Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2021

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. Words which are separated by a solidus and which are underlined must appear in the correct context by including the rest of the statement to merit the assigned mark.

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

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

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

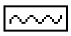
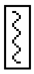
6. For omission of appropriate units (or for incorrect units) in final answers, one mark is deducted, unless otherwise indicated.

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

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

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

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

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

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

Marcanna Breise as ucht freagairt trí Ghaeilge

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

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

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

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

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

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

SECTION A (80 MARKS)

Answer **two** questions from this section.
Each question carries 40 marks.

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1. In an experiment to determine the acceleration due to gravity, a student set up a simple pendulum of length 300 mm. The student suspended the pendulum from a fixed point, set it to oscillate, and measured the time *t* for 20 oscillations. This procedure was repeated for different lengths *l* of the pendulum.

The following data were recorded.

l (mm)	300	400	500	600	700	800
t (s)	22.0	25.4	28.4	31.1	33.6	35.9

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

correct arrangement of bob **(3)**

string **(3)**

split cork or similar / timer / metre stick **(3)**

(–1 if no diagram present or no label present)

(*ii*) Indicate on the diagram

(*a*) the fixed point of suspension,

bottom of split cork or similar **(3)**

(*b*) the distance *l*.

from fixed point of suspension

to midpoint of bob **(2 + 2)**

(*iii*) Why did the student measure the time for 20 oscillations rather than the time for one oscillation?

to get an average / to get a larger value (for time) / greater accuracy / it is difficult to know when an oscillation starts or finishes **(6)**

(*iv*) Use the data to draw a suitable graph to calculate the acceleration due to gravity, *g*.

values for $(t/20)^2$ **(3)**

labelled axes **(3)**

correct points plotted **(3)**

line of best fit **(3)**

(*v*) Hence determine *g*.

slope formula **(3)**

g (≈ 9.8 m s^{-2}) **(3)**

2. In an experiment to determine the focal length of a concave mirror a student first made an approximate measurement of the focal length of the mirror. He then measured the image distance *v* for each of two different object distances *u*.

The following data were recorded.

u (cm)	20.0	25.0
v (cm)	31.2	23.2

(*i*) Why did the student first make an approximate measurement of the focal length?

to ensure that the object was placed outside the focal point / so that a real image would be formed / so that the image can be formed on a screen / to check final answer **(6)**

(*ii*) How did the student determine the image positions?

moved a screen until a sharp image was seen **(3)**

(*iii*) Draw a labelled diagram of how the apparatus was arranged.

object, mirror, screen, correct arrangement **(4 × 1)**

(–1 if no diagram present or no label present)

(*iv*) On your diagram, indicate *u* and *v*. **(2 × 3)**

(*v*) Use all of the data to calculate the focal length of the mirror.

formula **(3)**

average value for *f* (≈ 12.1 cm) **(3)**

(–1 if average not found)

Another student carried out this experiment but she measured the image distance *v* for each of **six** different object distances *u*. She then drew a graph and used the graph to calculate the focal length.

(*vi*) Sketch a suitable graph that might have been drawn.

correct x-axis (1/*u*) **// correct x-axis (*u*)** **(3)**

correct y-axis (1/*v*) **// correct y -axis (*v*)** **(3)**

correct shape of curve (straight line with m = −1) **// correct shape of curve** **(3)**

(*vii*) How could this graph be used to calculate the focal length?

intercept(s) **// point on curve** **(3)**

= 1/*f* **// substitute into formula** **(3)**

3. A student investigated how the fundamental frequency *f* of a stretched string varied with its tension *T*. The string was kept at a length of 65 cm.

The following data were recorded.

f (Hz)	256	320	341	427	480	512
T (N)	15	24	27	43	54	61

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

stretched string **(3)**

newtonmeter / weights and pan **(3)**

metre stick / bridge(s) / paper rider **(3)**

tuning fork **(3)**

(–1 if no diagram present or no label present)

(*ii*) Describe how the student used the apparatus.

held (vibrating) tuning fork to string and changed *T* **(3)**

paper rider fell off / loud sound **(3)**

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

values for f^2 *or* $\sqrt{T}$ **(3)**

labelled axes **(3)**

correct points plotted **(3)**

line of best fit **(3)**

(*iv*) Use your graph to calculate the mass per unit length (linear density) of the string.

slope formula **(3)**

value of slope (e.g. ≈ 64.8) **(2)**

formula **(3)**

μ (≈ 1.4×10^{-4} kg m^{-1}) **(2)**

4. A student measured the resistance R of a wire of length 30 cm at different values of temperature θ.

The following data were recorded.

θ (°C)	0	20	40	60	80	100
R (Ω)	5.35	5.60	5.85	6.04	6.28	6.51

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

resistor (in liquid), ohmmeter, source of heat, thermometer **(4 × 3)**

(–1 if no diagram present or no label present)

(*ii*) How did the student make the temperature of the wire 0 °C?

ice bath **(3)**

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

labelled axes **(3)**

correct points plotted **(3)**

line of best fit **(3)**

(*iv*) Use your graph to determine the temperature when the resistance is 6 Ω.

value consistent with graph (≈ 55.5 °C) **(3)**

The student measured the diameter of the wire to be 2.4 mm.

(*v*) How did the student measure the diameter of the wire?

micrometer / digital callipers / vernier callipers **(4)**

(*vi*) Calculate the resistivity of the metal at a temperature of 20 °C.

formula **(3)**

substitution / area = 4.52×10^{-6} (m^2) **(3)**

$\rho = 8.44 \times 10^{-5}$ Ω m **(3)**

5. In an experiment to verify Joule's law a constant current *I* was passed through a heating coil immersed in water. The current was allowed to flow for four minutes and the rise in temperature $\Delta\theta$ was determined. This procedure was repeated for a number of different currents. The mass of the water was kept constant at 105 g.

The following data were recorded.

I (A)	1.0	1.5	2.0	2.5	3.0	3.5
$\Delta\theta$ (°C)	2.0	4.6	8.2	12.6	18.3	25.0

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

power source **(3)**

means of varying current **(3)**

ammeter in series **(3)**

thermometer / coil (in water) **(3)**

(–1 if no diagram present or no label present)

(*ii*) Why was the current allowed to flow for a constant period of time?

to remove time as a variable **(3)**

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

values for I^2 **(3)**

labelled axes **(3)**

correct points plotted **(3)**

line of best fit **(3)**

(*iv*) Use your graph to calculate the average resistance of the heating coil.

slope formula **(3)**

value of slope (≈ 2.03) **(3)**

I^2Rt / $mc\Delta\theta$ **(3)**

$I^2Rt = mc\Delta\theta$ **(2)**

R (≈ 3.71 Ω) **(2)**

(*specific heat capacity of water = 4180 J kg^{-1} K^{-1}*)

SECTION B (224 MARKS)

Answer **four** questions from this section.
Each question carries 56 marks.

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

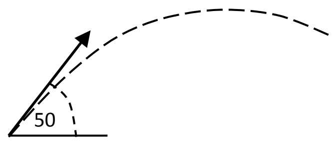
(*a*) Define acceleration. Hence derive the expression $v = u + at$.

rate of change of velocity / equation plus notation **(3)**

$a = (v - u)/t$ **(2)**

rearrangement **(2)**

(*b*) A ball is kicked with an initial velocity of 20 m s^{-1} at an angle of 50° to the horizontal. Calculate the horizontal distance it travels in 1.2 seconds.



$s = ut$ **(3)**

$u = 20\text{Cos}50° = 12.86$ **(m s^{-1})** **(2)**

15.43 m **(2)**

(*c*) State the laws of equilibrium for a set of co-planar forces.

sum of the forces (in any direction) is zero

sum of the moments (about any axis) is zero **(4 + 3)**

(*d*) State an expression for the acceleration due to gravity at a distance of *2R* above the surface of a planet of mass *M* and radius *R*.

$g = GM/d^2$ **(4)**

$g = GM/9R^2$ **(3)**

(*e*) Two different types of thermometer can give different readings when placed in the same environment. Explain why this happens.

different thermometric properties **(7)**

(*f*) Draw a labelled diagram to represent the second harmonic of a stationary wave in a pipe that is open at both ends.

antinode shown at both ends **(4)**

one full wave shown (i.e. antinode-node-antinode-node-antinode) **(3)**

(–1 if no label present)

(*g*) Calculate the sound intensity 6 m from a loudspeaker of power 20 mW.

I = P/A **(3)**

substitution / *A* = *4πr*² **(2)**

4.4×10^{-5} W m^{-2} **(2)**

(*h*) List two primary colours of light. What colour of light is produced when equal intensities of these two primary colours are mixed?

red and blue // blue and green // green and red **(2 × 2)**

magenta // cyan/turquoise // yellow **(3)**

(*i*) Distinguish between *earthing* and *bonding* in domestic electricity.

earthing means providing a (conducting) path to Earth, i.e. joining to Earth

bonding means providing a (conducting) path between objects, i.e. joining objects **(4 + 3)**

(*j*) Draw a circuit diagram to show how voltage and current are measured for a diode in reverse bias.

diode shown in reverse bias **(3)**

(micro)ammeter in series with diode **(2)**

voltmeter across diode and microammeter **(2)**

(*k*) Carbon–14 undergoes nuclear decay. The daughter nucleus is nitrogen–14. Write a nuclear equation for this decay.

$\mathrm{C}_{6}^{14} \rightarrow \mathrm{N}_{7}^{14} + \mathrm{e}_{-1}^{0}$ **(7 × 1)**

(–3 for each additional incorrect species)

(*l*) In terms of how they interact with the neutrons in a fission reactor, distinguish between a *moderator* and a *control rod*.

a moderator slows down neutrons

a control rod absorbs/stops/blocks neutrons **(4 + 3)**

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

force is proportional to **// expression** **(3)**

rate of change of momentum **// notation** **(3)**

(allow maximum of 3 marks for F = ma with notation)

(*ii*) State the principle of conservation of momentum.

momentum before interaction = momentum after interaction / formula and notation **(3)**

(*iii*) State the principle of conservation of energy.

energy is not destroyed or created (just converted into a different form) **(3)**

An object A of mass 45 g is travelling at a horizontal speed of 6.2 m s^{-1} when it strikes a resting sphere B of mass 80 g. B hangs vertically at the end of a string, as shown in the diagram. The string is free to move about point *P* which is 1.2 m above the centre of B.

During the collision, A and B are in contact for 25 ms.

After the collision, A recoils with a speed of 1.1 m s^{-1}.

Calculate

(*iv*) the force exerted by B on A,

$F = (mu - mv)/t$ **(3)**

$F = 0.045(6.2 + 1.1)/0.025 = 13.14$ **N** **(3)**

(*v*) the maximum velocity of B,

$0.045(6.2) = 0.045(-1.1) + 0.08(v)$ **(3)**

$v = 4.11$ **m s^{-1}** **(3)**

(*vi*) the magnitude and direction of the maximum centripetal force on B,

$F = mv^2/r$ **(3)**

$F = 0.08(4.11)^2/1.2 = 1.12$ **N** **(3)**

upwards / towards *P* **(2)**

(*vii*) the maximum height gained by B,

$\frac{1}{2}mv^2$ / mgh **(3)**

$h = 0.86$ **m** **(3)**

(*viii*) the maximum angular displacement of the string.

$\cos\alpha = (1.2 - h)/1.2$ **(3)**

$\alpha = 73.6°$ **(3)**

(*ix*) Draw a labelled diagram to show the force(s) acting on B when it is at its maximum height.

downward arrow, labelled as weight **(3)**

labelled tension arrow in correct direction **(3)**

(–3 for each additional incorrect force)

The string is cut at the instant B is at its maximum height.

(*x*) What is the magnitude and direction of the acceleration of B after the string is cut?

9.8 m s^{-2} **(3)**

downwards **(3)**

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

8. The bright outline along the edge of a cloud – the 'silver lining'– is an example of the diffraction of light in nature. Diffraction is a wave phenomenon.

(*i*) What is meant by diffraction?

spreading of a wave **(2)**

through a gap / around an obstacle **(2)**

(*ii*) A diffraction experiment can be used to demonstrate the wave nature of light. Describe such an experiment.

apparatus, method, observation **(3 × 3)**

(*iii*) What is a diffraction grating?

a series of (transparent) gaps **(3)**

(*iv*) Derive the diffraction grating formula, $n\lambda = d\sin\theta$.

d indicated **(3)**

θ indicated as angle between straight through and higher order image **(3)**

extra path length = $d\sin\theta$ **(3)**

for constructive interference, extra path length = $n\lambda$ **(3)**

(*v*) Calculate the angular separation between the two 3rd order images formed when blue light of wavelength 442 nm is incident on a diffraction grating of 600 lines per mm.

$d = 1.67 \times 10^{-6}$ (m) **(3)**

$\sin\theta = 3(442 \times 10^{-9})/d = 0.7956$ **(3)**

$2\theta = 105.4°$ **(3)**

(*vi*) Calculate the distance between these images on a screen placed 50 cm from the grating.

$\tan\theta = x/0.5$ **(3)**

$2x = 1.31$ m **(3)**

(*vii*) What changes would be observed if the blue light was replaced with (*a*) with red light, (*b*) with white light?

(*a*) greater angular separation / fewer images **(3)**

(*b*) spectrum (on either side of white zero-order image) **(3)**

(*viii*) Compare the wavelengths of radio waves with those of visible light.

radio waves have longer wavelengths (than visible light) **(3)**

(*ix*) Why are radio waves not observed to undergo diffraction when incident on a diffraction grating of 600 lines per mm?

d is too small / λ is too big **(4)**

9. Ice is used as a coolant due to the high specific heat capacities of ice and water and the high specific latent heat of fusion of ice. It is the principal coolant used in ice packs for insulated picnic boxes, such as the one shown.

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

energy to change temperature of 1 kg of a substance // equation for *c* **(3)**

by one kelvin // notation **(3)**

(*ii*) Why does the high specific latent heat of fusion of ice make it a good coolant?

takes in a lot of energy **(3)**

when melting **(3)**

(*iii*) Suggest two reasons why the walls of a picnic box are made from hollow plastic rather than solid plastic.

better insulator, lower heat capacity, lighter, lower environmental impact **(*any* 2 × 3)**

A picnic box contains food items with an initial temperature of 10.5 °C. The heat capacity of the food is 17.8 kJ K^{-1}. An ice pack that contains 250 g of ice was taken from a freezer held at a temperature of –18 °C and placed in the picnic box. As the temperature of the ice increases and it melts, the temperature of the food decreases.

(*iv*) Calculate the final temperature inside the picnic box when its contents have reached thermal equilibrium.

$mc\Delta\theta$ or $C\Delta\theta$ **(3)**

ml **(3)**

$(0.25 \times 2100 \times 18) + (0.25 \times 330000) + (0.25 \times 4180 \times \theta)$ **(3)**

$= 17800(10.5 - \theta)$ **(3)**

$\theta = 5.04$ °C **(3)**

Freezers and refrigerators operate by use of a heat pump.

(*v*) Draw a labelled diagram of a heat pump.

compressor indicated **(3)**

(expansion) valve indicated **(3)**

correct arrangement of liquid/vapour indicated **(3)**

(*vi*) Explain how a heat pump works.

heat taken in by liquid evaporating **(3)**

heat given out by vapour condensing **(3)**

A student used the apparatus shown below to investigate how heat travels through water.

(*vii*) What observations did the student make?

ice didn't melt / bottom of the tube stayed cold **(4)**

(*viii*) What conclusion could the student have made?

water is a poor conductor (of heat) **(4)**

(*specific heat capacity of ice = 2100 J kg^{-1} K^{-1}; specific heat capacity of water = 4180 J kg^{-1} K^{-1}*)

(*specific latent heat of fusion of ice = 3.3×10^5 J kg^{-1}*)

10. A current flowing through a conductor creates a magnetic field around it.

(*i*) What is a magnetic field?

the region where magnetic forces can be experienced **(3)**

(*ii*) Describe an experiment to show the magnetic field around the conductor.

apparatus, method, observation **(3 × 3)**

(*iii*) Draw the shape and direction of this magnetic field.

correct shape **(3)**

correct direction **(3)**

When placed in an external magnetic field, a current-carrying conductor may experience a force.

(*iv*) The magnitude of this force depends on a number of factors. Name three of them.

magnetic flux density, current, length, angle **(*any* 3 × 2)**

(*v*) Derive an expression for the force F experienced by a charge q travelling with velocity v perpendicular to a magnetic field of flux density B.

$F = BIl$ **(3)**

$I = q/t$ **and** $l = vt$ **(3)**

$F = qvB$ **(3)**

A square loop of side 5 cm enters a magnetic field of flux density 0.4 T while travelling at a velocity of 6 m s^{-1} parallel to one side of the square. The square is perpendicular to the direction of the field.

(*vi*) Use Faraday's law of electromagnetic induction to calculate the average emf induced in the loop as it enters the field.

$V = d\Phi/dt$	// $V = d\Phi/dt$	**(3)**
$\Phi = BA = 0.001$ Wb	// $V = BA/t = BAv/s$	**(3)**
$t = s/v = 0.00833$ s	// $V = Bsv$	**(3)**
$V = 0.12$ V	// $V = 0.12$ V	**(3)**

The other law of electromagnetic induction is Lenz's law.

(*vii*) State Lenz's law.

the direction of an induced current **(3)**

is such as to oppose the change that caused it **(3)**

(*viii*) Explain how Lenz's law is a special case of the principle of conservation of energy.

otherwise energy would be created **(5)**

11. The photograph shown was taken during a meeting of the Deutsche Bunsen-Gesellschaft (German Bunsen Society) in 1932.

The three people sitting at the left of the table are James Chadwick, Hans Geiger and Ernest Rutherford. Lise Meitner and Otto Hahn are standing behind Rutherford.

The careers of Chadwick and Geiger were very similar. They both worked under Rutherford early in their careers. Later they were on opposite sides in the efforts to build the first nuclear bombs, Chadwick with the Manhattan Project in America and Geiger with the Uranium Club in Germany.

Shortly before this photograph was taken, Chadwick had discovered the neutron. In his experiment an alpha particle was absorbed by a beryllium–9 nucleus and a neutron was emitted.

(*i*) Write the nuclear equation for this event.

$\mathrm{Be}_4^9 + \mathrm{He}_2^4 \rightarrow \mathrm{C}_6^{12} + \mathrm{n}_0^1$ **(11 × 1)**

(–3 for each additional incorrect species)

(*ii*) Calculate the increase in kinetic energy during this event.

E = mc² **(3)**

conversion between a.m.u. and kg **(3)**

mass defect calculation **(3)**

conversion to J (9.13 × 10^{-13} J) **(3)**

Geiger is best remembered for co-inventing the Geiger-Müller tube.

(*iii*) A G-M tube and a solid-state detector have the same function. What is this function?

to detect (ionising) radiation **(3)**

(*iv*) Describe, with the aid of a labelled diagram, the principle of operation of a detector of this sort.

gas / anode	**//**	**semiconductor**	**//**	**charged gold leaf electroscope**		**(3)**
ionisation	**//**	**electron-hole pair**	**//**	**ionisation**		**(3)**
current	**//**	**current**	**//**	**leaves collapse**		**(3)**

(–1 if no diagram present)

While working with Rutherford, Geiger assisted on the gold foil experiment.

(*v*) Describe with the aid of a labelled diagram the gold foil experiment.

alpha source and gold target **(3)**

flashes of light on detector **(3)**

(–1 if no diagram present)

(*vi*) What observations were made during the experiment?

most particles went straight through, some were slightly deflected, a few went almost straight back **(3 × 2)**

(*vii*) What did Rutherford conclude about the structure of the atom?

mostly empty space with positive nucleus **(3)**

(*viii*) How did Niels Bohr improve Rutherford's model to explain emission line spectra?

electrons in energy levels **(3)**

photon emitted when electrons move between energy levels / $hf = E_n - E_m$ **(3)**

12. The Wimshurst machine is an electrostatic generator for generating high voltages. It uses the principles of charging by induction and point discharge to store energy in two large capacitors. Wimshurst machines provided a source of high voltage for early X-ray tubes.

(*i*) Describe a laboratory experiment to demonstrate charging by induction.

charged object **(3)**

charged object brought close to conductor **(3)**

conductor earthed **(3)**

earth removed **(3)**

(last 3 marks not awarded if charged object removed before or at the same time as earth)

(*ii*) Explain how point discharge occurs.

charge accumulates at a point **(3)**

the air around the point is ionised / ions in the air neutralise the point **(3)**

The plates of a parallel plate capacitor of capacitance 3.2 pF have a common area of 20 cm^2 and are 15 mm apart.

(*iii*) Calculate the relative permittivity of the capacitor's dielectric.

$C = \varepsilon A/d$ **(3)**

$\varepsilon = 2.4 \times 10^{-11}$ **(F m^{-1})** **(3)**

$\varepsilon_r = 2.71$ **(3)**

(*iv*) What would be the effect on the capacitance if the distance between the plates was doubled?

decreased by a factor of 2 **(3)**

(*v*) Three such capacitors are connected in parallel as shown below. Explain why the effective capacitance of this combination is 9.6 pF.

(common) area increases by a factor of 3 (and C is proportional to A) **(3)**

(*vi*) Draw the electric field pattern in a charged parallel plate capacitor.

parallel field lines **(3)**

from + to − **(3)**

A voltage of 20 kV is applied between the cathode and the anode in an X-ray tube.

(*vii*) Why is the cathode of an X-ray tube hot?

for thermionic emission to occur / so that electrons will be released **(3)**

(*viii*) Calculate the maximum speed of an electron as it moves between the cathode and the anode.

$\frac{1}{2}mv^2$ / qV **(3)**

$\frac{1}{2}mv^2 = qV$ **(3)**

$v = 8.4 \times 10^7$ **m s^{-1}** **(3)**

(*ix*) What happens to the energy of the electrons when they hit the anode?

converted into heat

converted into X-rays **(3 + 2)**

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

(*a*) Read the following passage and answer the accompanying questions.

In the beginning, nearly 14 billion years ago, all the space, matter and energy of the universe was contained in a volume less than one trillionth the size of the full stop that ends this sentence. The forces of nature that define the universe were unified. As the universe rapidly expanded within a fraction of a second, in what is known as the Planck era, this unified force split into the four distinct forces that we now understand.

At this time, matter in the form of subatomic particles and energy in the form of photons incessantly interplayed. Photons converted into matter-antimatter pairs which immediately annihilated returning their energy back to photons.

The universe was now a seething soup of quarks and leptons. As it continued to expand and cool quarks joined to form new particles called hadrons. At this stage the universe had expanded to a few light years across and one second had elapsed.

In CERN a circular particular accelerator called the Large Hadron Collider is being used to recreate these conditions.

Adapted from '*Astrophysics for People in a Hurry' (Neil deGrasse Tyson) W.W. Norton & Company 2017*

(*i*) State the quark composition of the proton.

up, up, down **(7)**

(*ii*) List the forces experienced by a proton in decreasing order of strength.

strong, electromagnetic, weak, gravitational **(4 × 1)**

order **(3)**

(*iii*) The Planck constant relates energy and frequency. Its value is 6.6×10^{-34} J s. Express this unit in terms of metres, kilograms and seconds.

kg m^2 s^{-1} **(7)**

(*iv*) Write a nuclear equation for the pair annihilation of a proton and an antiproton.

$\mathrm{p}^{1}_{1} + \bar{\mathrm{p}}^{1}_{-1} = 2\gamma$ **(7 × 1)**

(–3 for each additional incorrect species)

(*v*) A photon produces a muon anti-muon pair. Calculate the minimum energy of the photon in electronvolts.

$E = mc^2$ **(3)**

$m = 2m_\mu$ **(3)**

$m = 2 \times 206.9 \times 9.109 \times 10^{-31} = 3.769 \times 10^{-28}$ **(kg)** **(3)**

$E = 3.388 \times 10^{-11}$ **(J)** **(3)**

$E = 2.115 \times 10^{8}$ **eV** **(2)**

(*vi*) In the Large Hadron Collider, how are the particles (*a*) accelerated, (*b*) maintained in circular motion?

(*a*) voltage / electric field / magnetic field

(*b*) magnetic field **(4 + 3)**

(*vii*) In 1932 Walton and Cockcroft manufactured one of the first useful particle accelerators. State two reasons why their experiments using this accelerator were of scientific significance.

first experimental verification of $E = mc^2$

first transmutation using artificially accelerated particles **(4 + 3)**

(*b*) Read the following passage and answer the accompanying questions.

December 16, 1947 marked the start of humankind's information age when physicists John Bardeen and Walter Brattain connected upper electrodes to specially treated germanium that sat on a third electrode. When a small current flowed through one of the electrodes, a much larger current flowed through the other two. The transistor was born.

A transistor is a semiconductor device that can be used to amplify voltage or switch electronic signals.

Adapted from '*The Physics Book: From the Big Bang to Quantum Resurrection' (Clifford A. Pickover) Sterling New York 2011*

(*i*) Explain how a photodiode works.

diode in reverse bias **(3)**

photons absorbed to create an electron-hole pair **(2)**

current flows **(2)**

(*ii*) Diodes can be used to make a bridge rectifier. Draw a circuit diagram of a bridge rectifier.

four diodes **(4)**

correct arrangement shown **(3)**

(*iii*) Sketch the input and output voltage patterns for a bridge rectifier.

axes labelled (*V* and *t*) **(3)**

a.c. input **(2)**

d.c. output **(2)**

(*iv*) Draw the structure of a bi-polar transistor.

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

(*v*) Draw a circuit diagram of a voltage amplifier. Indicate clearly the input and output voltages.

symbol for a transistor **(3)**

source of voltage **(3)**

input voltage between base and emitter **(3)**

output voltage across load resistor **(3)**

bias resistor shown in correct position **(2)**

(*vi*) In a voltage amplifier, what is the function of (*a*) the load resistor, (*b*) the bias resistor?

(*a*) converts a change in collector current to a large output voltage

(*b*) ensures the base-emitter junction is forward biased **(4 + 3)**

(*vii*) A transistor can be used in a circuit to act as a NOT gate. What is the name of this circuit? Draw a truth table for a NOT gate.

voltage inverter **(3)**

input 1 : output 0 **(2)**

input 0 : output 1 **(2)**

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

(*a*) An iron sphere of mass 40 g hangs from a spring and oscillates with simple harmonic motion. The period of oscillation is 0.74 s.

(*i*) What is simple harmonic motion?

acceleration proportional to displacement / equation and notation **(3)**

(*ii*) Calculate the spring constant.

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

$\omega = 8.49\ (s^{-1})$ **(3)**

$\omega^2 = k/m$ **(3)**

$k = 2.88\ N\ m^{-1}$ **(3)**

(*iii*) Calculate the acceleration of the sphere when its displacement is 18 mm from its equilibrium position.

$a = \omega^2 s$ **(3)**

$a = 1.3\ m\ s^{-2}$ **(3)**

The iron sphere and the spring are brought to rest and a small magnet is attached to the sphere. When the magnet is attached, the length of the spring increases by 15 mm.

(*iv*) Calculate the mass of the magnet.

mg / kx **(3)**

$mg = kx$ **(2)**

$m = 4.4$ g **(2)**

(*acceleration due to gravity = 9.8 m s*$^{-2}$)

(*b*) Hydroacoustics is the study of sound in water. The Doppler effect is observed in hydroacoustics.

(*i*) What is the Doppler effect?

(apparent) change in frequency **(2)**

due to the relative motion between a source and an observer **(3)**

(*ii*) Describe how the Doppler effect can be demonstrated in the laboratory.

apparatus, method, observation **(3 × 3)**

A moving underwater source emits a sound of frequency 800 kHz while travelling towards an underwater detector, which detects a frequency of 806 kHz.

(*iii*) Calculate the speed of the source.

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

substitution **(3)**

$u = 11.02 \text{ m s}^{-1}$ **(3)**

Sound travels faster in water than in air. When a sound wave travels from water into air, it undergoes refraction.

(*iv*) Draw a ray diagram to show the refraction of a sound wave as it travels from water into air.

wave changing direction as it travels from water to air **(3)**

towards the normal **(2)**

(*speed of sound in water = 1480 m s*$^{-1}$)

(*c*) In the photoelectric effect electrons are emitted from the surface of a metal when the incoming light of intensity I has a frequency f that exceeds a certain value f_o, the threshold frequency.

Describe what happens when

(*i*) $f > f_o$, f is constant and I is increasing,

more electrons emitted **(2)**

with the same energy/speed **(2)**

(*ii*) $f > f_o$, f is increasing and I is constant,

same number of electrons emitted **(2)**

but with greater energy/speed **(2)**

(*iii*) $f < f_o$, f is constant and I is increasing.

no electrons emitted **(4)**

Light of wavelength 440 nm is incident on a metal that has a work function of 2.6 eV.

(*iv*) Calculate the threshold frequency of the metal.

$hf_0 = \Phi$ **(3)**

$f_0 = 6.3 \times 10^{14}$ **Hz** **(3)**

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

$hf = \Phi + \frac{1}{2}mv^2$ **(3)**

$c = f\lambda$ **(3)**

$\frac{1}{2}mv^2 = 3.5 \times 10^{-20}$ **(J)** **(2)**

$v = 2.8 \times 10^5$ **m s^{-1}** **(2)**

(*d*) Ball lenses are glass spheres which can be used for special effects in photography.

Light travels at a different speed in air and in glass.

(*i*) The photograph shows the inverted image of a mountain formed in a ball lens. Draw a ray diagram to show how an inverted image is formed in a lens. Is the image real or virtual?

converging lens **(3)**

object outside *f* **(3)**

correct rays shown **(3)**

the image is real **(3)**

The critical angle of the glass in a ball lens is 41.4°.

(*ii*) What is meant by critical angle?

angle of incidence (in denser medium) **(3)**

such that angle of refraction is 90°

/ greater than which total internal reflection occurs **(3)**

(*iii*) Calculate the speed of light in the ball lens.

$n = 1/\sin C$ **or** $n = c_1/c_2$ **(2)**

$1/\sin C = c_1/c_2$ **(2)**

$c_2 = 1.98 \times 10^8$ m s^{-1} **(2)**

(*iv*) Explain why white light is dispersed as it passes through the ball lens.

different colours of light **(2)**

travel at different speeds (in glass) / have different refractive indices **(2)**

(allow for 4 marks "the faces of the lens are not parallel")