Coimisiún na Scrúduithe Stáit

State Examinations Commission

Leaving Certificate 2026

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.

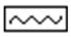
6. For omission of appropriate units (or for incorrect units) in final answers, one mark is deducted, unless otherwise indicated.

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
$\boxed{-1}$	−1	−1
$\boxed{\wedge}$	^	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. In an experiment to verify Boyle's law, a student measured the volume *V* of a fixed mass of gas at different values of the pressure *p*. The temperature was kept constant.
The following data were recorded.

p (kPa)	100	120	140	160	180	220
V (cm^3)	52	43	36	32	29	23

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

trapped gas **[3]**
pressure gauge **[3]**
method of reading volume **[3]**
[–1 if no label present on diagram]

(*b*) Describe the steps that the student could have used to determine the volume *V* and the pressure *p* readings.

open valve / move plunger **[2]**
volume: read graduated tube **[2]**
pressure: read pressure gauge **[2]**

(*ii*) How could the student have ensured that the temperature of the gas was kept constant?

allow time between readings **[3]**

(*iii*) Draw a suitable graph to show the relationship between the pressure and the volume of the gas.

1/*V* (cm^{-3})	**0.019**	**0.023**	**0.027**	**0.031**	**0.034**	**0.043**

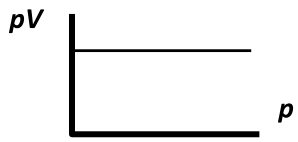
calculations of 1/*V* or 1/*p* **[3]**
axes labelled **[3]**
points plotted **[3]**
line of best fit **[3]**

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

straight line through origin **or** ***p* ∝ 1/*V*** **[5]**

(*v*) Sketch a graph to show the relationship between *pV* and *p* for the gas.

labelled axes



[3 + 2]

2. A simple pendulum consisting of a light inextensible string and a small heavy bob was set up so that it could swing freely about a fixed point. The length l of the pendulum was measured and the pendulum was allowed to oscillate through a small angle. The time t for 25 oscillations was recorded. This procedure was repeated for different values of l.

The following data were recorded.

l (cm)	40.0	50.0	60.0	70.0	80.0	90.0
t (s)	32.0	35.4	38.8	42.5	44.8	47.5

(i) Suggest a reason why the student measured the time for 25 oscillations instead of just one oscillation.

to get an average / to reduce error **[3]**

(*ii*) Describe, with the aid of a labelled diagram, how

(a) the pendulum was set up so that it swung freely about a fixed point,

split cork **[3]**

(b) the student determined the length of the pendulum.

measure distance from fixed point to **[3]**

centre of bob **[3]**

[–1 if no label present on diagram]

(*iii*) Explain why

(a) the student used a small heavy bob,

to reduce air resistance / to keep string taut **[3]**

(*b*) the student used a small angle.

the equation works for small angles **[3]**

(*iv*) (*a*) Draw a suitable graph to show the relationship between the period and the length of the simple pendulum.

T^2 (sec^2)	**1.64**	**2.01**	**2.41**	**2.89**	**3.21**	**3.61**

calculations of T^2 **[3]**

axes labelled **[3]**

points plotted **[3]**

line of best fit **[3]**

(b) State this relationship.

T^2 is proportional to l **[3]**

(*v*) Use your graph to calculate the acceleration due to gravity, g.

slope formula

$$T = 2\pi\sqrt{\frac{l}{g}}$$ **[3 + 2]**

$g \approx 9.88$ m s^{-2} **[2]**

3. In an experiment to measure the wavelength of a narrow beam of monochromatic light, the angle θ between the central bright image (n = 0) and the first and second order images on both the left and right sides were measured. A diffraction grating with 400 lines per mm was used.

The following data were recorded.

	left	left	centre	right	right
n	2	1	0	1	2
θ (degrees)	28.2	13.7	0	13.8	28.3

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

spectrometer / screen **[3]**

light source **[3]**

diffraction grating **[3]**

[–1 if no label present on diagram]

(*b*) Describe the method the student used to obtain the data.

rotate telescope to locate image on RHS of zero // measure the distance *D* from grating to screen **[2]**

rotate telescope to locate image on LHS of zero // measure distance *x* from central image to other images **[2]**

reference to reading on circular scale // reference to use of trigonometry **[2]**

(ii) State one precaution the student should take when carrying out the experiment.

diffraction grating perpendicular to incident light / make sure straight beam at zero / avoid parallax **[3]**

(iii) Use all of the data to calculate an average value for the wavelength of the light.

$n\lambda = d\,\mathrm{Sin}\theta$ **[3]**

$d = 2.5 \times 10^{-6}$ **m** **[3]**

any one calculation of λ **[3]**

average λ = 593 nm **[3]**

(*iv*) Describe the effect that each of the following changes would have on the position of the bright images formed.

(a) A light source with a shorter wavelength is used.

images closer together **[3]**

(b) A diffraction grating with fewer lines per mm is used.

images closer together **[3]**

(*v*) Describe the pattern produced if a narrow beam of white light is used instead of the monochromatic light.

coloured fringes at the orders / white light at the zero order **[4]**

4. In an experiment to measure the specific latent heat of vaporisation of water, a student used a copper calorimeter containing water. Before introducing dry steam to the water in the calorimeter, the water was cooled to a temperature below room temperature.

The following data were recorded.

mass of copper calorimeter (g)	64.6
initial mass of calorimeter + water (g)	144.7
final mass of calorimeter + water + condensed steam (g)	145.8
initial temperature of calorimeter and cooled water (°C)	13
final temperature of calorimeter and water (°C)	21

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

calorimeter with water **[3]**

steam generator **[3]**

point of detail e.g. steam trap / thermometer / lagging **[3]**

[–1 if no label present on diagram]

(ii) Why is it important to use dry steam in this experiment?

only steam added / no water added **[3]**

(iii) How was the steam dried?

steam trap / delivery tube sloped up / insulated delivery tube **[3]**

(iv) Suggest a reason why the water in the calorimeter was initially cooled below room temperature.

heat gained = heat lost / a larger mass of steam could be used **[3]**

(v) Why is the rise in temperature the least accurate value?

read to only one significant figure / temperature in the water may not be uniform **[3]**

(vi) Use the data given to calculate

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

$mc\Delta\theta$ **[3]**

198.97 J **[3]**

(*b*) the mass of steam used,

0.0011 (kg) **[3]**

(*c*) the specific latent heat of vaporisation of water.

m_{water} **= 0.0801 (kg),** $\Delta\theta$ **= 79 (K),** $\Delta\theta$ **= 8 (K)** **[3 × 1]**

use of ml **(&** $mc\Delta\theta$**)** **[3]**

$l = 2.29 \times 10^6$ **J kg^{-1}** **[4]**

specific heat capacity of water = 4180 J kg^{-1} K^{-1}; specific heat capacity of copper = 385 J kg^{-1} K^{-1}

5. In an experiment to investigate how the resistance R of a metallic conductor varies with its temperature θ, a student measured the resistance of a wire at different temperatures.

The following data were recorded.

θ (°C)	10	20	30	40	50	60
R (mΩ)	29.5	30.7	31.9	33.1	34.3	35.5

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

connected conductor in liquid **[3]**

thermometer **[3]**

ohmmeter **[3]**

[–1 if no label present on diagram]

(ii) Draw a suitable graph to show the variation of R with θ.

axes labelled **[3]**

points plotted **[3]**

line of best fit **[3]**

(iii) Use your graph to determine the resistance of the wire when its temperature is 25 °C.

$\approx 31.3 \times 10^{-3}$ (Ω) **[3]**

The wire has a length of 37 cm. The diameter of the wire is 0.5 mm.

(iv) Describe how the student measured the diameter of the wire.

micrometer / digital calipers **[3]**

place wire between jaws and take readings **[3]**

(v) State one experimental precaution that should be taken when determining the length of the wire.

wire taut / no kinks / inside clips / constant temperature / no parallax **[3]**

(vi) Calculate the resistivity of the wire at 25 °C.

$\rho = \frac{RA}{l}$ **[3]**

$A = 1.96 \times 10^{-7}$ (m^2) **[3]**

$\rho = 1.66 \times 10^{-8}$ Ω m **[4]**

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

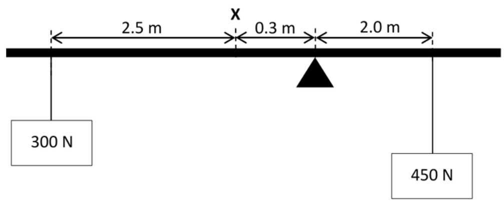
(*a*) Draw a vector diagram to explain what is meant by friction.

two surfaces shown

direction of motion / applied force

frictional force opposing motion / frictional force opposing applied force **[3 + 2 + 2]**

(*b*) The diagram shows weights hanging from a uniform wooden plank at given distances. The plank is balanced on a triangular block as shown. It is in stationary equilibrium. **X** marks the centre of gravity of the plank. Calculate the mass of the plank.



acceleration due to gravity = 9.8 m s^{-2}

$M = Fd$ or $840 + 0.3W = 900$ **[3]**

$W = 200$ (N) **[2]**

$m = 20.4$ kg **[2]**

(*c*) Describe an experiment to demonstrate Archimedes' principle.

apparatus: overflow can, beaker, water, (newton) balance **[3]**

method: measure weight in air, measure weight in water **[2]**

result: (apparent) loss in weight = weight of displaced water **[2]**

(*d*) The motion of a body undergoing simple harmonic motion is described by the equation $a = -\pi^2 s$. Calculate the period of its motion.

$a = (-)\omega^2 s$

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

$T = 2$ s **[2]**

(*e*) Distinguish between heat and temperature.
Your answer should reference a distinguishing characteristic of each.

heat is a form of energy / joule

temperature is a degree of hotness / kelvin **[4 + 3]**

(*f*) 66 000 m^3 of water goes over the Victoria Falls every minute. The water falls through a vertical height of 108 m.
Calculate the power generated by the water.

acceleration due to gravity = 9.8 m s^{-2}; density of water = 1.0×10^3 kg m^{-3}

$m = \rho V$

$E = mgh$ **[3 + 2]**

$P = 1.16 \times 10^9$ W **[2]**

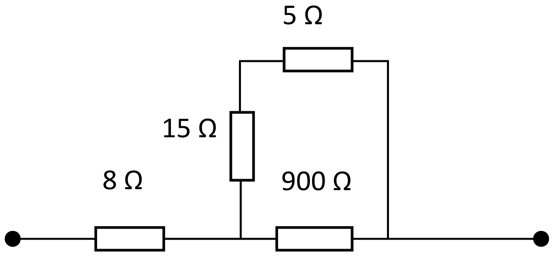
(*g*) Explain why a strong magnet falling through a copper tube falls more slowly than a similar-sized piece of non-magnetised steel falling through the same copper tube.

changing magnetic flux

induces emf/current

opposes the falling magnet ***any two lines* [4 + 3]**

(*h*) Calculate the effective resistance of the arrangement of the resistors shown below.



series formula or parallel formula **[3]**

parallel resistance = 19.6 Ω **[2]**

effective resistance = 27.6 Ω **[2]**

(*i*) State three factors that affect the amount of heat produced in a current-carrying conductor.

resistance, current(squared), time **[3 + 2 + 2]**

(*j*) Carbon–12 (C–12) which is necessary for life on Earth can be formed from alpha particles in a process called the triple-alpha process. The process can be described by this simplified nuclear equation.

$$3\,{}^{4}_{2}\alpha \rightarrow {}^{12}_{6}\mathrm{C}$$

alpha particle mass = 6.644656 × 10^{-27} kg; C–12 nucleus mass = 1.992101 × 10^{-26} kg

Calculate the energy released in this reaction.

mass defect = 1.295 × 10^{-29} (kg) **[3]**

$\boldsymbol{E = mc^2}$ **[2]**

$\boldsymbol{E}$ **= 1.166 × 10^{-12} J** **[2]**

(*k*) The energy of a photon of light is 3.75 × 10^{-19} J. Calculate the wavelength of the light.

$\boldsymbol{E = hf}$

$\boldsymbol{c = f\lambda}$ **[3 + 2]**

$\boldsymbol{\lambda}$ **= 5.3 × 10^{-7} m** **[2]**

(*l*) (*i*) State two reasons why it is difficult to detect a neutrino.

negligible mass

no charge **[4 + 3]**

or

(*ii*) State two factors that affect the efficiency of a transformer.

any two: **resistance of the wires, magnetising the core, currents in the core, etc.**

[4 + 3]

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

(*a*) momentum,

momentum = mass × velocity / $p = mv$ with notation **[4]**

(*b*) force.

force causes acceleration / force causes change in velocity **[4]**

(*ii*) Use Newton's second law of motion to derive the relationship between force, mass and acceleration.

force is proportional to rate of change of momentum **[3]**

force is proportional to mass × acceleration **[3]**

$k = 1$ **[2]**

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

A pile driver is used to sink steel rods, known as piles, into the ground. During the operation of a pile driver, a steel block of mass 500 kg is released from rest and falls through a height onto the top of a stationary steel rod.

(*iii*) The steel block falls for 1.01 s before striking the steel rod. Calculate the distance that the steel block has fallen.

$s = ut + \frac{1}{2} at^2$ **[3]**

$s = 4.998$ m **[3]**

After the steel block strikes the steel rod, the block bounces vertically upwards. The steel block rises by a maximum vertical displacement of 1.8 cm. The steel rod of mass 1500 kg is driven vertically downwards into the ground.

(*iv*) Calculate the upward velocity of the steel block immediately after the collision.

$v^2 = u^2 + 2as$ or $\frac{1}{2} mv^2 = mgh$ **[3]**

$v = 0.59$ m s^{-1} **[3]**

(*v*) Calculate the downward velocity of the steel rod immediately after the collision.

p = mv or any reference to conservation of momentum or $v_{before} = 9.9$ m s^{-1} **[3]**

$(500 \times 9.9) = (500 \times -0.59) + (1500 \times v_{\text{after}})$ **[3]**

$v_{after} = 3.5$ m s^{-1} **[3]**

(*vi*) The steel rod takes 2 ms to come to rest. Calculate the average force exerted by the ground on the steel rod to bring it to rest.

$F = ma$ or $v = u + at$ **[3]**

average force = 2.6×10^6 N **[3]**

The pile driver generates a loud sound as the steel block strikes the steel rod. At a certain distance *d* from the pile driver, an observer can measure both the sound intensity and the sound intensity level due to the sound generated.

(*vii*) The observer moves to a distance 4*d* from the pile driver. Describe the effect on

(*a*) the sound intensity measured,

S.I. is proportional to $1/d^2$ or sound intensity is reduced **[4]**

16 times less **[2]**

(*b*) the sound intensity level measured.

reference to 3 dB or sound intensity level reduced **[2]**

(–) 12 dB **[2]**

8. Philosophers have struggled to explain exactly what light is and why it behaves as it does. The laws of reflection were known to ancient Greeks while the laws of refraction were discovered in 1621. These phenomena can be explained through the principles of geometric optics. Later, Dutch mathematician, Christiaan Huygens, proposed that light was a wave motion.

Let There Be Light by Alex Montwell and Ann Breslin

(*i*) Explain what is meant by reflection of light.

bouncing back of light from a surface **[3]**

(*ii*) An object is placed in front of a concave mirror which has a focal length of 20 cm. An image that is half the size of the object is formed.
Calculate the position of the object.

1/u + 1/v = 1/f

m = v/u **[3 + 3]**

position = 60 cm **[3]**

(*iii*) Suggest a reason why a dentist may choose a concave mirror over a convex mirror when examining teeth.

concave mirror magnifies **[3]**

Lenses work due to the refraction of light.

(*iv*) Draw a ray diagram to show how a virtual image can be formed by a converging lens.

object (inside focus) **[3]**

two correct rays drawn **[3]**

position of virtual image **[3]**

An underwater lamp is placed at a depth of 0.5 m in a pool of water. When the lamp is switched on at night, a circular disc of light becomes visible on the surface of the water.

(*v*) Explain why the region on the surface of the water surrounding the circular disc of light remains dark.

total internal reflection occurs / critical angle has been exceeded **[3]**

(*vi*) The diameter of the circular disc is 1.14 m. Calculate the refractive index of the water.

$\boldsymbol{C = 48.74°}$ **[3]**

$\boldsymbol{n = \frac{1}{\sin C}}$ **[6]**

$\boldsymbol{n = 1.33}$ **[3]**

(*vii*) Using a labelled diagram explain why the underwater lamp does not appear to be at a depth of 0.5 m when viewed by an observer outside the pool.

light refracted as it goes from water to air / refracted ray bends away from normal / refracted ray appears to come from image of lamp / image closer to the surface

***any two* [4 + 4]**

[–1 if no label present on diagram]

Light travels as a transverse wave.

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

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

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

observation: the light intensity decreases **[3]**

9. The music produced by a violin and an organ is due to vibrations in the air caused by oscillations within the instruments themselves. For the violin the bow causes a string to oscillate, while for the organ air is blown into pipes to create vibrations. Both instruments generate stationary waves with resonance playing a key role. Each note has unique characteristics.

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

transfer of energy (between two systems) **[3]**

of the same (natural) frequencies **[3]**

(*ii*) Describe an experiment to demonstrate resonance.

apparatus **[3]**

method **[3]**

result **[3]**

The fundamental frequency of a stretched string depends on the tension in the string as well as two other factors.

(*iii*) (*a*) Name these two factors.

length, mass per unit length **[3 + 3]**

(*b*) State the relationship between the fundamental frequency and each of these two factors.

inverse length, inverse of square root of mass per unit length **[3 + 3]**

(*iv*) A violin string is initially tuned to a fundamental frequency of 250 Hz under a tension of 10 N. Calculate the new tension required to adjust the fundamental frequency to 375 Hz assuming the tension is the only factor being changed.

$\boldsymbol{f \propto \sqrt{T}}$ **[3]**

***T* = 22.5 N** **[3]**

(*v*) State one condition necessary for a stationary wave to form on a stretched string.

whole number of half wavelengths / constructive interference / two waves of the same frequency travelling in opposite directions meet **[4]**

In an organ the pipes can act as if they are open at both ends, or open at one end and closed at the other end.

(*vi*) Draw a labelled diagram to show the standing wave formed in a pipe that is open at one end and closed at the other end when it is vibrating at its third harmonic.

antinode at open end **[3]**

node at closed end **[3]**

correct shape **[3]**

[–1 if no label present on diagram]

(*vii*) A pipe that is open at both ends has a length of 2.3 m and it generates a particular fundamental frequency. A second pipe that is open at one end and closed at the other end generates the same fundamental frequency.
Calculate the length of the second pipe.

$\boldsymbol{c = f\lambda}$ **[3]**

***l* = 1.15 m** **[3]**

(*viii*) Suggest a reason why the same musical note can have a different quality when played on different instruments.

overtones / harmonics **[4]**

10. A parallel-plate capacitor consists of two metal plates separated by an insulating layer called a dielectric. It is designed to store separated electric charge, and so store energy.

(*i*) Explain what is meant by

(*a*) capacitance,

charge **// *C* = *Q*/*V*** **[3]**

per unit voltage **// notation** **[3]**

(*b*) potential difference.

work **// *V* = *W*/*q*** **[3]**

per unit charge **// notation** **[3]**

(*ii*) Describe the movement of electrons when an uncharged parallel-plate capacitor is connected to a battery.

electrons move away from negative terminal / electrons move towards positive terminal

[5]

(*iii*) Describe a demonstration to show that a charged capacitor can store energy.

apparatus **[3]**

method **[3]**

result **[3]**

A student carried out an experiment to verify the relationship between the capacitance *C* of a parallel-plate capacitor and the distance *d* between its plates. The area *A* of the plates was kept constant and a dielectric of permittivity ε was used, where $\varepsilon = 8.85 \times 10^{-12}$ F m^{-1}.

The student's results are shown in the following table.

d (m)	0.021	0.042	0.063	0.084	0.105	0.124
C (F)	9.69×10^{-12}	4.85×10^{-12}	3.23×10^{-12}	2.42×10^{-12}	1.94×10^{-12}	1.64×10^{-12}

(*iv*) Draw a suitable graph on graph paper to show the relationship between the *C* and *d*.

1/*d* (m^{-1})	**47.6**	**23.8**	**15.9**	**11.9**	**9.5**	**8.1**

calculated 1/*d* values **[3]**

labelled axes and points plotted **[3]**

line of best fit **[3]**

(*v*) Calculate the slope of the graph and use it to calculate *A*.

slope formula **[3]**

$C = \frac{\varepsilon A}{d}$ **[3]**

A ≈ 2.3×10^{-2} m^2 **[3]**

The circuit diagram shows a 200 µF capacitor connected in series with a 40 kΩ resistor, a switch, and a 12 V battery. At a certain moment after the switch is closed, the current in the circuit is measured to be 130 µA.

(*vi*) Calculate

(a) the potential difference across the capacitor at that moment,

***V* = *IR* / 5.2 V** **[3]**

***V* = 6.8 V** **[3]**

(b) the energy stored in the capacitor at that moment.

***E* = ½ *CV*^{2}** **[3]**

***E* = 4.6×10^{-3} J** **[3]**

11. (*i*) State two properties of an electron.

mass of 9.1×10^{-31} kg, negative charge / charge of 1.6×10^{-19} C, orbits nucleus, deflected by electric or magnetic fields, fundamental particle ***any two* [4 + 2]**

(*ii*) For a cathode ray tube, describe

(*a*) how the beam of electrons is generated,

(*b*) where the electrons are given a linear acceleration.

(*a*) cathode is heated / thermionic emission

(*b*) between the cathode and the anode **[4 + 2]**

The principle involved in a cathode ray tube was used in devices like older colour televisions. Three beams of electrons were used to produce the primary colours on a screen.

(*iii*) Explain how the primary colours of light can be combined to form

(a) a yellow colour,

red + green **[2 + 2]**

(b) a white colour.

red + green + blue **[2 + 2 + 2]**

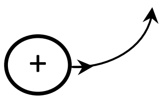
(*iv*) Derive the formula $F = qvB$ for the force F acting on a particle with charge q moving with a velocity v perpendicular to a magnetic field of magnetic flux density B.

$\boldsymbol{F = BIl}$ **[3]**

$\boldsymbol{I = q/t}$ **[3]**

$\boldsymbol{v = l/t}$ **[3]**

A positively charged particle enters a magnetic field with its direction of travel perpendicular to the field. The path of the positively charged particle just after it enters the magnetic field is shown below.



(*v*) Using Fleming's left-hand rule, or otherwise, determine the direction of the magnetic field.

into the page **[3]**

An electron in a cathode ray tube starts from rest and is accelerated to a speed of 2.66×10^{7} m s^{-1}.

(*vi*) Calculate the voltage in the tube.

$\boldsymbol{E_k = \frac{1}{2} mv^2}$

$\boldsymbol{W = qV}$ **[3 + 3]**

$\boldsymbol{V}$ **= 2011 V** **[3]**

An electron travels with a speed of 2.66×10^{7} m s^{-1} and enters a uniform magnetic field with a magnetic flux density of 2 mT perpendicular to its direction of motion.

(*vii*) Calculate the force on the electron due to the magnetic field.

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

8.5×10^{-15} N **[2]**

(*viii*) Calculate the radius of curvature of the circular path followed by the electron.

$\boldsymbol{F_c = \frac{mv^2}{r}}$ **[6]**

$\boldsymbol{r = 7.6 \times 10^{-2}}$ **m** **[3]**

12. Radioactivity was first discovered by Henri Becquerel in 1896 when he observed that a uranium salt darkened a nearby photographic plate, even without exposure to sunlight. He concluded that uranium was emitting an unknown type of radiation. Subsequent research revealed that three distinct types of nuclear radiation can be emitted: alpha, beta, and gamma rays.

(*i*) Explain what is meant by each type of nuclear radiation: alpha, beta, and gamma.

alpha: helium nucleus; beta: (high speed) electron; gamma: photon **[2 + 2 + 2]**

(*ii*) Compare each type of radiation under the following headings:

(*a*) ionising ability,

alpha: strong; beta: moderate; gamma: poor **[2 + 2 + 2]**

(*b*) deflection in a magnetic field.

alpha: yes; beta: yes; gamma: no **[2 + 2 + 2]**

(*iii*) (*a*) Name one type of detector used to detect nuclear radiation.

Geiger-Muller tube // solid state detector **[2]**

(*b*) Describe the principle of operation of the detector.

ionisation // free electrons produced **[2]**

current flows // current flows **[2]**

In a radioactive decay series thorium–232 (Th–232) decays to thorium–228 (Th–228).

(*iv*) Calculate how many

(*a*) alpha particles are emitted,

(*b*) beta particles are emitted.

one alpha particle; two beta particles **[3 + 3]**

An alpha particle emitted by Th–232 has a kinetic energy of 1.47×10^{-12} J and travels a distance through the air. As it moves, it produces ion pairs by colliding with molecules of the air.

(*v*) Given that the energy needed to create one ion pair is 5.6×10^{-18} J, calculate the maximum number of ion pairs that could be produced by the alpha particle due to its kinetic energy.

262 500 ion pairs **[3]**

(*vi*) Explain what is meant by

(*a*) half-life,

time for half a sample to decay **[3]**

(*b*) the becquerel (Bq).

one disintegration per second **[3]**

Polonium was discovered by Marie and Pierre Curie in 1898. A 210 g sample of polonium–210 contains 6.0×10^{23} nuclei. The decay constant of polonium–210 is 5.8134×10^{-8} s^{-1}.

(*vii*) Calculate the activity of a 3.0 mg sample of polonium–210.

number of nuclei in 3 mg = 8.57×10^{18} **[3]**

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

4.98×10^{11} Bq **[3]**

(*viii*) Estimate by calculation how many nuclei of polonium–210 remain in the 3.0 mg sample after 276 days.

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ **[4]**

$T_{1/2} = 1.19 \times 10^{7}$ s / 138 days **[2]**

2.14×10^{18} nuclei **[2]**

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

Let's look at what your home could look like by 2030.

Imagine arriving at your home, greeted by sleek solar panels integrated into your roof, harnessing Ireland's sunlight and storing excess energy in state-of-the-art batteries. Solar panels generate DC and are known as photovoltaic (PV) modules. Solar PV systems are rated in kW and made from a variety of semiconductor materials e.g. silicon. In Ireland, the maximum intensity of solar radiation that reaches these solar panels is 1196 W m^{-2}.

Heat pumps quietly and efficiently regulate the temperature of your home. They extract heat from the air or ground (even in cold temperatures) and use it to warm your living spaces.

Imagine parking your electrical vehicle (EV) in your garage, where it seamlessly connects to your home's energy system. When electricity demand and prices are lower during off-peak, your EV charges automatically. Vehicle-to-grid (V2G) lets you use the car's battery to power your home, which uses AC, or sell electricity back to the grid.

The house of 2030 will feature very low U-values and average values of 0.1 W m^{-2} K^{-1} will guarantee exceptional thermal insulation and energy efficiency. This high level of insulation will reduce heat loss and help maintain a steady indoor temperature.

The lighting in your home will be more efficient and integrated into a smart home system. Ultra efficient LEDs will be the standard.

Adapted from Sustainable Energy Authority of Ireland

(*i*) Silicon is classed as a semiconductor. Explain what is meant by a semiconductor.

resistivity **[4]**

between that of a conductor and an insulator // decreases with temperature **[3]**

(*ii*) A 10 W LED bulb gives out the same light as a 60 W filament bulb.

(*a*) What do the letters in the acronym LED stand for?

light, emitting, diode **[3 × 1]**

(*b*) Calculate how much energy is saved in one hour by using a 10 W LED bulb in place of a 60 W filament bulb.

difference in power usage = 50 (W) **[2]**

180 000 J **[2]**

(*iii*) Sketch voltage-time graphs for

(*a*) the output from a solar panel,

(*b*) the input from the national grid, which is used in our homes.

label axes **[3]**

(*a*) sketch d.c. **[2]**

(*b*) sketch a.c. **[2]**

(*iv*) The lithium-ion battery in an electric car has a capacity of 75 kWh, which is sufficient to power a house during the night.

(*a*) Calculate how long would it take to give an electric car 75 kWh using a 7.2 kW home charger.

75 kWh = 270 MJ or 75/7.2 **[2]**

37500 s = 10.4 hours **[2]**

(*b*) What type of energy conversion takes place when the car powers the home?

chemical to

electrical **[2 + 2]**

(*c*) Calculate the average current drawn if the V2G provides a peak AC voltage of 328 V to power a 2 kW electric kettle.

$\boldsymbol{V_{rms} = \frac{V_{peak}}{\sqrt{2}}}$ **[2]**

***P* = $\boldsymbol{VI}$** **[2]**

$\boldsymbol{I}$ **= 8.62 A** **[2]**

(*v*) A single solar panel covers an area of 0.9 m^2. The efficiency of the solar panel is 25%. Calculate the maximum power generated by the solar panel in Ireland.

power for the panel = 1076.4 W **[4]**

25% = 269.1 W **[3]**

(*vi*) State two desirable properties of a refrigerant fluid used in a heat pump.

low boiling point

high latent heat of vaporisation **[4 + 3]**

(*vii*) The temperature inside the home described is 21 °C and the temperature outside is 10 °C. Calculate the average rate of heat loss per square metre.

$\Delta\theta$ = 11 °C **[3]**

1.1 W **[4]**

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

(*a*) (*i*) Explain what is meant by a vector quantity.

magnitude **[3]**

direction **[3]**

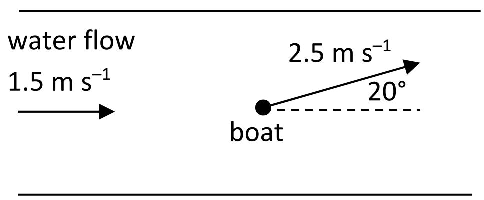
(*ii*) Describe a laboratory experiment to find the resultant of two vectors.

apparatus: three newton balances **[3]**

method: read each force when the system is at rest **[3]**

result: vector sum of two forces = third force **[3]**

A river flows with a velocity of 1.5 m s^{-1} downstream. A boat propels itself with a velocity of 2.5 m s^{-1} at an angle of 20° to the flow of the water, as shown in the diagram.



(*iii*) (*a*) Resolve the velocity of the boat into parallel and perpendicular components relative to the water flow.

parallel component = 2.349 m s^{-1} **[3]**

perpendicular component = 0.855 m s^{-1} **[3]**

(*b*) Calculate the magnitude and the direction of the resultant velocity of the boat.

magnitude of *v* = 3.94 m s^{-1} **[4]**

angle = 12.5° **[3]**

(*b*) (*i*) Explain what is meant by

(*a*) angular velocity,

rate of change **// $\omega = \theta/t$** **[3]**

of angle **// notation** **[3]**

(*b*) frequency.

number of cycles per second / $f = 1/T$ *with notation* **[3]**

When a sound-emitting source moves towards a stationary observer, the frequency of the note appears to change.

(*ii*) State the name of this phenomenon.

Doppler effect **[4]**

A whistle which is emitting a note of frequency 1.1 kHz is swung in a horizontal circle at the end of a string 1.3 m long with a constant angular velocity of 24 rad s^{-1}.

(*iii*) (*a*) Calculate the minimum frequency heard by a person standing some distance away.

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

$v = 31.2$ (m s^{-1}) **[3]**

$f' = \frac{fc}{c \pm u}$ **[3]**

$f_{min} = 1008$ Hz **[3]**

(*b*) State the observed frequency at the centre of the circle.

1100 Hz **[3]**

velocity of sound in air = 340 m s^{-1}

(*c*) (*i*) Describe how charge is distributed on a pear-shaped conductor.

charge is concentrated at the pointed end **[4]**

(*ii*) Describe an experiment that demonstrates how charge is distributed over the surface of a pear-shaped conductor.

apparatus: proof plane, electroscope **[3]**

method: sample at different positions (on pear-shaped object) **[3]**

result: leaves open to varying degrees **[3]**

(*iii*) Explain why it is not possible to charge the dome of a Van de Graaff generator to a very high voltage when a pointed object is attached to it.

point discharge **[6]**

A positive and a negative point charge are placed a distance apart in a vacuum, as shown in the diagram below. The electric field strength at **X** due to the positive charge is 2.3×10^3 N C^{-1}. The electric field strength at **X** due to negative charge is 4.5×10^3 N C^{-1}.

(*iv*) Draw a diagram to show the electric field due to the two charges.

shape **[2]**

direction **[2]**

(*v*) Calculate the electric field strength at **X**.

6.8×10^3 (N C^{-1}) **[3]**

towards the negative charge **[2]**

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

Part (*a*)

The following reaction represents the pair annihilation of a proton p, and an anti-proton $\overline{\text{p}}$

$$\text{p} + \overline{\text{p}} \rightarrow 2\gamma$$

(*i*) Explain what is meant by anti-matter.

(made of particles with) the same mass but opposite charge (to that which make up matter) **[3]**

(*ii*) Explain how the quark model can be used to predict the charge of an anti-proton.

anti-up, anti-up, anti-down **[3]**

(–2/3) + (–2/3) + (+1/3) = –1 **[3]**

(*iii*) Express the minimum frequency *f* of the gamma rays emitted during this pair annihilation, in terms of the mass of a proton *m*, the speed of light *c*, and the Planck constant *h*.

$\boldsymbol{hf}$ **and** $\boldsymbol{mc^2}$ **[3]**

$\boldsymbol{f = mc^2/h}$ **[4]**

Two protons are at a distance of 1.5 fm from each other in a nucleus.

(*iv*) Given that, at this distance, the strong nuclear force between the two protons is 120 times stronger than the force due to their charge, calculate

(a) the strong nuclear force between the two protons,

$\boldsymbol{F = \frac{q_1 q_2}{4\pi\epsilon d^2}}$ **[2]**

103 (N) **[2]**

$\boldsymbol{1.23 \times 10^4}$ **N** **[2]**

(b) how many times stronger this strong nuclear force is than the gravitational force between the two protons.

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

$\boldsymbol{8.3 \times 10^{-35}}$ **(N)** **[2]**

ratio: $\boldsymbol{1.48 \times 10^{38}}$ **[2]**

Part (*b*)

(*i*) Explain what is meant by a bi-polar transistor.

consists of npn / pnp **[2 + 2 + 2]**

(*ii*) State the relationship between the base current, the collector current and the emitter current.

$I_e = I_c + I_b$ **[4]**

(*iii*) (*a*) Draw a circuit diagram to show how a transistor can be used as a voltage amplifier.

transistor **[3]**

base resistor **[3]**

load resistor **[3]**

(*b*) Label the input voltage and the output voltage in your circuit diagram.

input across base resistor **[3]**

output across collector–emitter **[3]**

(*iv*) State one example of a device that uses a voltage amplifier.

microphone **[3]**