Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2024

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 carried out a laboratory experiment to investigate the relationship between the acceleration *a* of a body and the force *F* applied to it. During the experiment the student recorded values for the force and measured the associated acceleration.

The following data were recorded.

F (N)	0.2	0.3	0.4	0.5	0.6	0.7
a (m s^{-2})	0.280	0.422	0.554	0.702	0.837	0.982

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

trolley **[4]**

applied force **[3]**

ticker timer/light gates **[3]**

[–1 if no label present on diagram]

(*ii*) Describe how the student determined the acceleration of the body.

calculate initial velocity and final velocity **[3]**

measure distance/time interval between velocities **[3]**

use relevant formula **[3]**

(*iii*) Draw a suitable graph to show the relationship between *F* and *a.*

labelled axes **[3]**

points plotted **[3]**

line of best fit **[3]**

(*iv*) Explain how your graph verifies the relationship between *F* and *a*.

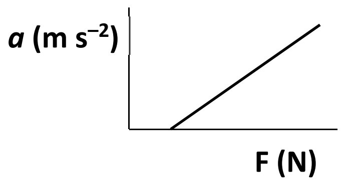
straight line through the origin shows *F* is proportional to *a* **[3]**

(*v*) Use your graph to calculate the mass that had been accelerated.

slope formula **[3]**

***m* = 0.71 kg** **[2]**

(*vi*) Sketch the graph that a student would get if they did not account for the presence of a constant frictional force of less than 0.2 N.



[4]

2. In an experiment to measure the focal length *f* of a converging lens, a student first found an approximate value for the focal length. Then the student set up the apparatus and recorded the image distance *v* for different values of the object distance *u*.

The following data were recorded.

u (cm)	20.0	30.0	40.0	50.0
v (cm)	78.7	35.2	26.9	23.4

(*i*) Describe how the student found an approximate value for the focal length.

focus the image of a distant object on a screen **[3]**

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

(*ii*) Draw a labelled diagram of the apparatus and clearly identify the distances *u* and *v*.

lens **[2]**

object **[2]**

screen **[2]**

***u* and *v* shown** **[3]**

(*iii*) Describe, with reference to your diagram, how the values for *v* were determined and measured.

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

until a sharp image is formed **[3]**

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

(*iv*) Calculate the focal length of the lens using all of the data in the table.

$1/u + 1/v = 1/f$ **// values for $1/u$ and $1/v$** **[3]**

1st calculation of *f* **// labelled axes** **[3]**

three further calculations for *f* **// points and line of best fit** **[3]**

average for *f* **// value for *f*** **[3]**

(*v*) The student also completed an experiment to measure the focal length of a concave mirror. Why does the arrangement of the apparatus differ in this experiment?

reflection of light **[4]**

3. A student carried out an experiment to measure the specific latent heat of fusion of ice.

The following data were recorded.

Mass of copper calorimeter		83.2 g
Mass of calorimeter + water	before adding ice	132.9 g
	after adding ice	138.5 g
Temperature of water	before adding ice	26.8 °C
	after adding ice	17.4 °C

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

ice **[2]**

calorimeter with water **[2]**

balance **[2]**

thermometer **[2]**

[–1 if no label present on diagram]

(*ii*) (*a*) State two steps the student took to prepare the ice taken from the freezer.

crush the ice **[3]**

dry the ice **[3]**

(*b*) Describe the importance of each step.

crush the ice: ensure the ice was at 0 °C / it would melt faster **[3]**

dry the ice: no additional water added / only ice added **[3]**

(*iii*) Use the data in the table to calculate the energy lost by the calorimeter after the ice was added.

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

$\Delta\theta_{cal}$ **= 9.4 (°C)** **[1]**

305 J **[2]**

(*iv*) Hence, or otherwise, calculate the specific latent heat of fusion of ice.

m_{water} **= 49.7 (g);** m_{ice} **= 5.6 (g);** $\Delta\theta_{ice}$ **= 17.4 (°C)** **[1 + 1 + 1]**

ml **[3]**

$(ml)_{ice} + (mc\Delta\theta)_{melted\ ice} = (mc\Delta\theta)_{cal} + (mc\Delta\theta)_{water}$ **[2]**

$l = 3.3 \times 10^5$ **J kg^{-1}** **[2]**

(*v*) State two properties of a thermometer that would help improve the accuracy of the experiment.

low heat capacity, reacts quickly, measures to at least 2 decimal places **[2 + 2]**

specific heat capacity of water = 4180 J kg^{-1} K^{-1}; specific heat capacity of copper = 390 J kg^{-1} K^{-1}

4. A student investigated how the fundamental frequency f of a stretched string of length 70 cm varied with its tension T. During the experiment, the length of the string was kept constant, and the student varied the tension.

The following data were recorded.

f (Hz)	256	320	341	426.5	480	512
T (N)	29	44	51	79	100	115

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

stretched string **[2]**

newtonmeter / weights **[2]**

tuning fork / signal generator **[2]**

meter stick / bridges / paper rider **any two [2 + 2]**

[–1 if no label present on diagram]

(*ii*) How did the student determine that resonance had occurred?

paper rider fell off / maximum displacement of the string observed **[3]**

(*iii*) Describe how the student determined

(*a*) the frequency f,

read from tuning fork/signal generator **[2]**

(*b*) the tension T.

read from newtonmeter/weights **[2]**

(*iv*) Draw a suitable graph to show the relationship between f and T.

values for $\sqrt{T}$ or f^2 **[3]**

f^2	65536	102400	116281	181902	230400	262144
$\sqrt{T}$	5.39	6.63	7.14	8.89	10.00	10.72

labelled axes **[3]**

correct points plotted **[3]**

line of best fit **[3]**

(*v*) State the relationship between f and T.

frequency is proportional to square root of tension **[3]**

(*vi*) Use your graph to determine the mass per unit length of the string used in this experiment.

slope formula, $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ **[3 + 2]**

$\mu = 2.2 \times 10^{-4}$ **kg m^{-1}** **[3]**

5. In an experiment to investigate the relationship between current I and potential difference V for a length of copper wire the following data were recorded.

V (V)	1.0	2.0	3.0	4.0	5.0	6.0
I (A)	0.14	0.26	0.43	0.58	0.70	0.84

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

power supply, copper wire, ammeter, voltmeter **[any 3 × 1]**

power supply, copper wire and ammeter in series **[3]**

voltmeter in parallel with copper wire **[3]**

means of varying voltage **[3]**

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

labelled axes **[3]**

correct points plotted **[3]**

line of best fit **[3]**

(*iii*) Use your graph to calculate the resistance R of the copper wire.

slope formula **[3]**

R = 7.03 Ω **[2]**

The student used their results to calculate the resistivity of the copper wire. The following additional data were recorded:

length of wire = 65 cm
diameter of wire = 0.32 mm

(*iv*) Describe how the student determined both the length and the diameter of the copper wire.

length: meter stick

diameter: micrometer/digital callipers **[3 + 3]**

(*v*) Calculate the resistivity of the copper wire.

$\boldsymbol{\rho = \frac{RA}{l}, A = \pi r^2}$ **[3 + 2]**

$\boldsymbol{\rho = 8.7 \times 10^{-7}\ \Omega\ m}$ **[3]**

6. (*a*) A meter stick is suspended from its centre of gravity as shown in the diagram. The meter stick is in equilibrium.
Calculate the mass of the apple.

$M = Fd$ **[3]**

$W = mg$ **[2]**

m = 0.11 kg **[2]**

(*b*) Explain what is meant by a geostationary orbit and state a use of a satellite in geostationary orbit.

remains in the same position above earth / has a period of 24 hours **[4]**

any use **[3]**

(*c*) A simple pendulum has a period of 1.24 s. Calculate the length of the pendulum.

$T = 2\pi\sqrt{\frac{l}{g}}$ **[4]**

l = 0.38 m **[3]**

(*d*) Conduction and convection are methods of heat transfer. Distinguish between conduction and convection.

conduction is transfer of heat (by vibration) from particle to particle

convection is transfer of heat by means of circulating currents **[4 + 3]**

(*e*) Describe an experiment to demonstrate that sound is a wave.

two coherent sound sources **[3]**

movement relative to the sources **[2]**

interference observed **[2]**

(*f*) Explain what is meant by a stationary wave.

(superposition of) two waves of the same frequency and amplitude

maximum amplitude at each point is constant / no net transfer of energy **[4 + 3]**

(*g*) Define critical angle.

angle of incidence

angle of refraction of 90° **[4 + 3]**

(*h*) A lightning conductor can be placed on top of a tall building as shown. Explain how a lightning conductor works.

point discharge

transfers charge to ground **[4 + 3]**

(*i*) A current of 6 A passes a point in a circuit. Calculate the number of electrons that pass that point every minute.

$q = It$ **[3]**
q = 360 (C) **[2]**
2.25×10^{21} (electrons) **[2]**

(*j*) Calculate the electrostatic force between two protons that are 5.6×10^{-15} m apart in a vacuum.

$F = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{d^2}$ **[4]**

7.36 N **[3]**

(*k*) Einstein's photoelectric law is explained by the equation $hf = \phi + \frac{1}{2}mv^2$. Explain what each of the symbols in the equation stands for.

h = Planck constant

f = frequency

ϕ = work function

m = mass

v = velocity **[2 + 2 + 1 + 1 + 1]**

(*l*) Cockcroft and Walton won a Nobel Prize for their experiment that bombarded a lithium nucleus with a proton. State two reasons why their experiment was significant.

first artificial splitting of nucleus, first transmutation using artificially accelerated particles, verification of $E = mc^2$, major step in the development of particle accelerators **[4 + 3]**

or

Draw a diagram to show how a galvanometer can be converted into a voltmeter.

galvanometer in series with

(large valued) resistor/multiplier **[4 + 3]**

7. The hammer throw is an athletics event where athletes rotate a metal ball, attached to a wire, in a circle before releasing it**.**

(*i*) Derive the formula to show the relationship between the radius, velocity and angular velocity of an object moving with uniform circular motion.

$\theta = s/r$ *or* $v = s/t$ *or* $\omega = \theta/t$ **[3]**

combination of two formulae **[3]**

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

(*ii*) Explain what is meant by centripetal force.

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

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

(*iii*) Draw a force diagram to show the forces acting on the ball just before it is released.

weight down **[3]**

tension towards centre **[3]**

[–3 for additional/incorrect forces]

An athlete rotates a ball of mass 4 kg in a circle of radius 1.25 m. The ball is moving with an angular velocity of 21.6 rad s^{-1} just before it is released.

(*iv*) Calculate the centripetal force acting on the ball just before it is released.

$F = mr\omega^2$ **[3]**

F = 2332.8 N **[3]**

(*v*) Calculate the magnitude of the velocity of the ball just as it is released.

($v = r\omega$ =) 27 m s^{-1} **[3]**

The velocity of the ball as it is released is at an angle of 36° above the horizontal. The ball is released at a height of 1.26 m above the ground and lands 3.79 s later.

(*vi*) With the aid of a labelled diagram, resolve the velocity of the ball into its horizontal and vertical components.

diagram showing horizontal and vertical components **[3]**

u_x = 27 cos 36° **[3]**

u_y = 27 sin 36° **[3]**

(*vii*) Ignoring air resistance,

(a) calculate the maximum height above the ground reached by the ball,

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

s_y = 12.85 (m) **[2]**

(above ground = 12.85 + 1.26 =) 14.11 m **[2]**

(b) calculate the horizontal distance travelled by the ball in 3.79 s.

$s = ut$ **[3]**

s_x = 82.79 m **[2]**

(*viii*) How would air resistance affect the path of the ball?

reduction in the horizontal and vertical distance travelled **[5]**

An inconsistency arises within the question, all valid alternative calculations & answers are acceptable.

8. A moving-coil loudspeaker is based on the principle that a current-carrying conductor in a magnetic field experiences a force.

(*i*) State two quantities that affect the magnitude of the force on a current-carrying conductor in a magnetic field.

magnetic flux density, current, length of conductor, angle **[2 + 2]**

(*ii*) Describe a laboratory experiment to demonstrate that a current-carrying conductor in a magnetic field experiences a force.

apparatus **[3]**
method **[3]**
observation **[3]**

(*iii*) Draw a diagram of the magnetic field produced by a current flowing in a long straight wire.

shape **[3]**
direction **[3]**

(*iv*) A wire of length 65 cm carrying a current of 3 A experiences a force of 7 mN when placed in a magnetic field. Calculate the magnetic flux density of the field when the current is flowing at right angles to the field.

$F = BIl$ **[3]**
$B = 0.0036$ **T** **[3]**

A loudspeaker has three main components as shown in the diagram: the magnet, the coil and the cone. The cone vibrations cause pressure variations in the air that produce sound waves of frequency 512 Hz.

(*v*) What type of wave is sound?

longitudinal / mechanical **[3]**

(*vi*) Calculate the wavelength of the sound wave produced.

$c = f\lambda$ **[3]**
$\lambda = 0.66$ **m** **[3]**

The amplitude of the vibrations of the cone determines the amplitude of the sound wave produced.

(*vii*) What musical characteristic is determined by the amplitude of the wave?

loudness/volume **[3]**

A loudspeaker has a power of 80 mW.

(*viii*) Calculate the sound intensity for a person standing 7 m from the loudspeaker.

$I = P/A$ **[3]**
$A = 4\pi r^2$ **[3]**
$I = 1.3 \times 10^{-4}$ **W m^{-2}** **[3]**

(*ix*) This sound intensity is halved for the person when they stand a distance d from the loudspeaker. Calculate d.

$I \propto \frac{1}{d^2}$ **/ reference to √2** **[3]**
9.9 m **[2]**

(*x*) After this, the speaker of power 80 mW is replaced by a speaker of power 20 mW. Calculate the decrease in sound intensity level.

reference to 3 dB **[2]**
6 dB **[3]**

9. (*a*) The resistance of a semiconductor depends on multiple factors, one of which is temperature. A thermistor is a temperature-dependent semiconductor.

(*i*) What is a semiconductor?

material with a resistivity **[3]**

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

(*ii*) Sketch a graph to show the relationship between temperature and resistance for a thermistor.

axes labelled **[3]**

shape **[3]**

(*iii*) Explain the shape of the graph in terms of the charge carriers in semiconductors.

as temperature increases, the number of electron hole pairs increase **[3]**

resistance decreases **[3]**

(*iv*) Distinguish between intrinsic and extrinsic conduction in semiconductors.

intrinsic: pure // equal number of electrons & holes // low conductivity **[2]**
extrinsic: doped // unequal number of electrons & holes // high conductivity **[2]**

(*b*) A current of 5 A flows in an electric drill when it is connected to the mains supply. Some of the input energy is dissipated as heat.

(*i*) State Joule's law.
power is proportional to // $P \propto I^2$ **[3]**
the current squared & the resistance // notation & reference to constant resistance **[3]**

(*ii*) The drill has an electrical resistance of 22 Ω and it runs for 30 s. Calculate the heat energy produced by the drill.

$W = I^2Rt$ **[3]**

W = 16 500 J **[3]**

(*iii*) Calculate the input power supplied to the drill by the 230 V mains supply.

$P = VI$ **[3]**

P = 1150 W **[3]**

(*iv*) Calculate the percentage efficiency of the drill.

$\frac{Po \times 100}{Pi}$ **or** **$P = W/t$** **[3]**

52.2 % **[3]**

(*c*) The mains supply is provided to homes at 230 V. However, electrical energy is transmitted using high voltages of approximately 300 kV in power lines.

(*i*) Explain why high voltages are used in the transmission of electrical energy.

high voltage means low current and therefore less energy/heat loss **[6]**

(*ii*) Name a device that is used to reduce the voltage from 300 kV to 230 V.

transformer **[4]**

10.(*a*) Food irradiation is used to delay spoilage and prevent illness caused by microorganisms. It is the process of exposing food and food packaging to ionising radiation, such as X–rays and gamma rays.

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

loss/gain **[3]**

of an electron **[3]**

(*ii*) Describe a laboratory experiment to demonstrate the ionising ability of nuclear radiation.

apparatus **[3]**

method **[3]**

observation **[3]**

X–rays used for food irradiation have a minimum wavelength of 1.02×10^{-11} m.

(*iii*) Explain how X–rays are produced.

high energy electrons **[3]**

strike a metal target **[3]**

(*iv*) Calculate the maximum energy of the X–rays used for food irradiation.

$c = f\lambda$ and $E = hf$ **[3]**

$E = 1.95 \times 10^{-14}$ J **[3]**

Cobalt–60 is commonly used to produce gamma rays for food irradiation. Cobalt–60 emits gamma rays with an average energy of 1.25 MeV.

(*v*) Explain what is meant by gamma rays.

electromagnetic radiation of highest energy / electromagnetic radiation due to the radioactive decay of a nucleus **[6]**

(*vi*) How many times bigger is the average energy of the gamma rays than the maximum energy of the X–rays?

1 eV = 1.6×10^{-19} J **[3]**

10.28 times **[3]**

(*b*) Cobalt–60 is a radioactive isotope. It is produced artificially in nuclear fission reactors.

(*i*) What are isotopes?

same atomic number **[3]**

different mass number **[3]**

(*ii*) Explain what is meant by nuclear fission.

breaking up of a large nucleus **[3]**

into two similar sized nuclei with the release of energy and neutrons **[3]**

(*iii*) Distinguish between the role of the moderator and the control rods in a nuclear fission reactor.

moderator: slows the neutrons to allow for fission

control rods: absorbs neutrons to control the rate of fission **[3 + 2]**

11. A device that is designed to store energy when it holds a charge is called a capacitor.

(*i*) Define capacitance.

charge **// formula** **[3]**

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

(*ii*) Describe an experiment to demonstrate that capacitance depends on the common area of the plates of a parallel plate capacitor.

apparatus **[3]**

method **[3]**

observation **[3]**

(*iii*) Sketch a suitable graph to show the relationship between capacitance *C* and the common area *A* between the plates of a parallel plate capacitor.

axes labelled **[3]**

correct shape **[3]**

A parallel-plate capacitor with metal plates of area 0.0225 m^2 are placed 8 mm apart in a vacuum.

(*iv*) A voltage of 3 kV is applied across the plates. Calculate the maximum potential energy stored in the capacitor.

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

$W = \frac{1}{2}CV^2$ **[3]**

$W = 1.12 \times 10^{-4}$ **J** **[3]**

(*v*) A material with a relative permittivity of 2 is then inserted to completely fill the space between the capacitor plates. What is the effect on the maximum potential energy stored by the capacitor?

increases **[3]**

by factor of 2 **[3]**

Capacitors and resistors can be combined to create timing circuits such as those used to create the flash on a camera. The circuit diagram below shows a resistor and a capacitator connected in series with a 30 V power supply. The current flowing in the circuit at a given instant is 0.3 mA.

(*vi*) Calculate the potential difference across the resistor at this instant.

$V = IR$ **[3]**

$V = 7.5$ **V** **[3]**

(*vii*) Calculate the charge held by the capacitor at this instant.

$V_{capacitor} = 30 - 7.5 = 22.5$ **(V)** **[2]**

$C = q/V$ **[3]**

$q = 1.91 \times 10^{-3}$ **C** **[3]**

(*viii*) Draw a diagram to show the electric field between the plates of the charged capacitor.

shape **[3]**

direction **[3]**

12.(*a*) All matter and energy in the universe must abide by one or more of the four fundamental forces of nature.

(*i*) Which force is the weakest of the four forces?

gravitational force **[3]**

(*ii*) Which force is responsible for binding the nucleus?

strong force **[3]**

(*iii*) State the two fundamental forces of nature that are based on inverse square laws.

gravitational force, electromagnetic force **[3 + 3]**

(*iv*) Name the fundamental force that allows for beta-decay.

weak force **[3]**

When it was observed that momentum did not appear to be conserved during beta-decay, Wolfgang Pauli proposed that an additional particle must be emitted to carry away the missing momentum and energy.

Pauli wrote, "I have done something very bad today by proposing a particle that cannot be detected; it is something no theorist should ever do".

(*v*) Identify the particle that Pauli proposed.

neutrino **[3]**

(*vi*) Explain why it is difficult to detect this particle.

very small mass, no charge **[3 + 3]**

(*vii*) Write an equation to represent the decay of a neutron (n_0^1) by beta-decay.

$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$ **[7 × 1]**

[-3 for additional incorrect species]

(*viii*) Calculate the energy released during this beta-decay.

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

change in mass = 1.395×10^{-30} (kg) **[3]**

$E = 1.25 \times 10^{-13}$ **J** **[3]**

Neutrons involved in beta-decay are classified as baryons, while electrons and positrons are classified as leptons.

(*ix*) State a difference between baryons and leptons.

baryons are composed of smaller particles but leptons are fundamental particles /
baryons are subject to the strong force but leptons are not subject to the strong force **[3]**

(*x*) Neutrons are neutral baryons. Show how the quark model explains this.

neutron = udd

2/3 – 1/3 – 1/3 = 0 **[4 + 3]**

(*xi*) Pair annihilation occurs when an electron and a positron meet. Write an equation that represents this process.

${}^{0}_{-1}e + {}^{0}_{1}e \rightarrow 2\gamma$ **// $2mc^2 = 2hf$** **[6]**

(*b*) The mains electricity supply in Ireland is a.c. and operates at a frequency of 50 Hz. However, many electrical appliances in the home require d.c. to operate.

(*i*) Distinguish between a.c. and d.c..

a.c. changes direction **[3]**

d.c. travels in one direction **[3]**

(*ii*) Draw a voltage–time graph for an a.c. supply and a d.c. supply.

labelled axes **[3]**

a.c. shown **[3]**

d.c. shown **[3]**

(*iii*) Draw a circuit diagram of a half-wave rectifier that can be used to convert a.c. to d.c..

diode **[3]**

input and output voltage labelled **[3]**

arrangement **[3]**

(*iv*) Sketch the graph of the output voltage of this circuit.

shape **[3]**

A voltage inverter can be used to convert d.c. to a.c.. A transistor can be used to build a NOT gate in a voltage inverter circuit.

(*v*) Draw a labelled diagram of the structure of a bi-polar transistor.

n (collector), p (base), n (emitter) **[3 + 2 + 2]**

(*vi*) Draw a truth table for a NOT gate.

input 1 : output 0 **[2]**

input 0 : output 1 **[2]**

The induction coil was invented by Dr Nicolas Callan in 1836.

(*vii*) Draw a labelled diagram showing the main components of an induction coil.

coil and d.c power supply in primary circuit **[3]**

coil with more turns in secondary circuit **[3]**

labelled make and break mechanism and iron core **[3]**

(*viii*) Describe how an induction coil can be used to produce a large d.c. voltage.

primary coil switches off **[3]**

changing magnetic field cutting secondary coil **[3]**

emf induced in secondary coil **[3]**

13. John Tyndall ranks as one of Ireland's most successful scientists and educators. He reached the pinnacle of 19th century science and counted amongst his friends and collaborators many of the best-known scientists of that century. Tyndall's scientific interests spanned heat, sound, light and environmental phenomena.
Amongst his many achievements, perhaps he is best known for the explanation of why the sky is blue – the scattering of light by small particles suspended in the atmosphere. Blue light is scattered more than other colours because it travels at shorter wavelengths. This colour is known as Tyndall Blue.
His major scientific interest was the study of the interaction of light with matter, especially gases. He studied the absorption of infrared radiation by gases found in the atmosphere. He made the first studies of atmospheric pollution in London.
adapted from: *'The Ascent of John Tyndall: Victorian Scientist, Mountaineer, and Public Intellectual' (Roland Jackson) Oxford University Press 2018*

(*i*) Blue is a primary colour of light.

(a) Name the two other primary colours of light.

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

(b) Name the secondary colour produced by these two primary colours.

yellow **[3]**

(*ii*) What is meant by dispersion of light?

splitting of light **[4]**

into its different colours **[3]**

(*iii*) Name two other items that can cause dispersion of light.

two items **[4 + 3]**

(*iv*) The refractive index of a medium varies for different wavelengths of light. Therefore, different colours travel at different speeds and are turned through different angles.

(*a*) Explain what is meant by refractive index.

ratio of sine of the angle of incidence **// formula** **[3]**

to sine of the angle of refraction **// notation** **[3]**

(*b*) The refractive index of a block of glass for red light is 1.51 and for violet light is 1.53. Calculate the difference between the speed of the red light and the speed of the violet light as they travel through the block of glass.

$n = \frac{c_1}{c_2}$ **[3]**

$c_{red} = 1.985 \times 10^8$ **(m s⁻¹)** , $c_{violet} = 1.959\times 10^8$ **(m s⁻¹)** **[2 + 1]**

difference = 2.6×10^6 **m s⁻¹** **[2]**

(*v*) Tyndall also did work in the field of spectroscopy. A photon of blue light, of frequency 6.54×10^{14} Hz, is produced in a line emission spectrum. This occurs when an electron falls from an energy level 6×10^{-19} J to a lower energy level.

(*a*) Calculate the energy of the lower energy level.

$E_2 - E_1 = hf$ **[3]**

1.67×10^{-19} **J** **[3]**

(*b*) Distinguish between a line emission spectrum and a continuous emission spectrum.

line spectra: contain gaps / contain specific wavelengths and continuous spectra: no gaps / contain all wavelengths **[5]**

(*c*) State one use of spectroscopy as a tool in science.

one use **[3]**

(*vi*) Infrared radiation is part of the electromagnetic spectrum. List any four other parts of the electromagnetic spectrum in order of increasing frequency.

any 4 named **[4 × 1]**

order **[3]**

14.

(*a*) Ireland's Fittest Family is a competition where families compete across a range of different fitness challenges. These challenges exemplify many physics principles in action.

(*i*) State the law of conservation of energy.

energy cannot be created or destroyed **[4]**

A man is competing in a race where participants are required to slide from a raised horizontal platform down a 2.4 m long slide. The slide is at an angle of 32° to the horizontal from the platform. The end of the slide is a vertical distance of 90 cm above the water.

(*ii*) Calculate the height of the platform above the surface of the water.

slide height = 2.4 sin 32° (= 1.27 m) **[3]**

total height = 1.27 + 0.9 = 2.17 m **[3]**

(*iii*) The man starts from rest. Calculate his velocity as he enters the water.
Assume that there is no friction on the slide.

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

$v = 6.52 \text{ m s}^{-1}$ **[3]**

(*iv*) Draw a force diagram for the man

(a) as he slides down the slide,

weight down **[3]**

normal reaction perpendicular to surface **[3]**

(*b*) when he is floating in the water.

weight down **[3]**

upward force equal in size **[3]**

[–3 for additional/incorrect forces]

(*b*) Ra–224 is an unstable nucleus of radium.

(*i*) Ra–224 decays by releasing an alpha-particle. Write a nuclear equation for this decay.

$^{224}_{88}Ra \rightarrow {}^{4}_{2}He + {}^{220}_{86}Rn$ **[7 × 1]**

[-3 for additional incorrect species]

(*ii*) A sample of Ra–224 decays to form Pb–208, an isotope of lead.

(*a*) How many alpha-particles are released?

4

(*b*) How many beta-particles are released?

2 **[4 + 2]**

Ra–224 has a half-life of 3.6 days.

(*iii*) Explain what is meant by the term half-life.

the time taken **[3]**

for half of the nuclei to decay **[3]**

[-1 for incorrect reference to atoms]

(*iv*) Calculate the total number of alpha-particles emitted per second by a sample of Ra–224 containing 4.7×10^{14} atoms.

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

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

$A = 1.05 \times 10^9$ **(Bq)** **[3]**

(*c*) (*i*) What is meant by thermionic emission?

emission of electrons **[3]**

from the surface of a hot metal **[3]**

(*ii*) Draw a labelled diagram of a cathode ray tube.

heating coil **[2]**

voltage across cathode and anode **[2]**

labelled vacuum **[2]**

one other detail **[2]**

A high-speed electron that strikes the screen of an oscilloscope produces the green light that is seen.

(*iii*) Calculate the minimum voltage required across the tube to give an electron a velocity of 2.7×10^7 m s^{-1}.

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

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

V **= 2072 V** **[3]**

(*iv*) How does the photoelectric effect differ from thermionic emission?

(energy needed) to release the electron is provided by light **[5]**

(*d*) A spectrometer can be used to measure the wavelength of light.

(*i*) Draw a labelled diagram of a spectrometer.

labelled collimator, table, telescope, other detail **[2 + 2 + 2 + 2]**

Green light of wavelength 530 nm is passed through a diffraction grating with 400 lines per mm.

(*ii*) Calculate the angle of separation between the second order images.

$d = \frac{1}{\text{number of lines per metre}}$ **[3]**

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

θ **= 25.1** **[3]**

angle of separation = 50.2° **[3]**

(*iii*) Identify a different colour of light that could be used to produce a greater angle of separation.

red / orange / yellow **[4]**

(*iv*) Explain how the number of lines per mm on a diffraction grating affects the angle of separation.

increased number of lines per mm means increased angle **[4]**