Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2025

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 item but does not merit marks. If a candidate does not attempt a question item, 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. 300 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 300 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 400 @ 10%

Bain úsáid as an tábla seo i gcás na n-ábhar a bhfuil 400 marc san iomlán ag gabháil leo agus inarb é 10% gnáthráta an bhónais.

Bain úsáid as an ngnáthráta i gcás 300 marc agus faoina bhun sin. Os cionn an mharc sin, féach an tábla thíos.

Bunmharc	**Marc Bónais**
301 - 303	29
304 - 306	28
307 - 310	27
311 - 313	26
314 - 316	25
317 - 320	24
321 - 323	23
324 - 326	22
327 - 330	21
331 - 333	20
334 - 336	19
337 - 340	18
341 - 343	17
344 - 346	16
347 - 350	15

Bunmharc	**Marc Bónais**
351 - 353	14
354 - 356	13
357 - 360	12
361 - 363	11
364 - 366	10
367 - 370	9
371 - 373	8
374 - 376	7
377 - 380	6
381 - 383	5
384 - 386	4
387 - 390	3
391 - 393	2
394 - 396	1
397 - 400	0

1. A student investigated the laws of equilibrium for a set of co-planar forces acting on a metre stick.

First, he found the centre of gravity of the metre stick, which was at the 50.0 cm mark. He then found the weight of the metre stick to be 0.96 N.

The metre stick was supported vertically from above at two points. He also hung three known weights from the metre stick. He adjusted their positions until the metre stick was in equilibrium.

The student recorded the position of each force, and the direction in which each of these forces was acting.

The following additional data were recorded.

position of force on metre stick (cm)	2.0	11.2	40.1	72.7	82.9
force (N)	3.4	3.0	2.0	5.5	3.0
direction	up	down	down	up	down

(*i*) Describe how the student found the centre of gravity of the metre stick.

balance on a pivot **[3]**

(*ii*) How did the student know that the metre stick was in equilibrium?

not accelerating **[3]**

(*iii*) Draw a labelled diagram to show all the forces acting on the metre stick.

two forces up and four forces down with weight arrow labelled **[6 x 1]**

(*iv*) Why was it important to have the forces applied vertically to the metre stick?

(distance to each force position is) a perpendicular distance **[3]**

(*v*) Using the given data, calculate the net force acting on the metre stick.

forces up = 8.9 (N) **[3]**

forces down = 8.96 (N) **[3]**

net force (= 0.06 N) ≈ 0 **[3]**

(*vi*) Using an axis at the 5 cm mark on the metre stick, calculate

(a) the sum of the clockwise moments,

(b) the sum of the anticlockwise moments.

M = Fd **[3]**
any one moment calculated **[3]**
clockwise moments calculated **[3]**
anticlockwise moments calculated **[3]**

(*vii*) Use your results to verify the laws of equilibrium for a set of co-planar forces.

(total) force up ≈ (total) force down

(total) clockwise moment ≈ (total) anticlockwise moment **[2 + 2]**

2. In an experiment to verify the principle of conservation of momentum, two trolleys, A and B, were held in contact and at rest with a light compressed spring between them.

When the spring was released, both trolleys moved with a constant velocity in opposite directions.

Trolley A travelled a distance s_A in a time t_A, while trolley B travelled a distance s_B in a time t_B.

The following data were recorded.

mass of A (g)	mass of B (g)	s_A (cm)	t_A (ms)	s_B (cm)	t_B (ms)
200	250	10	185	8	190

(*i*) Explain how the masses could have been measured.

(electronic) balance **[3]**

(*ii*) Describe how the constant velocity of a trolley can be determined.

(measure) length *l* of card // (measure) distance between dots **[3]**

(measure) time for *l* // (measure) time between dots **[3]**

$v = l/t$ **[3]**

(*iii*) Calculate the velocity of trolley A and the velocity of trolley B after the spring was released.

$v_A = 0.54$ m s^{-1} , $v_B = 0.42$ m s^{-1} **[2 + 1]**

(*iv*) What is the total momentum of the trolleys before they are released?

zero **[3]**

(*v*) Use the data to show that this experiment verifies the principle of conservation of momentum.

$p = mv$ **[3]**

$p_A = 0.108$ (kg m s^{-1}) / $p_B = 0.105$ (kg m s^{-1}) **[3]**

p_{total} (= 0.003 kg m s^{-1}) ≈ 0 **[3]**

(*vi*) External forces acting on the trolleys were minimised in the experiment.

(*a*) State two principal external forces that should be minimised.

frictional, gravitational **[3 + 3]**

(*b*) Describe how the effect of these forces could be minimised.

cushion of air or clean air track // oil wheels or clean track **[2]**

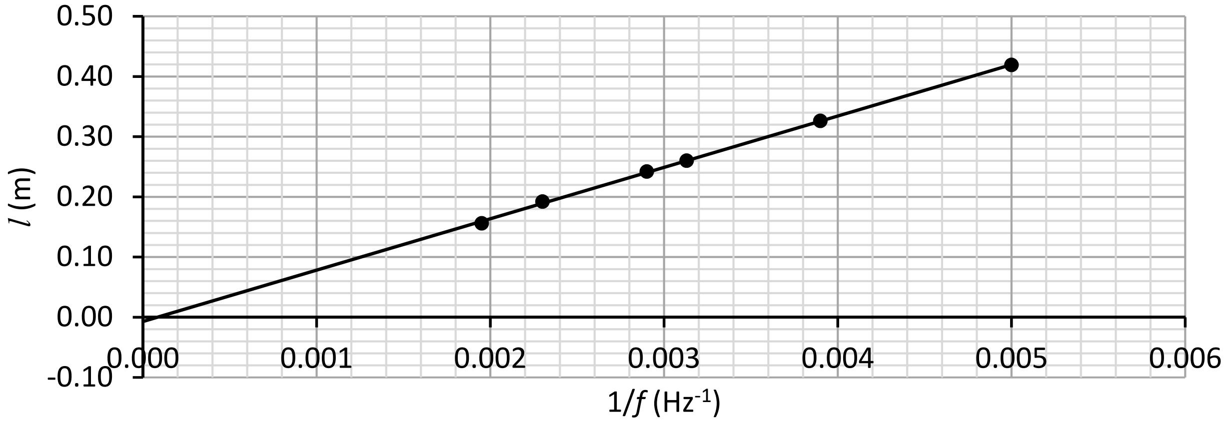
horizontal air track // slope track **[2]**

[allow 4 marks for adjust the track until frictional force = gravitational force]

(*vii*) State one other way to improve the accuracy of the experiment.

e.g. repeat the experiment / reduce the error of parallax / more accurate balance/timer **[3]**

3. In an experiment to measure the speed of sound in air, a student used a cylindrical column of air which was closed at one end, and *six* different tuning forks. A tuning fork of frequency *f* was set vibrating and held over the column of air. The length of the column of air was adjusted until the first position of resonance was found and its length *l* was measured. The procedure was repeated for each tuning fork. The student plotted the following graph based on his recorded data.



(*i*) Draw a labelled diagram of the arrangement of the apparatus used in this experiment.

tube **[4]**

means of varying length *l* **[4]**

tuning fork / metre stick **[4]**

[–1 if no label present on diagram]

(*ii*) Describe how the first position of resonance was found.

increase length of the pipe (from *l* = 0 cm) **[3]**

until (loud) sound is heard **[3]**

(*iii*) Describe how the frequency values were determined.

(read) the tuning fork(s) **[3]**

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

slope formula **[3]**

calculate slope **[3]**

$v = 4 \times$ slope or $c = f\lambda$ **[3]**

$v \approx 343.7$ m s^{-1} **[3]**

(*v*) Why does the student's graph not go through the origin?

end correction / antinode forms outside opening of pipe **[3]**

(*vi*) Identify the frequency of the tuning fork that had the lowest frequency.

$f = 200$ Hz **[4]**

4. 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 passing from air into a rectangular glass block.

The experiment was repeated for different values of the angle of incidence.

The following data were recorded.

i (°)	20	30	40	50	60	70
r (°)	13	19	27	30	35	39

(*i*) Copy the above diagram into your answerbook and show the path of a ray of light as it enters and exits the rectangular glass block. On your diagram, clearly indicate the angle of refraction, *r*.

normal drawn at point of entry **[3]**

ray refracted (towards normal) **[3]**

emergent ray **[3]**

angle *r* indicated **[3]**

(*ii*) Draw a suitable graph, on graph paper, to show the relationship between *i* and *r*.

sin *i*	**0.342**	**0.500**	**0.643**	**0.766**	**0.866**	**0.940**
sin *r*	**0.225**	**0.326**	**0.454**	**0.500**	**0.574**	**0.629**

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

axes labelled **[3]**

points plotted **[3]**

line of best fit **[3]**

(*iii*) Explain how your graph verifies Snell's law.

straight line through origin / sin *i* ∝ sin *r* **[3]**

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

slope formula **[3]**

***n* = 1.5** **[3]**

(*v*) Explain why the student placed the glass block flat on a sheet of paper, as shown below, and not on one of its narrow faces.

reduce (percentage) error (in *r*) **[3]**

(*vi*) Describe what the student would observe if the incident ray of light was perpendicular to the block.

ray would pass straight through **[4]**

5. A student investigated the variation of the current I through a filament bulb for a range of different values of potential difference V.

The following data were recorded.

V (V)	1	2	3	4	5	6	7
I (mA)	25	47	68	80	91	100	104

(*i*) Draw a circuit diagram for this experiment.

power supply **[3]**

voltmeter in parallel with filament bulb **[3]**

ammeter in series with filament bulb **[3]**

means of changing voltage **[3]**

(*ii*) Draw a suitable graph, on graph paper, to show the relationship between V and I.

axes labelled **[3]**

points plotted **[3]**

curve of best fit drawn **[3]**

(*iii*) Does the graph show that Ohm's law is obeyed for the filament bulb? Justify your answer.

no **[2]**

not a straight line **[2]**

(*iv*) Calculate the resistance of the bulb when the current is

(*a*) 40 mA,

(*b*) 90 mA.

$R = V/I$ **[3]**

(*a*) $R \approx 43\ \Omega$ **[2]**

(*b*) $R \approx 54\ \Omega$ **[2]**

(*v*) Explain what happens to the resistance of the filament bulb as the current increases.

(increase in current causes) increase in temperature

(increase in temperature causes) increase in resistance **[4 + 4]**

6. (*a*) State the function of a hydrometer and state a practical example of its use.

density **[4]**

example given **[3]**

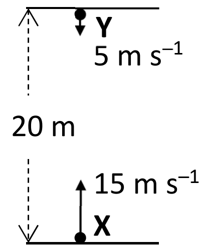
(*b*) A car is driving up a hill, which has a constant steep incline to the horizontal. It travels at a constant speed against a constant frictional force.

Draw a labelled vector diagram to show the forces acting on the car.

applied force, frictional force, gravitational force, normal/reaction force **[2 + 2 + 2 + 1]**

[–1 mark if no label present on diagram] & [–1 mark for additional incorrect forces]

(*c*) The diagram on the right shows a smooth particle **X** being projected vertically upwards with a velocity of 15 m s^{-1} from a point on the ground, and at the same time (t = 0 s) a smooth particle **Y** being projected vertically downwards with a velocity of 5 m s^{-1}.
Using the diagram, calculate the time it takes for the two particles to meet.
acceleration due to gravity = 9.8 m s^{-2}



equation of motion given; e.g. $s = ut + \frac{1}{2}at^2$ **[3]**

$s_X = 15t + \frac{1}{2}(-9.8)t^2$ **or** $s_Y = 5t + \frac{1}{2}(9.8)t^2$ **[2]**

$t = 1$ **s** **[2]**

(*d*) Explain what is meant by complementary colours of light. State an example of complementary colours.

a primary and a secondary colour that combine to give white light

blue–yellow / green–magenta / red–cyan **[4 + 3]**

(*e*) Draw a ray diagram to show the formation of a virtual image using a concave mirror.

object (inside focus)

two reflected rays

magnified virtual image **[3 + 2 + 2]**

(*f*) The Atlantis XII is a submarine which takes tourists to a depth of 30 m to view a reef off the coast of Cozumel in Mexico.
Calculate the total pressure on the submarine at this depth.
acceleration due to gravity = 9.8 m s^{-2}; density of seawater = 1025 kg m^{-3}; atmospheric pressure = 101 kPa.

$P = \rho g h$ **[3]**

P **= 301350 (Pa)** **[2]**

P_{total} **= (301350 + 101000) = 402350 Pa** **[2]**

(*g*) A 12 μF parallel-plate capacitor is connected to a 2 V cell.
Calculate

(*i*) the charge stored on one of the plates,

(*ii*) the energy stored by the capacitor.

(*i*) $C = \frac{q}{V}$

$q = 2.4 \times 10^{-5}$ **C**

(*ii*) $E = \frac{1}{2} CV^2$

$E = 2.4 \times 10^{-5}$ **J** **[2 + 2 + 2 + 1]**

(*h*) A guitar string is vibrating at its first harmonic with a frequency of 196 Hz.

(*i*) Draw a diagram of the string vibrating at its third harmonic.

(*ii*) Determine the frequency of the third harmonic.

(*i*) four nodes, three antinodes on a string fixed at both ends

(*ii*) $f = 588$ **Hz** **[4 + 3]**

(*i*) A spectral line in a distant galaxy is observed in a laboratory on Earth to have a frequency of 7.14×10^{14} Hz. The same line produced and observed in the laboratory has a frequency of 7.59×10^{14} Hz.
Calculate the velocity of the galaxy.

$f' = \frac{fc}{c \pm u}$ **[4]**

$u = 1.89 \times 10^{7}$ **m s**$^{-1}$ **[3]**

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

p-n junction with depletion layer **[4]**

negatively charged section, positively charged section, neutral section **[1 + 1 + 1]**

(*k*) Explain the principle of the source of the Sun's energy.

fusion **[7]**

[award 4 marks for reference to nuclear reactions / $E = mc^2$]

(*l*) Under Rutherford's supervision, Geiger and Marsden carried out an experiment where alpha particles were scattered by a thin film of gold.
State two conclusions drawn from their experiment about the distribution of mass and charge in the atom.

any two: mass concentrated at centre, nucleus positively charged, atom mostly empty space
[4 + 3]

7. (*i*) Explain what is meant by

(*a*) weight,

gravitational force acting on a mass // $W = mg$ & notation **[3]**

(*b*) centripetal force.

force towards centre of circle **[3]**

(that keeps) object moving in a circle **[3]**

[allow 3 marks for $F_{centripetal} = \frac{mv^2}{r}$]

(*ii*) State Newton's law of universal gravitation.

gravitational force is proportional to the product of two masses // $F \propto \frac{m_1 m_2}{d^2}$ **[3]**

inversely proportional to square of distance between them // notation **[3]**

(*iii*) Derive an equation for the angular velocity of an object in terms of its linear velocity when the object moves in a circle.

$\theta = \frac{s}{r}$ **or** $v = \frac{s}{t}$ **or** $\omega = \frac{\theta}{t}$ **[2]**

combination of two formulae **[2]**

$\omega = \frac{v}{r}$ **[2]**

The distance from the centre of the Earth to the centre of the Moon is 3.84×10^8 m. The Moon orbits the Earth every 27.3 days.

(*iv*) Calculate

(*a*) the angular velocity of the Moon,

$\theta = 2\pi$ **[3]**

$\omega = 2.664 \times 10^{-6}$ **rad s^{-1}** **[3]**

(*b*) the linear velocity of the Moon.

$v = r\omega$ **[3]**

$v = 1023$ **m s^{-1}** **[3]**

(*v*) Calculate the force of gravity that the Earth exerts on the Moon according to Newton's law of universal gravitation.

$F = G\frac{m_1 m_2}{d^2}$ **[3]**

force of earth on moon = 1.986×10^{20} N (towards the centre of the Earth) **[3]**

(*vi*) Why does the Moon not fall down to Earth?

(tangential) velocity // gravitational force is too weak **[5]**

A person of mass 80 kg is standing at the equator of the Earth. The person rotates in circular motion with a linear velocity of 463 m s^{-1} at the equator.

(*vii*) $F_{centripetal} = \frac{mv^2}{r}$ **[2]**

$F_{centripetal}$ **= 2.68 N** **[2]**

(*viii*) $W = mg$ **[2]**

$F_{normal} = (W - F_{centripetal}) = 781.32$ **N** **[2]**

(*ix*) **weight**

(approximately) equals normal/reaction force **[2 + 2]**

[–1 mark if no label present on diagram] & [–1 mark for additional incorrect forces]

mass of the Earth = 5.97×10^{24} kg; mass of the Moon = 7.35×10^{22} kg; radius of the Earth at the equator = 6.4×10^6 m; acceleration due to gravity = 9.8 m s^{-2}

8. (*i*) Explain what is meant by a transverse wave.

vibration is perpendicular **[3]**

to the direction of travel **[3]**

(*ii*) Describe an experiment to demonstrate that light waves are transverse waves.

apparatus: two pieces of polaroid material and a light source **[3]**

method: rotate one polaroid relative to the other **[3]**

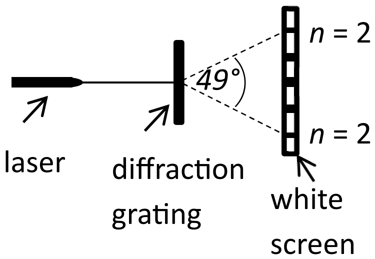
result: light intensity decreases **[3]**

Destructive interference can be observed when waves meet.

(*iii*) State two conditions necessary for total destructive interference to occur.

same amplitude

crest meets trough **[4 + 2]**



Laser light of wavelength 691 nm is used to produce the interference pattern shown in the diagram.

(*iv*) Explain how this pattern is formed from the laser light.

each slit acts as a source / waves diffract / waves meet

constructive interference gives bright fringes **[6 + 3]**

(*v*) Calculate the number of lines per mm on the diffraction grating.

$n\lambda = d \sin \theta$ **[6]**

$\theta = 24.5°$ **[3]**

number of lines/mm = 300 **[3]**

(*vi*) Calculate the maximum number of images that could be observed.

$n_{max} = d/\lambda$ **[3]**

$n_{max} = 4$ **[2]**

maximum number of images = (4 + 1 + 4) = 9 **[1]**

(*vii*) Describe the effect on the pattern when

(*a*) the wavelength of the laser light is increased,

(*b*) a diffraction grating of more lines per mm is used.

(*a*) distance between fringes increases / less images produced

(*b*) distance between fringes increases / less images produced **[4 + 2]**

(*viii*) State one type of electromagnetic radiation that has a shorter wavelength than visible light.

UV / X-rays / gamma rays **[2]**

9. (*i*) Explain what is meant by

(*a*) a photon,

a bundle of energy **// $E = hf$ & notation** **[3]**

(*b*) the photoelectric effect.

emission of electrons from metal surface **[3]**

by electromagnetic radiation of a suitable frequency **[3]**

(*ii*) Outline Einstein's explanation of the photoelectric effect.

electromagnetic radiation consists of photons **[3]**

an electron absorbs the energy of one photon only **[3]**

energy gained by electron ≥ work function / formula & notation **[3]**

(*iii*) Draw a labelled diagram of the structure of a photocell.

vacuum in tube, cathode, anode **[3 + 3 + 3]**

[–1 if no label present on diagram]

(*iv*) Monochromatic radiation falls on a photocell whose work function is 2.7 eV. The maximum kinetic energy of an emitted electron is 2.24×10^{-19} J and the maximum photocurrent observed is 0.005 mA.

Calculate

(*a*) the energy of a photon falling on the photocell,

$\Phi = 4.33 \times 10^{-19}$ (J) **[3]**

$E = \Phi + \frac{1}{2}mv^2$ **[3]**

$E = 6.57 \times 10^{-19}$ J **[3]**

(*b*) the frequency of the photon,

$f_{photon} = \frac{E_{photon}}{h}$ **[3]**

$f_{photon} = 9.91 \times 10^{14}$ Hz **[3]**

(*c*) the number of electrons emitted per second.

$q = It$ **[3]**

number of electrons emitted per second = 3.12×10^{13} **[3]**

(*v*) Explain how thermionic emission differs from photoelectric emission.

thermionic emission due to heat

photoelectric effect due to electromagnetic radiation **[2 + 2]**

(*vi*) Explain why X-ray production can be described as the inverse of the photoelectric effect.

X-ray production: electrons produce X-rays

photoelectric effect: X-rays produces electrons **[2 + 2]**

10. (*i*) Explain what is meant by

(*a*) specific heat capacity,

energy // $c = \frac{\Delta E}{m\Delta\theta}$ **[3]**

required to raise the temperature of 1 kg by 1 K **// notation** **[3]**

(*b*) specific latent heat.

energy // $l = \frac{\Delta E}{m}$ **[3]**

required to change the state of 1 kg of substance **// notation** **[3]**

Dry steam at 100 ˚C was passed into an insulated copper calorimeter of mass 200 g, which contained a mixture of 450 g of cold water and 50 g of ice. The calorimeter, water and ice were all initially at 0 ˚C. The final temperature of the water and the calorimeter was 20 ˚C.

(*ii*) Calculate

(*a*) the energy gained by the calorimeter,

$\Delta E_{cal} = mc\Delta\theta$ **[3]**

$\Delta E_{cal} =$ **1560 J** **[3]**

(*b*) the energy needed to melt the ice,

$\Delta E_{ice} = ml_{ice}$ **[3]**

$\Delta E_{ice} =$ **16500 J** **[3]**

(*c*) the mass of steam added to the water in the calorimeter.

ΔE_{steam} **= (1560 + 16500 + (0.5)(4180)(20)) = 59860 (J)** **[3]**

$(ml)_{steam} = 2.3 \times 10^6\ m$ **[2]**

$(mc\Delta\theta)_{condensed\ steam} = 334400\ m$ **[2]**

m_{steam} **= 0.0227 kg** **[2]**

The SI unit of temperature is the kelvin.

(*iii*) State the equation that defines temperature on the Celsius scale.

θ**/°C = *T*/K – 273.15** **[6]**

[accept reference to 273(.15) for 3 marks]

(*iv*) Suggest a reason why the Celsius scale is used for most everyday purposes.

developed before Kelvin scale / based on melting & freezing point of water **[3]**

(*v*) When a mercury-in-glass thermometer with no markings is placed in melting ice, the length of the mercury column is 3.0 cm. When it is placed in boiling water, the length of the mercury column is 30.0 cm.

Calculate the length of the mercury column when placed in water at 42 ˚C.

100 units = 27 (cm) **// axes labelled** **[3]**

1 units = 0.27 (cm) **// points plotted** **[3]**

42 units = 11.34 (cm) **// line of best fit** **[2]**

length = (11.34 + 3) = 14.34 cm **// length ≈ 14.34 cm** **[2]**

(*vi*) Explain why it is necessary to have a standard thermometer.

different thermometers have different thermometric properties **[4]**

specific heat capacity of copper = 390 J kg^{-1} K^{-1}; specific heat capacity of water = 4180 J kg^{-1} K^{-1};
specific latent heat of fusion of ice = 3.3 x 10^5 J kg^{-1}; specific latent heat of vaporisation of water = 2.3 x 10^6 J kg^{-1}

11. (*i*) Explain what is meant by

(*a*) resistance,

voltage // $R = V/I$

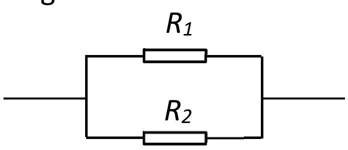
per unit current // **notation** **[4 + 2]**

(*b*) potential difference.

work done // $V = W/q$

per unit charge // **notation** **[4 + 2]**

(*ii*) Derive an expression for the total resistance of resistors R_1 and R_2 as shown in the following diagram.

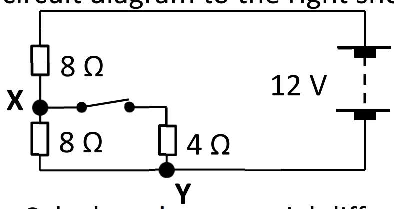


$I_{tot} = I_1 + I_2$ **[3]**

$I = \frac{V}{R}$ **[3]**

$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2}$ **[3]**

The circuit diagram to the right shows three resistors connected to a 12 V power supply.



(*iii*) Calculate the total resistance of the circuit when the switch is closed.

$R_{parallel}$ = **2.67 (Ω)** **[3]**

$R_{circuit}$ = **10.67 Ω** **[3]**

(*iv*) Calculate the potential difference between **X** and **Y** when the switch is closed.

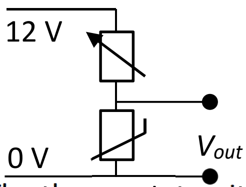
$I = \left(\frac{V}{R} = \frac{12}{10.67} \right) = 1.125$ **(A)** // **2.67/10.67** **[3]**

$V_{XY} = (R \times I = 2.67 \times 1.125) = 3$ **V** // **(0.25 x 12) = 3 V** **[3]**

(*v*) What happens to the potential difference between **X** and **Y** when the switch is opened?

potential difference increases **[4]**

The diagram below shows a potential divider circuit with a thermistor that can be found inside a thermostat.



(*vi*) Explain what is meant by a thermistor.

resistance changes **[3]**

(significantly) with temperature **[3]**

(*vii*) The thermostat switches on an electric heater when the output potential difference V_{out} reaches 8 V. The value of the variable resistor is 5 kΩ.

Calculate the minimum value of the thermistor's resistance that is required to switch on the heater.

$\frac{R_2}{R_1} = \frac{V_2}{V_1}$ **[3]**

$R_2 = 5000\left(\frac{8}{4} \right)$ **[3]**

$R_2 = 10000\ \Omega$ **[3]**

(*viii*) What change must be made to the resistance of the variable resistor so that the thermistor switches on the heater at a higher temperature?

resistance must decrease **[4]**

Note: valid reference to PTC thermistor acceptable for full marks

12.(*a*) In an experiment conducted in 1932, Cockcroft and Walton accelerated protons through a potential difference and used them to bombard lithium nuclei. Two alpha particles were produced by each collision.

They subsequently determined the energy of the alpha particles.

They provided the first major experimental proof of Einstein's prediction that mass and energy are equivalent.

(*i*) State the nuclear equation for the reaction in the experiment.

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

[–2 additional incorrect species]

(*ii*) In addition to mass and energy, state two other properties that are conserved in the reaction.

momentum

charge **[3 + 3]**

(*iii*) A proton is an example of a baryon. Identify a baryon that could not have been used in their experiment. Justify your answer.

neutron **[3]**

no charge **[3]**

(*iv*) Protons were accelerated through a potential difference of 1 MV. Calculate the energy of the incident proton in joules.

$E = qV$ **[3]**

$E = 1.60218 \times 10^{-13}$ **J** **[3]**

(*v*) Given that the mass of the lithium nucleus is 1.16461×10^{-26} kg, calculate the energy released due to the nuclear reaction.

$$^{1}_{1}H + ^{7}_{3}Li \rightarrow 2^{4}_{2}He$$

$m_p = 1.67262 \times 10^{-27}$ **(kg),** $m_\alpha = 6.64466 \times 10^{-27}$ **(kg)** **[3]**

$\Delta m = 2.938 \times 10^{-29}$ **(kg)** **[3]**

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

$E = 2.641 \times 10^{-12}$ **J** **[3]**

(*vi*) Given that the alpha particles produced had a kinetic energy of 2.77×10^{-12} J, show how the given data can be used to verify Einstein's prediction that mass and energy are equivalent.

reference to energy of incident proton / reference to energy released in the reaction

$(1.60218 \times 10^{-13} + 2.64053 \times 10^{-12}) = 2.801 \times 10^{-12}$ **J** **[4 + 2]**

Also in 1932, the American physicist Carl Anderson of Caltech, USA, carried out an experiment to show the existence of the anti-particle of the electron, called the positron, which had been proposed in 1928.

(*vii*) Name the English physicist who proposed the existence of anti-particles in 1928.

Dirac **[2]**

(*viii*) State a difference between an electron and a positron.

electron has a negative charge; positron has a positive charge // opposite charge **[3]**

A PET scanner is used to see how cancer patients respond to treatment. It uses the isotope F–18 which emits a positron as it decays.

(*ix*) Write a nuclear equation for this decay.

$^{18}_{9}\mathrm{F} \rightarrow ^{18}_{8}\mathrm{O} + ^{0}_{+1}\mathrm{e}$ **[7 × 1]**

[–3 additional incorrect species]

(*b*) (*i*) Draw a labelled diagram of an a.c. generator.

magnet **[3]**

coil **[3]**

slip rings and brushes **[3]**

(*ii*) What is the principal energy transformation that takes place in an a.c. generator?

kinetic **[3]**

to electrical **[3]**

(*iii*) Draw a circuit diagram showing how a smooth d.c. output can be obtained from an a.c. source.

four diodes **[3]**

arrangement as bridge rectifier **[3]**

smoothing capacitor **[3]**

(*iv*) State the principle on which the induction motor is based.

electromagnetic induction **[6]**

(*v*) State one advantage of an induction motor over a simple d.c. motor.

no brushes **[3]**

(*vi*) A simple induction motor is connected to a 50 Hz a.c. supply. Calculate the maximum number of revolutions per minute of the motor.

3000 rpm **[6]**

(*vii*) List three principal components of a moving-coil galvanometer.

magnet **[2]**

coil **[2]**

spring **[2]**

(*viii*) A galvanometer has a resistance of 40 Ω. The full-scale deflection of the galvanometer is 2 mA.
Calculate the maximum potential difference that should be applied across its terminals.

$V = RI$ **[3]**

$V = 0.08$ V **[2]**

(*ix*) Draw a circuit diagram to show how a galvanometer can be converted to a voltmeter.

large resistor **[3]**

in series with the galvanometer **[3]**

13. Read the following passage and answer the accompanying questions.

The work of Michael Faraday (1791 – 1867), who is generally regarded as one of the greatest of all experimental scientists, ushered in the electrical age. From his work on electric currents and magnetism he developed the concept of "lines of force" or "field lines". Faraday's major discovery was electromagnetic induction.

After Oersted and Ampere had shown that electric currents produce magnetic fields, it seemed reasonable to assume that magnetic fields should produce electric currents.

The electrification of American cities began in the 1880s, using direct current, following the invention of the filament light bulb by Thomas Edison. However, in 1886, alternating current was used to provide street lighting in Buffalo, New York. Alternating current was more efficient to transmit because its voltage can be easily changed using a transformer, which had been invented by Joseph Henry in 1838.

Adapted from "Physics: Teacher's Reference Handbook", Department of Education and Science

(*i*) Explain what is meant by (*a*) a magnetic field (*b*) a magnetic field line.

(*a*) space in which magnetic force is experienced

(*b*) line showing direction of magnetic field **[4 + 3]**

A magnetic field is described as a vector field.

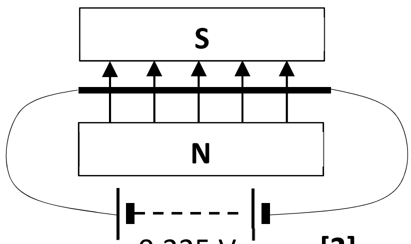
(*ii*) Distinguish between scalar and vector quantities.

scalar has magnitude only

vector has magnitude and direction **[4 + 3]**

(*iii*) The diagram shows a 5 cm long nichrome wire with a diameter of 0.3776 mm and a resistivity value of 1.12×10^{-6} Ω m. It is in a uniform magnetic field of flux density 150 mT.

Calculate



(*a*) the resistance of the wire,

$\boldsymbol{A = 1.119 \times 10^{-7}}$ **(m²)** **[2]**

$\boldsymbol{p = RA/l}$ **[2]**

$\boldsymbol{R = 0.5\ \Omega}$ **[2]**

(*b*) the force acting on the wire.

$\boldsymbol{I = V/R = 0.45}$ **(A)** **[2]**

$\boldsymbol{F = BIl}$ **[2]**

$\boldsymbol{F = 3.375 \times 10^{-3}}$ **N** **[2]**

out of the page **[2]**

A coil consists of 150 turns of wire and is connected to an a.c. supply. The flux threading each turn of the coil increases by 4.5×10^{-4} Wb over a time of 1.1 ms.

(*iv*) Calculate the average EMF induced in the coil.

$\boldsymbol{E = (-)\frac{d\Phi}{dt}}$ **[4]**

$\boldsymbol{E = 61.4}$ **V** **[3]**

(*v*) (*a*) Explain what is meant by self-induction.

changing current in a coil / changing magnetic field produced by a coil **[3]**
induces a (back) emf in the coil itself **[2]**

(*b*) State one practical use of self-induction.

examples : smoothing in power supply units / tuning circuits / stage lighting **[2]**

(*vi*) (*a*) A step-down transformer converts 345 kV to 230 V. State the ratio of the number of turns in the primary coil to the number of turns in the secondary coil.

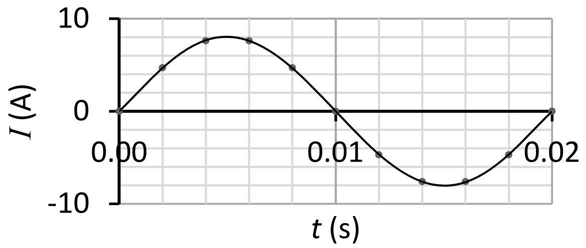
$\frac{N_s}{N_p}$ **[3]**

1500:1 **[2]**

(*b*) Explain why a transformer does not work with direct current.

no changing current / no changing magnetic field **[2]**

(*vii*) The diagram shows a graph of current I against time *t* for an alternating current flowing through an appliance.



Calculate the RMS current flowing in the appliance.

$I_{rms} = \frac{I_0}{\sqrt{2}}$ **[4]**

I_{rms} **= 5.65 A** **[3]**

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

(*a*) (*i*) State Hooke's law.

(restoring) force **// $F = (-)ks$** **[2]**

proportional to displacement **// notation** **[2]**

A mass attached to a spring hangs vertically at rest. It will oscillate with simple harmonic motion if pulled down and released.

(*ii*) Using Hooke's law, show that the mass executes simple harmonic motion.

$F = ma$ **[3]**

$F = (-)ks$ **[3]**

(*k* & *m* are constant means) $a \propto (-)s$ **[3]**

(*iii*) For a mass undergoing simple harmonic motion, explain what is meant by amplitude.

maximum displacement **[6]**

[accept reference to equilibrium position or extreme positions for 3 marks]

A 150 g mass is attached to a spring that is hanging vertically. The mass is displaced vertically so that it oscillates with simple harmonic motion. The spring constant of the spring is 25 N m^{-1}.

(*iv*) Calculate the period of the oscillation.

$a = (-)\omega^2 s$ **or** $\omega^2 = \frac{k}{m}$ **[3]**

$T = \frac{2\pi}{\omega}$ **[3]**

$T = 0.49$ s **[3]**

(*b*) National Broadband Ireland is responsible for bringing high speed fibre to all homes across Ireland. They use optical fibre cables to connect premises to local exchanges.

An optical fibre consists of a core made from glass surrounded by cladding made from a different type of glass. The following table shows the refractive index for three types of glass.

types of glass	core	**Y**	**Z**
refractive index	1.47	1.44	1.50

(*i*) State which glass **Y** or **Z** would be suitable for the cladding. Justify your answer.

Y

(lower refractive index in cladding allows) total internal reflection **[4 + 2]**

(*ii*) Explain what is meant by critical angle.

angle of incidence (in denser medium causing)

angle of refraction of 90° **[4 + 2]**

(*iii*) Explain, with the aid of a labelled diagram, how a signal is transmitted along the optical fibre.

light ray showing reflection in fibre

stated: $i > C$ or total internal reflection **[4 + 2]**

(*iv*) Calculate the critical angle between the core and the cladding.

$n = \frac{\sin i}{\sin r}$ **or** $n = \frac{1}{\sin C}$ **[3]**

$C = 78.4°$ **[3]**

(*v*) Identify the type of glass, from the table, in which light travels fastest.

Y **[4]**

[accept $n = c_1/c_2$ for 3 marks]

(*c*) In 2011, an accident in the Fukushima nuclear power station in Japan released radioactive Iodine, I–131, into the environment. Iodine–131 is a radioactive isotope with a half-life of 8 days, and it emits beta particles and gamma rays.

(*i*) Determine the number of neutrons in an atom of Iodine–131.

number of neutrons = 131 – 53 = 78 **[4]**

(*ii*) Write a nuclear equation to represent the beta decay of Iodine–131.

$^{131}_{53}\mathrm{I} \rightarrow \, ^{131}_{54}\mathrm{Xe} + \, ^{0}_{-1}\beta$ **[7 × 1]**

[–3 additional incorrect species]

(*iii*) Calculate the decay constant of Iodine–131.

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ **[3]**

$\lambda = 1.0028 \times 10^{-6}\ \mathrm{s}^{-1}$ **[3]**

(*iv*) A sample of Iodine–131 contains 2×10^{15} atoms.
Calculate

(*a*) the rate of decay of the sample,

$A = (-)\lambda N$ **[3]**
$A = 2.01 \times 10^{9}\ \mathrm{s}^{-1}$ **[2]**

(*b*) how long it would take for 1.75×10^{15} nuclei to decay.

reference to ⅛ **[3]**

24 days **[3]**

(*d*) (*i*) State Coulomb's law.

force between two charges is proportional to product of the charges // $F \propto \frac{q_1 q_2}{d^2}$ **[3]**

and inversely proportional to the square of distance between them // **notation** **[3]**

(*ii*) Explain what is meant by electric field strength.

force per // $E = \frac{F}{q}$ **[2]**

unit charge // **notation** **[2]**

(*iii*) Describe how an electric field pattern may be demonstrated in the laboratory.

apparatus: oil and semolina/seeds **[2]**

method: high voltage connected to two plates **[2]**

observation: lines of semolina/seeds show electric field pattern **[2]**

An insulated metal sphere has a diameter of 10 cm and is positively charged. The electric field strength at a distance of 1.3 cm from the surface of the sphere is 4×10^4 N C^{-1}.

(*iv*) Draw a diagram to show the electric field pattern around the sphere.

radial lines from surface **[3]**

direction away (from surface) **[3]**

(*v*) Calculate the total charge on the sphere.

$F = \frac{q_1 q_2}{4\pi\varepsilon_0 d^2}$ **or** $E = \frac{F}{q}$ **or** $E = \frac{q}{4\pi\varepsilon_0 d^2}$ **[3]**

q **= 1.77 x 10^{-8} C** **[3]**