Coimisiún na Scrúduithe Stáit

State Examinations Commission

Leaving Certificate 2023

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.

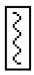
6. For omission of appropriate units (or for incorrect units) in final answers, one mark is deducted, unless otherwise indicated.

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)
	$Tick_n$	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. In an experiment to determine the acceleration due to gravity *g*, the time *t* for an object to fall from rest through a distance *s* was measured. The procedure was repeated for a series of values of *s*.

The following data were recorded.

s (cm)	40	50	60	70	80	90
t (cs)	29	32	35	38	40	43

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

object, release mechanism, pressure plate/trapdoor, means of measuring distance/time

[any three correct items merit 3 × 3]

[–1 if no label present on diagram]

(*ii*) Indicate the distance *s* on your diagram.

(bottom of) the object to the plate **[3]**

(*iii*) Describe how the time interval *t* was measured.

(electronic) timer **[3]**

started when object is released and stops when object hits plate **[3]**

(*iv*) Draw a suitable graph to show the relationship between *s* and *t*.

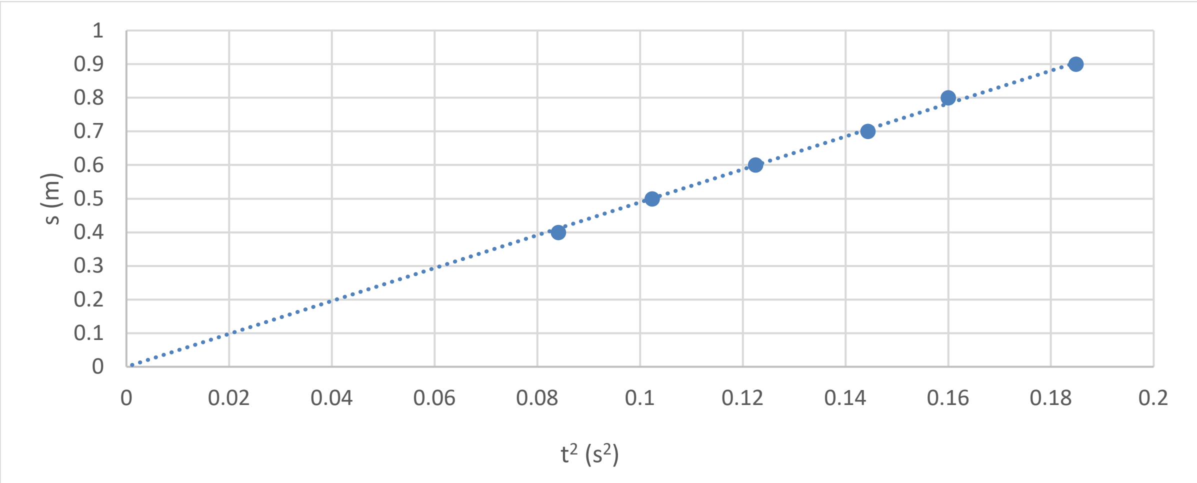
t^2 values **[3]**

s (m)	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
t^2 (s^2)	**0.0841**	**0.1024**	**0.1225**	**0.1444**	**0.16**	**0.1849**

labelled axes **[3]**

6 points plotted **[3]**

straight line with good fit **[3]**



(*v*) Use the graph to calculate a value for *g*.

slope formula / $s = ut + ½ at^2$ **[3]**

$g ≈ 9.8$ m s^{-2} from calculation **[3]**

(*vi*) The object used was a smooth metal sphere. Explain why.

to reduce air resistance **[2]**

high density / magnetic / conductor **[2]**

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

The following data were recorded.

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

(*i*) How did the student find an approximate value for *f*?

focus the image of a distant object on a screen **[6]**

measure the distance from the screen to the mirror **[3]**

(*ii*) Why did the student find an approximate value for *f?*

object must be outside focal point / to get an image on the screen / to check answer **[3]**

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

Show *u* and *v* on your diagram.

object, screen, mirror **[3]**

***u* shown** **[3]**

***v* shown** **[3]**

(*iv*) Describe how the student determined and measured *v*.

move object/screen/mirror **[3]**

until a (sharp) image is formed on the screen **[3]**

measure *v* with a metre stick **[3]**

(*v*) Use all of the data to calculate *f*.

$1/u + 1/v = 1/f$ **[2]**

substitution for *u* and *v* (once) **[2]**

first calculation of *f* **[2]**

two further calculations for *f* **[2 × 1]**

average of values for *f* = 15.4 cm **[2]**

3. In an experiment to determine the wavelength of monochromatic red light, a collimated beam of light was incident perpendicular to a diffraction grating. The diffraction grating had 300 lines per mm. A series of images was observed on a screen placed 75 cm from the grating.

The distance between the third order images on the screen was measured. They were 1.04 m apart.

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

source of light **[3]**

screen/spectrometer **[3]**

diffraction grating **[3]**

arrangement **[3]**

[–1 if no label present on diagram]

(*ii*) How were the third order images identified?

third image on both sides of central image **[3]**

(*iii*) Calculate the grating constant *d*.

$1/300000 \approx 3.33 \times 10^{-6}$ m **[3]**

(*iv*) Calculate the wavelength of the red light.

$n\lambda = d \sin\theta$ **[3]**

1.04/2 = 0.52 (m) **[3]**

$\theta = 34.74°$ **[3]**

$\lambda = 6.33 \times 10^{-7}$ m **[3]**

(*v*) Describe how the pattern observed on the screen changes when:

(*a*) the diffraction grating is replaced with a diffraction grating of fewer lines per mm,

images are closer together **[4]**

(*b*) the red light is replaced with green light,

images are closer together **[4]**

(*c*) the screen is moved further away from the grating.

images are further apart **[2]**

4. In an experiment to determine the specific latent heat of vaporisation of water, cool water was placed in a copper calorimeter. Dry steam at a temperature of 100 °C was then added to the water.

The following data were recorded.

Mass of calorimeter		65.8 g
Mass of calorimeter + water	before adding steam	111.6 g
	after adding steam	114.3 g
Temperature of water	before adding steam	5.5 °C
	after adding steam	36.4 °C

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

steam generator and delivery tube **[3]**

calorimeter with water **[3]**

thermometer **[3]**

arrangement **[3]**

[–1 if no label present on diagram]

How did the student (*ii*) cool the water, (*iii*) dry the steam?

(*ii*) refrigeration / ice bucket / adding ice which was allowed to melt completely / etc. **[3]**

(*iii*) steam trap / delivery tube sloped upwards / insulated delivery tube **[3]**

Why did the student (*iv*) cool the water, (*v*) dry the steam?

(*iv*) to make sure that the energy lost to surroundings cancelled the energy gained from surroundings / to make sure that the steam condensed more quickly **[3]**

(*v*) to make sure that the steam had not lost its latent heat before it was added to the water / to make sure no water is added **[3]**

(*vi*) Use the data to calculate the specific latent heat of vaporisation of water.

$mc\Delta\theta$; ml **[6 + 3]**

$m_w = 45.8$ **(g)**; $m_s = 2.7$ **(g)**; $\Delta\theta_w = 30.9$ **(°C)**; $\Delta\theta_s = 63.6$ **(°C)** **[4 × 1]**

$l = 2.22 \times 10^6$ **J kg**$^{-1}$ **[3]**

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

The following data were recorded.

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

(*i*) Draw a circuit diagram for this experiment with the diode in forward bias.

source of voltage **[3]**

diode in forward bias **[3]**

voltmeter across the diode **[3]**

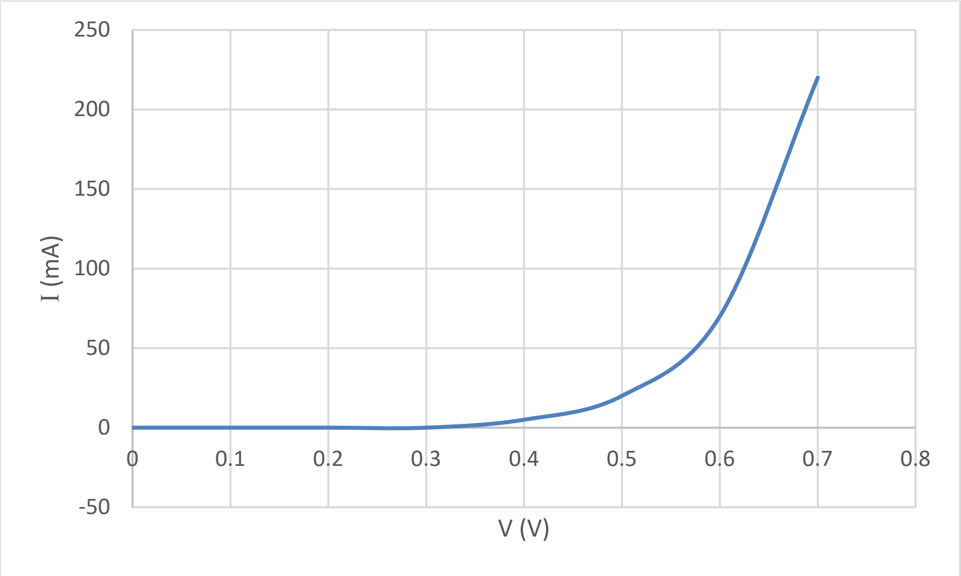
(milli)ammeter in series **[3]**

(*ii*) Draw a suitable graph to show the relationship between I and V for a diode in forward bias.

labelled axes **[3]**

6 points plotted **[3]**

curve with good fit **[3]**



(*iii*) Is Ohm's law obeyed for this diode? Justify your answer.

no **[3]**

not a straight line **[3]**

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

(*iv*) Draw a circuit diagram for this experiment with the diode in reverse bias.

diode in reverse bias **[3]**

voltmeter across the diode and (micro)ammeter **[3]**

(*v*) Sketch a graph to show the relationship between I and V for a diode in reverse bias.

axes labelled **[3]**

correct shape **[4]**

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

(*a*) An airplane starts from rest on a runway and reaches a velocity of 290 km hour^{-1} in 33 s. Calculate the acceleration of the airplane in terms of *g*, the acceleration due to gravity.

v = 80.56 (m s^{-1}) **[2]**

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

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

a = 0.25 g **[1]**

(*b*) Explain the term solar constant.

(solar) energy falling normally on the Earth **[3]**

per second **[2]**

per m^2 **[2]**

(*c*) A converging lens of focal length 15 cm is placed in combination with a diverging lens of focal length 5 cm. Calculate the power of the combination.

$P = 1/f$; $P_T = P_1 + P_2$ **[3 + 2]**

P_T = –13.33 m^{-1} **[2]**

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

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

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

(*e*) Draw a diagram to show how a ray of light can be turned through 90° using a 45°–90°–45° prism.

ray entering normally at one short face **[2]**

ray exiting at the other short face **[2]**

total internal reflection **[3]**

(*f*) State one application of stress polarisation.

e.g. to identify weaknesses in plastics **[7]**

(*g*) What is meant by potential difference?

work done **// formula** **[4]**

per unit charge (moved between two points) **// notation** **[3]**

(*h*) Calculate the power output of a resistor of resistance 3.4 Ω when a potential difference of 55 V is maintained across it.

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

P = 889.7 W **[2]**

(*i*) The peak voltage of an a.c. supply is 311 V. Calculate its rms voltage.

$V_{rms} = V_{peak}/\sqrt{2}$ **[4]**

V_{rms} = 219.9 V **[3]**

(*j*) A proton experiences a force of 4.59 × 10^{-16} N when it moves with velocity *v* perpendicular to a magnetic field of flux density 18.5 mT. Calculate *v*.

$F = qvB$ **[4]**

v = 1.55 × 10^5 m s^{-1} **[3]**

(*k*) Explain what is meant by a chain reaction in nuclear fission.

neutrons **[4]**

from one reaction initiate subsequent reactions / cause a self-sustaining reaction **[3]**

(*l*) The equation to describe an emission line spectrum is $hf = E_2 - E_1$. Explain what each of the symbols in this equation stands for.

h **= Planck constant** **[2]**

f **= frequency** **[2]**

E_2 **= higher energy;** E_1 **= lower energy** **[2 + 1]**

7. (*i*) State Newton's third law of motion.

when object A applies a force on object B **// every action** **[3]**

object B applies an equal but opposite force on object A **// equal but opposite reaction** **[3]**

(*ii*) Show that *F* = *ma* is a special case of Newton's second law of motion.

$F \propto \frac{mv-mu}{t}$ **[3]**

$F = \frac{k(mv - mu)}{t}$ **[3]**

$F = kma$ **[3]**

***k* = 1 from the definition of the newton** **[3]**

A force of 6.8 kN is applied to a golf ball at rest by the head of a golf club. The ball has a mass of 45.6 g and the club and ball are in contact for a time of 0.51 ms.

(*iii*) Calculate the velocity of the ball immediately after impact.

$F = \frac{mv-mu}{t}$ **[3]**

v = 76.05 m s^{-1} **[3]**

The velocity of the ball immediately after impact is at an angle of 15° to the horizontal.

(*iv*) Draw separate diagrams to show the forces acting on the ball

(*a*) during impact,

weight down **[3]**

force applied by club **[3]**

(*b*) immediately after impact.

weight down **[3]**

(*v*) Calculate the maximum height reached by the ball.

u_y = 76.05 sin 15° **[3]**

$v^2 = u^2 + 2as$ **[3]**

s = 19.77 m **[3]**

(*vi*) Calculate the time it takes for the ball to travel a horizontal distance of 280 m.

v_x = 76.05 cos 15° **[2]**

$v = s/t$ **[2]**

t = 3.81 s **[2]**

A wind blows as the ball travels through the air. The wind has a velocity of 8.2 m s^{-1} east and 3.7 m s^{-1} north.

(*vii*) Calculate the magnitude and direction of the velocity of the wind.

$a^2 = b^2 + c^2$ **[2]**

v = 9.0 (m s^{-1}) **[2]**

tan θ = opposite/adjacent **[2]**

θ = 24.3° (N of E) **[2]**

8. The strings of a guitar can be plucked so that they vibrate at certain frequencies. The guitar and the air inside it also vibrate due to resonance**.**

(*i*) What is resonance?

the transfer of energy **[3]**

between two systems with the same (natural) frequency **[3]**

(*ii*) Describe a laboratory experiment to demonstrate resonance.

apparatus **[3]**

method **[3]**

observation **[3]**

The frequency f of a stretched string depends on its length l, tension T and linear density (mass per unit length) μ.

(*iii*) For each of the following pairs of variables, sketch a suitable graph to show the relationship between them.

(*a*) f and T (*b*) f and l (*c*) f and μ

a labelled axis f and $\sqrt{T}$ **[2]**

straight line through the origin **[2]**

b labelled axis f and $1/l$ **[2]**

straight line through the origin **[2]**

c labelled axis f and $1/\sqrt{\mu}$ **[2]**

straight line through the origin **[2]**

(*iv*) For each of the following variables, state the effect on the frequency f if the variable is increased by a factor of four.

(*a*) T (*b*) l (*c*) μ

a **increases** **[2]**

by a factor of 2 **[2]**

b **decreases** **[2]**

by a factor of 4 **[2]**

c **decreases** **[2]**

by a factor of 2 **[2]**

A string is stretched between two fixed points which are 62 cm apart. The string vibrates with a number of different harmonics. The speed of sound in the string is 380 m s^{-1}.

(*v*) What are harmonics?

frequencies **[3]**

which are multiples of the fundamental **[2]**

(*vi*) Draw a diagram to show the string vibrating at its third harmonic.

node at both ends **[3]**

two additional nodes in correct arrangement **[3]**

(*vii*) Calculate the frequency of the string when it is vibrating at its third harmonic.

λ = 0.62/1.5 = 0.4133 (m) **[2]**

$c = f\lambda$ **[2]**

f = 919.4 Hz **[2]**

9. Voyager I and Voyager II are spacecraft that were launched in 1977 to investigate the outer planets of our solar system.

The spacecraft are powered with radioisotope thermoelectric generators. When the spacecraft were launched, each generator contained 4 kg of plutonium–238. Each atom of plutonium–238 has a mass of $3.9529085 \times 10^{-25}$ kg.

(*i*) Write a nuclear equation for the alpha decay of plutonium–238.

$^{238}_{94}Pu \rightarrow ^{234}_{92}\mathrm{U} + ^{4}_{2}\mathrm{He}$ **[8 × 1]**

[–3 for each additional incorrect species]

(*ii*) Calculate the energy released during each decay of plutonium–238, in MeV.

conversion from *u* to kg **[3]**

mass defect (= 9.95757×10^{-30} kg) **[3]**

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

$E = 8.95 \times 10^{-13}$ **(J)** **[3]**

$E = 5.6$ **(MeV)** **[3]**

The energy released by the decay is converted into electrical energy in thermocouples.

(*iii*) State the thermometric property of a thermocouple.

emf / voltage **[3]**

(*iv*) Draw a labelled diagram of the arrangement of a thermocouple.

two different metals **[3]**

first junction at one temperature **[3]**

second junction at a different temperature **[3]**

[–1 if no label present on diagram]

Plutonium–238 has a half-life of 87.8 years.

(*v*) Calculate the rate of decay of the plutonium in each generator in 1977.

$\lambda = \ln 2/T_{½}$ **[3]**

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

$T_{½} = 87.8 \times 365.25 \times 24 \times 60 \times 60 = 2.77 \times 10^9$ **(s)** **[3]**

$N = 4/3.9529085 \times 10^{-25} = 1.012 \times 10^{25}$ **(atoms)** **[3]**

$A = 2.53 \times 10^{15}$ **Bq** **[2]**

(*vi*) Calculate the year when only 1 kg of the plutonium will remain in each generator.

reference to two half-lives **[2]**

1977 + 2 × 87.8 = 2152 **[2]**

The Voyager spacecraft are now beyond our solar system and they are maintaining constant velocities.

(*vii*) Use one of Newton's laws to explain why the spacecraft maintain constant velocities.

no force acting on it **[3]**

10. The Van de Graaff generator is named after the American physicist Robert J. Van de Graaff, pictured. It is an electrostatic generator that accumulates charge on a hollow metal dome and produces high voltages which can be used in the production of X-rays.

In a Van de Graaff generator, point discharge is used to move charge on to a belt at the lower comb in the generator.

(*i*) Describe how point discharge occurs.

accumulation of charge at a point **[3]**

large electric field generated / ionisation of the air **[3]**

unlike charges attract and like charges repel **[3]**

(*ii*) Describe a laboratory experiment to demonstrate point discharge.

apparatus **[3]**

method **[3]**

observation **[3]**

The dome of a Van de Graaff generator has a diameter of 32 cm. A large electric field exists around the dome when it is given a charge of +200 nC.

(*iii*) Draw the electric field around the dome.

radial field lines **[3]**

away from the dome **[3]**

(*iv*) Calculate the electric field strength at the surface of the dome.

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

$\boldsymbol{r}$ **= 16 (cm)** **[3]**

$\boldsymbol{E = 7.0 \times 10^4\ \mathrm{N\ C^{-1}}}$ **[3]**

(*v*) Calculate the force experienced by an electron placed at the surface of the dome.

$\boldsymbol{E = F/q}$ **[3]**

$\boldsymbol{F = 1.12 \times 10^{-14}}$ **N towards the centre of the dome** **[3]**

A voltage of 70 kV is applied across an X-ray tube.

(*vi*) Calculate the maximum speed of the electrons produced in the tube.

$\boldsymbol{qV\ /\ \frac{1}{2}mv^2}$ **[3]**

$\boldsymbol{qV = \frac{1}{2}mv^2}$ **[3]**

$\boldsymbol{v = 1.57 \times 10^8\ \mathrm{m\ s^{-1}}}$ **[3]**

(*vii*) Draw a labelled diagram of an X-ray tube.

low voltage filament / heating coil **[2]**

cathode & anode/target **[2]**

(high) voltage (between cathode & anode) **[2]**

cooling / shielding / window / (partial) vacuum **[2]**

11. Metal detectors are used in treasure hunting and in airport security. They operate on the principle of electromagnetic induction. The coil in the detector is supplied with an alternating current.

(*i*) Give a detailed explanation of how a current is induced in the metal that is being detected.

changing magnetic field **[3]**

cutting the metal **[3]**

emf induced **[3]**

current flows **[3]**

The magnitude and direction of an induced emf are determined by Faraday's law of electromagnetic induction and Lenz's law of electromagnetic induction.

(*ii*) State Faraday's law of electromagnetic induction.

(size of) emf induced is proportional to **// formula** **[3]**

the rate of change of magnetic flux **// notation** **[3]**

(*iii*) State Lenz's law of electromagnetic induction.

direction of an induced current/emf **[3]**

is such as to oppose the change causing it **[3]**

(*iv*) Describe a laboratory experiment to demonstrate either one of these laws.

apparatus **[3]**

method **[3]**

observation **[3]**

A circular coil of 500 turns and radius 6.0 cm enters a magnetic field moving with a constant velocity of 8 m s^{-1} perpendicular to the field.

The resistance of the coil is 2.3 Ω and the magnetic flux density of the field is 4.5 mT.

(*v*) Calculate the time taken for the coil to fully enter the field.

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

$\boldsymbol{t}$ **= 0.015 s** **[3]**

(*vi*) Calculate the average emf induced as the coil enters the field.

$\boldsymbol{A = \pi r^2}$ **[3]**

$\boldsymbol{\text{Ø} = BA}$ **[3]**

$\boldsymbol{E = (-)\Delta\text{Ø}/\Delta t}$ **[3]**

$\boldsymbol{E}$ **= 1.70 V** **[3]**

(*vii*) Calculate the average current in the coil as it enters the field.

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

$\boldsymbol{I}$ **= 0.74 A** **[2]**

12.

(*a*) Anti-matter is the most expensive substance on Earth, costing about €65 trillion per gram.

(*i*) What is anti-matter?

same mass **[3]**

opposite charge **[3]**

(*ii*) Who made a mathematical prediction of the existence of anti-matter?

Dirac **[3]**

A positron is an example of anti-matter.

(*iii*) Write an equation to show the pair production of an electron-positron pair.

***hf* = / γ =** **[3]**

$2m_ec^2$ / ${}^{0}_{-1}e + {}^{0}_{1}e$ **[3]**

(*iv*) Explain how (*a*) charge, (*b*) momentum are conserved in this interaction.

a **charge before = charge after = 0** **[3]**

b **momentum before = momentum after ≈ 0 / particles move in opposing directions** **[3]**

(*v*) List the fundamental forces, in order of increasing strength, that a positron experiences.

gravitational, weak, electromagnetic **[3 × 1]**

correct order **[3]**

(*vi*) Name the fundamental force that a positron does **not** experience.

strong (nuclear) **[3]**

In the Large Hadron Collider researchers are investigating the pair annihilation of a proton anti-proton pair.

(*vii*) Calculate the wavelength of the electromagnetic radiation produced when a proton and an anti-proton annihilate.

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

$E = hf$ **[3]**

$c = f\lambda$ **[3]**

$\lambda = 1.32 \times 10^{-15}$ m **[3]**

(*viii*) Hadrons can be classified as baryons or mesons. Distinguish between baryons and mesons.

a baryon contains three quarks **[2]**

a meson contains a quark and an anti-quark **[2]**

(*ix*) State the quark composition of (*a*) a proton, (*b*) an anti-proton.

a **up, up, down** **[3]**

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

(*x*) The Large Hadron Collider is an example of a modern particle accelerator. Explain how it differs from the particle accelerator used by Cockroft and Walton.

e.g. circular **[4]**

(*b*) (*i*) Draw labelled diagrams to show the basic structure of (*a*) the semiconductor diode, (*b*) the transistor.

a **p-type connected to n-type** **[6]**

b **n-type – p-type – n-type** **[6]**

Light emitting diodes and bridge rectifiers are examples of diodes in use.

(*ii*) Describe the principle of operation of a light emitting diode.

diode in forward bias **[3]**

an electron recombines with a hole **[3]**

releasing a photon **[3]**

(*iii*) State one use of a light emitting diode.

any valid use **[3]**

(*iv*) Draw a circuit diagram, including a bridge rectifier and a capacitor, that can be used to convert a.c. to d.c..

four diodes in correct arrangement **[3]**

output resistor **[3]**

capacitor in parallel with output resistor **[3]**

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

transistor and resistor in series **[3]**

input voltage indicated **[3]**

output voltage indicated **[3]**

(*vi*) A voltage inverter is a NOT gate. Draw its truth table.

input 0, output 1 **[3]**

input 1, output 0 **[3]**

Electromagnetic relays are sometimes used with transistors.

(*vii*) Draw a labelled diagram of an electromagnetic relay.

coil and core **[2]**

armature **[2]**

make-break mechanism **[2]**

[–1 if no label present on diagram]

(*viii*) What is the function of an electromagnetic relay?

switch **[2]**

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

The electric power grid operates based on a delicate balance between supply and demand.
One way to help balance fluctuations in electricity supply and demand is to store electricity during periods of high production and low demand, then release it back to the electric power grid during periods of low production and high demand.

Energy can be stored in a variety of ways, including:

- Pumped storage: e.g. Turlough Hill, a pumped storage power station in Wicklow. It makes use of two water reservoirs, an artificial upper reservoir near the top of a mountain and the naturally occurring corrie lake, Lough Nahanagan, a lower reservoir which is 321 m below. The upper reservoir has a volume of 2.3×10^6 m^3. The two reservoirs are connected by a pipe of length 584 m. A motor pumps water from the lower reservoir to the upper reservoir, using surplus power available at times of low demand. Water is then allowed to fall by gravity from the upper reservoir back into the lower reservoir, passing through turbines attached to electric generators along the way.
- Flywheels: electricity is used to accelerate a large heavy flywheel which stores rotational kinetic energy.
- Batteries: similar to common rechargeable batteries, very large batteries can store electricity.

(*i*) Assume that the upper reservoir in Turlough Hill is full.

Calculate

(*a*) the mass (in kg) of water in this reservoir,

$\rho = m/V$ **[3]**

$m = 2.29 \times 10^9$ (kg) **[3]**

(*b*) the potential energy (in J) stored in this reservoir,

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

$E = 7.21 \times 10^{12}$ (J) **[2]**

(*c*) the maximum power (in W) that could be generated if the reservoir was fully emptied in 24 hours.

$P = E/t$ **[2]**

$P = 8.35 \times 10^7$ (W) **[2]**

(*ii*) State the main energy conversion that takes place (*a*) as the water flows down through the pipe at position **A** and (*b*) as the water flows through the generator at position **B**.

a **gravitational/potential to kinetic**

b **kinetic to electrical** **[4 + 3]**

(*iii*) A motor operates on the principle that a current carrying conductor in a magnetic field experiences a force. Describe a laboratory experiment to demonstrate this principle.

apparatus **[3]**

method **[2]**

observation **[2]**

(*iv*) A flywheel of diameter 1.4 m rotates with 5000 revolutions per minute.

Calculate

(*a*) the period (in s) of the flywheel's motion,

$T = 1/f$ **[3]**

$T = 0.012$ (s) **[3]**

(*b*) the angular velocity of the flywheel,

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

$\omega = 523.6$ (radians) s^{-1} **[2]**

(*c*) the centripetal acceleration at the circumference of the flywheel.

$a = r\omega^2$ **[2]**

$a = 1.9 \times 10^5$ m s^{-2} (towards the centre) **[2]**

(*v*) A battery is a source of emf. Name two other sources of emf.

e.g. mains, solar cell, thermocouple, etc. **[4 + 3]**

(*vi*) As we move away from generating electricity using non-renewable sources (e.g. fossil fuels) towards generating electricity using renewable sources (e.g. wind, solar) it is more essential than ever to have energy storage systems such as the ones described in the text. Explain why.

renewable sources are more likely to vary in the rate at which they produce electricity **[7]**

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

(*a*) In 1660 Robert Hooke investigated the elasticity of materials, including springs. His work led to Hooke's law.

(*i*) State Hooke's law.

(restoring) force	**// equation**	**[3]**
proportional to displacement	**// notation**	**[3]**

A spring has a natural length of 15.0 cm. When a block of mass 500 g is hung from the spring, its length increases to 17.5 cm. The block is then pulled down further, released and begins to oscillate.

(*ii*) Calculate the elastic constant of the spring.

$mg = ks$ **[3]**

k = 196 N m^{-1} **[3]**

(*iii*) Calculate the period of oscillation of the block.

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

$\omega = \sqrt{(k/m)}$ **[3]**

T = 0.32 s **[3]**

In 1665 Hooke, working as an assistant to Robert Boyle, built the vacuum pump that was used in the experiment that led to Boyle's law.

(*iv*) Sketch a graph that explains Boyle's law. Label the axes on your graph.

axes labelled as *p* and 1/*V* **[3 + 2]**

straight line through the origin **[2]**

(*b*) A speaker emits a sound of fixed frequency. The speaker is moving at a constant velocity towards an observer. The observer hears a frequency which is 20% greater than the frequency emitted.

(*i*) Name the effect which causes this increase in frequency.

Doppler **[3]**

(*ii*) Calculate the speed of the speaker.

$f' = cf/(c \pm u)$ **[3]**

substitution **[3]**

u **= 56.7 m s^{-1}** **[3]**

(*iii*) Red shift in astronomy is also due to this effect. What does red shift tell us about our universe?

it is expanding **[4]**

A fixed speaker of power *P* is emitting sound. At a certain distance from the speaker, an observer can measure both the sound intensity and the sound intensity level due to the speaker.

(*iv*) Distinguish between sound intensity and sound intensity level.

sound intensity is measured in W m^{-2} **[3]**

sound intensity level is measured in dB **[3]**

(*v*) The speaker of power *P* is replaced by a speaker of power 4*P*. Calculate the increase in sound intensity level measured.

reference to 3 dB / doubling / $I \propto P$ **[3]**

6 dB **[3]**

(*c*) A metal wire has length *l*, resistance *R* and cross-sectional area *A*.

(*i*) State the relationship between *R* and *A* for the wire.

inversely proportional **[4]**

(*ii*) Using an appropriate diagram, derive an expression for the effective resistance R_T of two resistors R_1 and R_2 in series.

circuit diagram showing resistors in series **[3]**

$V_T = V_1 + V_2$ **[3]**

$IR_T = IR_1 + IR_2$ **[3]**

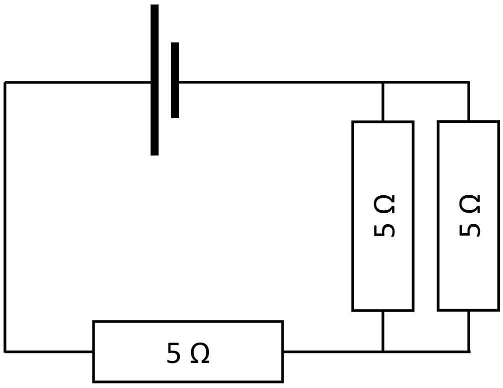
$R_T = R_1 + R_2$ **[3]**

(*iii*) Calculate the total resistance of the circuit shown below.

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

$R_p = 2.5\ (\Omega)$ **[3]**

$R_T = 7.5\ \Omega$ **[3]**



(*iv*) Describe how a fourth 5 Ω resistor could be added to the circuit so as to reduce the total effective resistance of the circuit.

in parallel **[3]**

(*d*) (*i*) Distinguish between thermionic emission and the photoelectric effect.

thermionic emission is caused by heat **[3]**

the photoelectric effect is caused by light **[3]**

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

apparatus **[3]**

method **[3]**

observation **[3]**

Electrons of maximum velocity 0.023c are emitted when electromagnetic radiation is incident on a zinc metal plate. Zinc has a work function of 4.3 eV.

(*iii*) Calculate the frequency of the incident radiation.

$hf = \text{Ø} + E_k$ **[3]**

$E_k = \frac{1}{2}mv^2$ **[3]**

$\text{Ø} = 4.3 \times 1.6 \times 10^{-19} = 6.88 \times 10^{-19}$ **(J)** **[2]**

$v = 6.9 \times 10^{6}$ **(m s^{-1})** **[2]**

$f = 3.37 \times 10^{16}$ **Hz** **[3]**