)\sqrt{(T/\mu)}$

$\mu = m/l$ **[= 0.00021/0.65 = 0.000323 kg m^{-1}]**

$T = 29.1$ **N** **[6 + 3 + 3]**

(*vi*) Determine the frequency of the string if the tension is now reduced by a factor of four.

220 Hz **[4]**

[accept partial answer for 2, e.g. any use of factor of two]

Archaeologists often use radiocarbon dating to estimate the age of wooden objects. They do this by measuring the ratio of carbon–14 to carbon–12 in a sample and comparing it to this ratio for the carbon in a living tree.

(*vii*) C–14 and C–12 are both isotopes of carbon. What are isotopes?

atoms with the same number of protons / atoms with the same atomic number / atoms of the same element **[3]**

with different number of neutrons / with different mass number **[3]**

(*viii*) The ratio of C–14 to C–12 in a sample from an archaeological artefact is found to be one quarter the ratio found in a living tree. Is the artefact from the Bronze Age? Justify your answer.

no **[2]**

two half-lives [> time since the beginning of the Bronze Age] **[2]**

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 = mc² **[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 = ½mv² **[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]** ***<u>or</u>***

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

14. Answer any **two** of the following parts, (*a*), (*b*), (*c*), (*d*).

(*a*) (*i*) Distinguish between a vector and scalar.

vector has [magnitude and] direction **[2]**

scalar has magnitude only / scalar has no direction **[2]**

(*ii*) Draw a labelled diagram of the arrangement of the apparatus in an experiment to find the resultant of two vectors.

three newtonmeters / three systems of weights and pulleys / three displacements **[3]**

correct arrangement **[3]**

An object is released with an initial velocity of 150 m s^{-1} at an angle of 20° to the horizontal.

(*iii*) Resolve the velocity into horizontal and vertical components.

v_H = 150cos20° [= 141 m s^{-1}] **[3]**

v_V = 150sin20° [= 51.3 m s^{-1}] **[3]**

(*iv*) Calculate the magnitude and direction of the velocity of the object after 8 s.

v_H = 150cos20° [= 141 m s^{-1}] **[4]**

$v = u + at$ / v_V = 51.3 – (9.8 × 8) = –27.1 [m s^{-1}] **[4]**

$|v|$ = 143.5 m s^{-1} **[2]**

10.9° [below the horizontal] **[2]**

(*b*) (*i*) What is the Doppler effect?

[apparent] change in frequency [of a wave] **[3]**

due to the [relative] motion between the source and the observer **[3]**

(*ii*) Describe, with the aid of labelled diagrams, how the Doppler effect occurs.

concentric/non-concentric circles drawn [representing wavefronts] **[3]**

motion of wave source towards/away from observer **[3]**

shorter wavelength as source approaches observer [or *vice versa*] **[2]**

therefore greater frequency [or *vice versa*] **[2]**

Pierre drops a child's toy which emits sound of fixed frequency 500 Hz from the top of the Eiffel tower.

(*iii*) Calculate the frequency Pierre observes after 3 seconds.

$v = u + at$ [= (9.8)(3) = 29.4 m s^{-1}]

$f' = fc/(c \pm u)$

f' = 460.2 Hz **[6 + 3 + 3]**

(*c*) The explanation of the photoelectric effect by Albert Einstein led to the quantum revolution in physics.

(*i*) Describe a laboratory experiment to demonstrate the photoelectric effect.

apparatus [e.g. gold leaf electroscope, metal plate, light source] [3]

method [e.g. charge electroscope, place plate on cap, shine light on plate] [3]

observation [e.g. leaves collapse] [3]

Light of wavelength 450 nm is incident on a metal that has a work function of 2.4 eV.

(*ii*) Calculate the maximum speed of the emitted electrons.

$hf = \Phi + \frac{1}{2}mv^2$

$c = f\lambda$ **<u>or</u>** $f = (3 \times 10^8)/(450 \times 10^{-9}) = 6.67 \times 10^{14}$ **[Hz]**

$\Phi = (2.4)(1.6 \times 10^{-19}) = 3.84 \times 10^{-19}$ **[J]**

$v = 3.56 \times 10^5$ m s^{-1} **[6 + 3 + 3 + 3]**

It is observed that as the wavelength of the incident light increases, the speed of the emitted electrons decreases and eventually no electrons are emitted.

(*iii*) Explain these observations.

incident energy decreases [2]

until the incident energy is below the work function / until the incident frequency is below the threshold frequency [2]

(*d*) (*i*) State the laws of electromagnetic induction.

induced emf // $E = d\phi/dt$ **[3]**

proportional to rate of change of flux // notation [3]

direction of induced current/emf [3]

is such as to oppose the change that caused it [3]

A strong magnet is suspended from the end of a string and oscillates in a plane with a constant amplitude.

(*ii*) Describe what is observed when a sheet of copper metal is placed under the oscillating magnet. Explain this observation.

amplitude of oscillations decreases [4]

[magnetic field from induced] currents in copper [4]

(*iii*) Describe what would be observed if instead of the copper, a sheet of plastic was placed under the oscillating magnet. Explain this observation.

oscillations continue [4]

no currents flow in plastic [4]