Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2020

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 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
✔ n	$Tick_n$	Correct element (n marks)
[	Left Bracket	To identify and separate one of several attempts at an answer
]	Right Bracket	To identify and separate one of several attempts at an answer
〰	Horizontal wavy line	To be noticed
⦚	Vertical wavy line	Additional page (at bottom of page)
-1	−1	−1
^	^	Missing element

1. In an experiment to verify the principle of conservation of momentum, body A was set in motion with a constant velocity. It was then allowed to collide with a second body B, which was initially at rest and the bodies moved off together at constant velocity.

The following data were recorded.

Mass of body A = 125.6 g

Mass of body B = 111.1 g

Distance travelled by body A for 0.2 s before collision = 11.4 cm

Distance travelled by bodies A and B for 0.2 s after collision = 6.1 cm

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

Two trolleys/riders on track	**3**	
Means of attachment	**3**	
Timing device	**3**	**9**

(*ii*) Describe how the time interval was measured.

Number of gaps // light gate	**3**	
× 0.02 (s) // rider passing through	**3**	**6**

(*iii*) How were the effects of (*a*) friction and (*b*) gravity minimised?

Air cushion // track sloped	**3**	
Horizontal track // frictional force = gravitational force / acceleration = 0	**3**	**6**

[“dust/polish runway” – maximum of 3 marks]

Use the data to

(*iv*) calculate the initial and final velocities of body A,

$v = \frac{s}{t}$	**3**	
$u = \frac{.114}{0.2}$ or $v = \frac{.061}{0.2}$	**3**	
$u = 0.57\ \text{m s}^{-1}$; $v = 0.305\ \text{m s}^{-1}$	**2 + 1**	**9**

(*v*) demonstrate how the experiment verifies the principle of conservation of momentum.

$p = mv$	**3**	
$p_b = (0.1256)(0.57)$ or $p_a = (0.1256 + 0.1111)(0.305)$	**3**	
$p_b = 0.072\ (\text{kg m s}^{-1})$; $p_a = 0.072\ (\text{kg m s}^{-1})$ ***[units not necessary]***	**1 + 1**	
$p_b = p_a$	**2**	**10**

2. In an experiment to determine the refractive index of glass, light was passed through a glass block and the angles of incidence *i* and refraction *r* were measured for different values of *i*.
The following data were recorded.

i (°)	30	40	50	60	70	80
r (°)	19	25	31	35	39	41

(*i*) Explain how the refracted ray and the angle of refraction were determined.

Using ray box / pins / laser the ray in the block is determined **3**

Normal is drawn at point of incidence **3**

Angle between the normal and the ray in the block is measured with a protractor **3** **9**

(*ii*) Why would using a smaller angle of incidence have led to a less accurate measurement of the angle of refraction?

Smaller angle **3**

Greater percentage error ***[−1 if "percentage" not mentioned]*** **3** **6**

(*iii*) Use the data to draw a suitable graph to verify Snell's law.

6 values of $\sin i$ and $\sin r$ calculated **3**

$\sin i$	0.50	0.64	0.77	0.87	0.94	0.98
$\sin r$	0.33	0.42	0.52	0.57	0.63	0.66

Labelled axes **3**

6 points plotted **3**

Straight line with good fit **3** **12**

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

Straight line graph **3**

Through origin **3** **6**

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

$m = \frac{y_2 - y_1}{x_2 - x_1}$ **3**

Correct substitution using two points from line on graph **2**

Appropriate answer with $m = n \approx 1.50$ **2** **7**

3. In an experiment to determine the speed of sound in air a student determined the lengths *l* of an air column when it was vibrating at different fundamental frequencies *f*.
The following data were recorded.

f (*Hz*)	250	300	350	400	450	500
l (*cm*)	34.0	28.3	24.0	20.5	19.1	17.0

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

Air column and tuning fork	**3**	
Means of adjusting the length of the air column	**3**	
Correct arrangement	**3**	**9**

(*ii*) How did the student determine the length of the air column for a particular frequency?

Hold a vibrating tuning fork over the air column	**3**	
Change length of air column until loud sound is heard	**3**	**6**

(*iii*) How did the student ensure that the fundamental frequency, not an overtone, was observed?

Start with a small length (and increase length until first loud sound is heard)	**3**	**3**

(*iv*) Use the data to draw a graph of *f* against $^1/_l$.

6 values of $^1/_l$ calculated	**3**	

f	250	300	350	400	450	500
1/l	2.94	3.53	4.17	4.88	5.24	5.88

Labelled axes	**3**	
6 points plotted	**3**	
Straight line with good fit	**3**	**12**

(*v*) Calculate the slope of your graph.

$m = \frac{y_2 - y_1}{x_2 - x_1}$	**2**	
Correct substitution using two points from line on graph	**2**	
Appropriate answer with $m \approx 85$	**2**	**6**

(*vi*) Hence or otherwise, calculate the speed of sound in air.

$v = f\lambda$	**2**	
$v \approx 340 \text{ m s}^{-1}$	**2**	**4**

4. In an experiment to determine the resistivity of nichrome, the resistance *R* of a length l of wire of uniform diameter was recorded. This was repeated for a number of different lengths of the wire. The diameter of the wire was also measured.
The following data were recorded.

l (cm)	30	40	50	60	70	80
R (Ω)	0.11	0.14	0.17	0.21	0.24	0.28

Diameter of wire = 2.05 mm

(*i*) Name the pieces of apparatus that were used to measure (*a*) the diameter, (*b*) the length and (*c*) the resistance of the wire.

(*a*) **Micrometer / vernier calipers / digital calipers** **3**

(*b*) **Metre stick** **3**

(*c*) **Ohmmeter / multimeter** **3** **9**

(*ii*) How did the student ensure that the diameter of the wire was uniform?

Measured diameter at different places on the wire / no kinks **3** **3**

(*iii*) Use the data to draw a graph of *R* against l.

Labelled axes **3**

6 points plotted **3**

Straight line with good fit **3** **9**

(*iv*) Calculate the slope of your graph.

$m = \frac{y_2 - y_1}{x_2 - x_1}$ **2**

Correct substitution using two points from line on graph **2**

Appropriate answer with $m \approx 0.34$ **2** **6**

(*v*) Hence calculate the resistivity of the metal.

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

$\rho \approx 1.12 \times 10^{-6}\ \Omega\ \text{m}$ **3** **6**

(*vi*) How would the resistance of a fixed length of wire change if its diameter was doubled?

$R \propto \frac{1}{d^2}$ // $\rho = \frac{RA}{l}$ **and** $A = \pi r^2$ **2**

4 times **2**

Smaller **3** **7**

5. (*a*) State Boyle's law.

For a fixed mass of gas

At constant temperature

Pressure is inversely proportional to volume **3 + 2 + 2** **7**

(*b*) A neutron star has a density of 3.7×10^{17} kg m^{-3}. What would the radius of the Earth be if it had the same density as the neutron star?

$\boldsymbol{\rho = \frac{m}{V}}$ **/** $\boldsymbol{V = 1.62 \times 10^{7}}$

$\boldsymbol{V = \frac{4}{3}\pi r^{3}}$

$\boldsymbol{r = 157\ \mathrm{m}}$ **3 + 2 + 2** **7**

(*c*) A spring has a length of 22 cm when a 2 N weight hangs from it. The spring constant is 50 N m^{-1}. Calculate the natural length of the spring.

$\boldsymbol{F = -ks}$

$\boldsymbol{s = 4\ \mathrm{cm}}$

Natural length $\boldsymbol{= 18\ \mathrm{cm}}$ **3 + 2 + 2** **7**

(*d*) Draw a ray diagram to show the formation of an image in a convex mirror.

Object and correct mirror

Two correct rays

Appropriate lines behind mirror and correct image **3 + 2 + 2** **7**

(*e*) What is meant by the amplitude of a wave?

Maximum

Displacement (from rest position) **4 + 3** **7**

(*f*) Name one of the three primary colours of light. What is its complementary colour?

Red // green // blue **4**

Cyan // magenta // yellow **3** **7**

(*g*) Draw a labelled diagram to show how an electric field pattern can be demonstrated in the laboratory.

Source of high voltage ***[−1 if "high" not mentioned]***

Connected across plates, with oil, semolina **4 + 3** **7**

(*h*) Distinguish between intrinsic and extrinsic conduction in a semiconductor

Intrinsic is through a pure semiconductor / intrinsic: equal number of holes and electrons

Extrinsic is through a doped semiconductor / extrinsic: excess of holes or electrons **4 + 3** **7**

(*i*) The diagram shows a sketch of a photocell.

a. What particles move between the electrodes of the photocell?

Electrons

b. In what direction do the particles move?

From cathode to anode **4 + 3** **7**

(*j*) *a.* Write a nuclear equation to show the pair annihilation of a positron and an electron.

$\boldsymbol{{}_{-1}^{0}e + {}_{1}^{0}e}$ **/** $\boldsymbol{e^{-} + e^{+}}$ **2 + 2**

$\boldsymbol{\rightarrow 2hf}$ **/** $\boldsymbol{\rightarrow 2\gamma}$ **2 + 1** **7**

or

b. Draw the truth table for an OR gate.

1 + 1 → 1; 1 + 0 → 1; 0 + 1 → 1; 0 + 0 → 0 **2 + 2 + 2 + 1** **7**

6. Motion and the effects of forces can be explained using Newton's three laws of motion.

(*i*) State Newton's laws of motion.

A body remains at a constant velocity / a body remains at rest	**2**	
Unless acted on by a force	**2**	
Force is proportional to	**2**	
The rate of change of momentum	**2**	
When body A applies a force to body B	**2**	
Body B applies an equal and opposite force to body A	**2**	**12**

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

$F = k\frac{\Delta(mv)}{\Delta t}$ **/ F is proportional to** $\frac{\Delta(mv)}{\Delta t}$	**2**	
$F = k\frac{m\Delta v}{\Delta t}$	**2**	
$F = kma$	**2**	
(From definition of the newton) k = 1 so *F = ma*	**2**	**8**

(*iii*) Describe an experiment to find the resultant of two co-planar vectors.

Apparatus	**3**	
Method	**3**	
Observation	**3**	**9**

A cricket player moves her hands away from the motion of the ball as she catches it.

(*iv*) Explain, using Newton's laws of motion, why she moves her hands away from the motion of the ball.

$F \propto \frac{1}{\Delta t}$ **/ longer time therefore smaller force**	**3**	**3**

She then throws a ball upwards with an initial velocity of 28 m s^{-1} at 45° to the horizontal. Her hand was 1.6 m above the ground. A short time later the ball was caught by another player. When it was caught the ball was again at a height of 1.6 m.

Calculate

(*v*) how long the ball was in the air,

$v = u + at$ **/** $s = ut + \frac{1}{2}at^2$	**3**	
4.04 s	**3**	**6**

(*vi*) the horizontal distance travelled by the ball,

$s = vt$ **//** $v = 28\cos 45\ \ (= 19.8)$	**3**	
$s = 80$ **m**	**3**	**6**

(*vii*) the maximum height above the ground reached by the ball.

$s = ut + \frac{1}{2}at^2$ **/** $v^2 = u^2 + 2as$	**3**	
$s = 20 + 1.6 = 21.6$ **m** ***[–1 if addition of 1.6 m is omitted]***	**3**	**6**

(*viii*) Draw a diagram to show the velocity *v*, acceleration *a* and force(s) *F* on the ball when it is at its maximum height. Use the letters *v*, *a* and *F* to label your vectors.

***v* horizontal; *a* vertically down; *F* vertically down**	**3 × 2**	**6**

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

7. All insulated metal bodies can store charge.

(*i*) Describe how a pear shaped metal body can be charged by induction.

Bring charged body close to pear shaped conductor	**3**	
Connect the conductor to Earth	**3**	
Remove the connection to Earth, then the charged body	**3**	**9**

(*ii*) Draw a diagram to show the distribution of charge on the body after charging.

Charge throughout with concentration at the pointed end	**3**	**3**

A charged capacitor stores energy.

(*iii*) Define capacitance.

$C = Q/V$	**3**	
Notation explained	**3**	**6**

(*iv*) Draw the circuit symbol for a capacitor.

Symbol	**3**	**3**

The stored energy of a 4000 μF capacitor, connected across 500 V, is converted to heat when the capacitor discharges through a heating element placed in 40 g of water in an insulated container.

(*v*) Calculate the maximum rise in temperature of the water.

$E = \frac{1}{2}CV^2$ **or** $E = mc\Delta\theta$	**3**	
$mc\Delta\theta = \frac{1}{2}CV^2$	**3**	
3 °C	**3**	**9**

(*vi*) Describe an experiment to demonstrate how the capacitance of a parallel-plate capacitor changes with the distance between its plates.

Apparatus	**3**	
Method	**3**	
Observation	**3**	**9**

A Leyden jar acts as a parallel-plate capacitor.

A student makes a Leyden jar in the laboratory. It consists of a cylindrical glass container of internal radius 6 cm. The glass in the jar is the capacitor's dielectric, with a relative permittivity of 2.1 and a thickness of 5 mm. Aluminium foil of height 17 cm coats the inside and outside vertical walls of the jar.

(*vii*) Calculate the surface area of the inner cylinder of aluminium foil.

$A = 2\pi rh$	**3**	
$A = 0.064$ **m²**	**3**	**6**

(*viii*) Calculate the capacitance of the Leyden jar.

$C = \frac{\epsilon A}{d}$	**3**	
$C = 0.238$ **nF**	**3**	**6**

(*ix*) What property of glass allows it to be used as a dielectric?

Insulator	**5**	**5**

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

8. Radioactivity was discovered in 1896 by Henri Becquerel**.**

Define (*i*) radioactivity, (*ii*) the becquerel.

(*i*)	**(Spontaneous) disintegration of a nucleus**	**3**	
	[−1 for "atom" instead of nucleus]		
	With emission of radiation	**3**	**6**
(*ii*)	**One disintegration per second**	**3**	**3**

In the uranium decay series, U–238 decays in a series of alpha and beta decays to Pb–206.
The first decay in this series is an alpha decay and the final decay is a beta decay.

(*iii*) Write a nuclear equation for the first decay in this series.

$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th$ **7 × 1** **7**

(*iv*) Write a nuclear equation for the final decay in this series.

$^{206}_{81}Tl \rightarrow {}^{0}_{-1}e + {}^{206}_{82}Pb$ **7 × 1** **7**

(*v*) Calculate the total number of alpha particles and the total number of beta particles emitted in the series.

8 alpha **3**

6 beta **3** **6**

The half-life of U–238 is 4.5 × 10^9 years.

(*vi*) How long will it take for the number of U–238 nuclei in a sample to decrease by a factor of 8?

3 half lives **3**

1.35 × 10^{10} years **3** **6**

(*vii*) A sample of U–238 nuclei contains 3.2 × 10^{10} nuclei. Calculate its activity.

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

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

$A = 1.56 \times 10^{-7}$ **Bq** **3** **9**

(*viii*) U–238 is an isotope of uranium. What are isotopes?

Same number of protons / same atomic number / same element **3**

Different number of neutrons / different mass number **3** **6**

Radon gas forms part of the uranium decay series.

(*ix*) Why is radon gas considered to be dangerous?

e.g.radioactive **3** **3**

(*x*) How can the build-up of radon gas in a building be reduced?

Sump / membrane / ventilation **3** **3**

9. There are two types of guitars, acoustic guitars and electric guitars.
In acoustic guitars, resonance occurs between the vibrating strings and other parts of the guitar.

(*i*) Define resonance.

Transfer of energy	**3**	
Between two bodies of the same natural frequency	**3**	**6**

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

Apparatus	**3**	
Method	**3**	
Observation	**3**	**9**

A guitar string has length 2 m and mass 0.88 g. It is stretched across two fixed points which are 65.1 cm apart on a guitar. It is then plucked and it vibrates at a fundamental frequency of 330 Hz.

(*iii*) Draw a labelled diagram to show a guitar string vibrating at its fundamental frequency.

Nodes at each end	**3**	
One antinode in the middle	**3**	**6**

Calculate

(*iv*) the tension in the string,

$\boldsymbol{\mu = \frac{m}{l}}$ / $\boldsymbol{\mu = \frac{0.88\times10^{-3}}{2}}$	**3**	
$\boldsymbol{f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}}$	**3**	
Substitution	**3**	
$\boldsymbol{T = 81}$ **N**	**3**	**12**

(*v*) the speed of sound in the string.

$\boldsymbol{v = f\lambda}$	**3**	
$\boldsymbol{v = 429}$ **m s^{-1}**	**3**	**6**

In an electric guitar a magnetic pickup detects the vibration in the string. The pickup consists of a stationary magnet and a coil around the magnet. When the string vibrates an emf is induced.

(*vi*) Draw the magnetic field around a bar magnet.

Correct shape	**3**	
Correct direction	**3**	**6**

(*vii*) Explain how the emf is induced in the coil.

Moving coil	**3**	
Changing magnetic field cutting the coil	**3**	**6**

(*viii*) Sketch a graph to show how the output current varies with time.

Labelled axes		
a.c.	**3 + 2**	**5**

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

(*a*)	(*i*)	What are the two fundamental forces that the neutrino experiences?		
		Weak, gravitational	**3 + 3**	**6**
	(*ii*)	Pions and kaons are members of the meson family. What are mesons?		
		Quark and anti-quark pair	**3**	**3**
	(*iii*)	List the three types of neutrino in order of increasing mass.		
		Electron neutrino, muon neutrino, tau neutrino ***[any order acceptable]***	**3 × 2**	**6**
	(*iv*)	Why is no tunnel required to transport the neutrinos underground to South Dakota?		
		Small mass / no charge / little interaction with matter	**3**	**3**
	(*v*)	Calculate the time taken for the neutrino to travel from *Fermilab* to South Dakota.		
		$v = \frac{s}{t}$	**3**	
		$t = 4.4$ **ms**	**3**	**6**

In another experiment in *Fermilab* two protons, each with a kinetic energy of 29 GeV, collide and new particles are created. After the collision, the total kinetic energy of the two protons and the new particles is 16 GeV.

(*vi*)	Calculate the total mass of the new particles created.		
	Change in energy = 42 (GeV)	**3**	
	6.72×10^{-9} **(J)**	**3**	
	$E = mc^2$	**3**	
	$m = 7.48 \times 10^{-26}$ **kg**	**3**	**12**

Enrico Fermi proposed the existence of the neutrino. He also built the first self-sustaining nuclear fission reactor.

(*vii*)	What is nuclear fission?		
	Splitting of a large nucleus into smaller nuclei	**3**	
	[−1 for "atom" instead of nucleus]		
	[−1 for omission of nuclear size]		
	With the emission of energy and neutrons	**3**	**6**
	[−1 for omission of neutrons]		
(*viii*)	Why was Fermi's nuclear reactor considered to be self-sustaining?		
	Chain reaction / on average every fission caused another fission	**4**	**4**
(*ix*)	Graphite was used in his fission reactor. What was the purpose of the graphite?		
	To slow down fast neutrons / to increase the rate of fission / to act as a moderator	**4**	**4**
(*x*)	Is nuclear fission a spontaneous or a non-spontaneous process? Explain your answer.		
	Non-spontaneous	**3**	
	A neutron is required to initiate	**3**	**6**

(*b*) A moving-coil galvanometer detects and measures small currents.

(*i*) Describe, with the aid of a labelled diagram, the principle of operation of a galvanometer.

Coil, core, magnets, spring, pointer and scale	**3**	
Current in coil	**3**	
Coil experiences a force and rotates	**3**	**9**

(*ii*) Draw labelled diagrams to show how a moving-coil galvanometer can be converted into (*a*) an ammeter, (*b*) an ohmmeter.

(*a*)	**Low resistance**	**3**	
	In parallel	**3**	
(*b*)	**Variable resistor and power supply**	**3**	
	In series	**3**	**12**

(*iii*) A moving-coil galvanometer has a full scale deflection of 50 mA and an internal resistance of 7.2 Ω. Calculate the resistance required to convert it into a voltmeter with full scale deflection of 10 V.

$\boldsymbol{R_{total} = x + 7.2}$	**3**	
$\boldsymbol{R = \frac{V}{I}}$	**3**	
$\boldsymbol{R_{multiplier} = 193\ \Omega}$	**3**	**9**

LEDs can also indicate the flow of current and are used in optical displays.

(*iv*) What is an LED?

Light emitting diode	**3**	**3**

(*v*) Describe, with the aid of a labelled diagram, the principle of operation of an LED.

Diagram with p-n junction and depletion layer	**3**	
Forward bias connection, electrons and holes interact	**3**	
Emitting photons	**3**	**9**

(*vi*) LEDs are fragile. How can they be protected in a circuit?

Resistor	**3**	
In series	**3**	**6**

(*vii*) State two difference between LEDs and photodiodes.

LEDs emit light, photodiodes need to absorb light	**4**	
LEDs in forward bias, photodiodes in reverse bias	**4**	**8**

11. (*a*) J.J. Thomson used cathode ray tubes in his research. How are electrons (*a*) produced, (*b*) deviated in a cathode ray tube?

(*i*) **Heated cathode / thermionic emission**

(*ii*) **Electric/magnetic fields** **4 + 3** **7**

(*b*) Cathode rays are accelerated through a potential difference of 4 kV in a cathode ray tube. Calculate the maximum speed of an electron in the tube.

$E = \frac{1}{2}mv^2$ **or** $E = QV$ **3**

$\frac{1}{2}mv^2 = QV$ **2**

$v = 3.75 \times 10^7$ **m s^{-1}** **2** **7**

(*c*) What pieces of apparatus can be used to demonstrate the diffraction of light in the laboratory?

Diffraction grating, light source, screen/spectrometer **3 + 2 + 2** **7**

(*d*) Geiger also played an important role in the development of the Geiger counter, a detector of nuclear radiation. Describe the principle of operation of *any* detector of radiation.

Ionisation **4**

Correct valid detail e.g. producing current **3** **7**

(*e*) Describe the Geiger-Marsden experiment that used thin sheets of gold. Include their setup, observations and conclusions.

Zinc sulphide / fluorescent screen; alpha source; gold foil; vacuum **any 3 × 1**

Flashes on screen / scintillations **3**

Most alphas straight through / deviated slightly **2**

A few alphas reflected **2**

Atom mostly empty space **2**

Small/dense positive core **2** **14**

(*f*) Describe with the aid of a labelled diagram the Bohr model of the atom. Use the model to explain emission line spectra.

Nucleus **3**

Electrons in different energy levels **3**

Electrons given energy **2**

Rise to higher energy level **2**

Fall to lower energy level **2**

Photon/light emitted **2** **14**

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

(*a*) Fifty years ago the Apollo 13 mission to the Moon captured the public's imagination when technical issues led to the aborting of the planned Moon landing. The three astronauts on the mission travelled further from the Earth than anyone before or since.

(*i*) Derive an expression for the period of orbit *T* of the Moon around the Earth (of mass *M*) with radius of orbit *R*.

$\frac{mv^2}{R} = \frac{GmM}{R^2}$ **3**

$v^2 = \frac{GM}{R}$ **3**

$T = \frac{2\pi R}{v}$ **3**

$T^2 = \frac{4\pi^2 R^3}{GM}$ **3** **12**

(*ii*) Calculate the period of the Moon as it orbits the Earth.

$T^2 = \frac{4\pi^2 (3.85\times10^8)^3}{(6.7\times10^{-11})(6.0\times10^{24})}$ **3**

$T = 2.37 \times 10^6\ \mathrm{s}$ **3** **6**

(*iii*) Calculate the gravitational force exerted by the Moon on an astronaut of mass 80 kg when he is 250 km above the surface of the Moon.

$F = \frac{GMm}{d^2}$ **3**

$F = 98.73\ \mathrm{N}$ **3** **6**

(*iv*) Astronauts appear to be weightless when they orbit the moon. Explain why.

Astronaut and spaceship have common acceleration / spaceship in freefall **4** **4**

(*mass of Earth = 6.0 × 10^{24} kg;*
mass of the Moon = 7.3 × 10^{22} kg;
radius of the Moon = 1740 km;
radius of the Moon's orbit around Earth = 3.85 × 10^8 m)

(*b*) In the greenhouse effect visible radiation passes through the atmosphere but infra-red radiation is reflected back to Earth. This leads to global warming.

(*i*) Radiation is one of three methods of heat transfer. What are the other two methods?

Conduction, convection **3 + 3** **6**

On a particular day, solar radiation falls on the surface of Antarctica at a rate of 850 W m^{-2}. 52% of the incoming radiation is infra-red radiation. The average frequency of the infra-red radiation is 15 THz.

(*ii*) Calculate the infra-red energy that falls on 0.25 m^2 of Antarctica in 3 minutes.

850 × 0.52 **3**

× 0.25 × 180 = 19890 J **3** **6**

(*iii*) Calculate the number of infra-red photons that fall on this area in this time.

$\boldsymbol{E = hf}$ **/** $\boldsymbol{E = 9.9 \times 10^{-21}}$ **3**

Number = $\boldsymbol{\frac{19890}{9.9 \times 10^{-21}} = 2 \times 10^{24}}$ **3** **6**

As the Earth warms, due in part to the greenhouse effect, the Earth's glaciers continue to melt. At present the total volume of ice in glaciers on Earth is 170,000 km^3.

(*iv*) Calculate the energy required to melt 0.5% of the Earth's glaciers if their average temperature is –6 °C and the melting point of glacier ice is –2 °C.

$\boldsymbol{\rho = \frac{m}{V}}$ **2**

$\boldsymbol{m = 7.82 \times 10^{14}}$ **(kg)** **2**

$\boldsymbol{E = mc\Delta\theta + ml}$ **2 + 2**

$\boldsymbol{E = 2.67 \times 10^{20}}$ **J** **2** **10**

(*density of glacier ice = 920 kg m^{-3};*
specific latent heat of fusion of glacier ice = 3.3 × 10^5 J kg^{-1};
specific heat capacity of glacier ice = 2900 J kg^{-1} K^{-1})

(*c*) Speed cameras make use of the Doppler effect.

(*i*) What is the Doppler effect?

Change of observed frequency	**3**	
Due to relative motion between the source and the observer	**3**	**6**

(*ii*) Explain, with the aid of labelled diagrams, how the Doppler effect occurs.

Labelled non-concentric circles	**2**	
Source moves towards observer	**2**	
Wavelength is shorter	**2**	
Frequency is higher	**2**	**8**

A source of sound approaching a stationary observer appears to have a frequency that is 20% greater than its frequency at rest.

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

$f' = \frac{fc}{c-u}$	**4**	
$f' = 1.2\,f$	**3**	
$u = 56.7\ \mathrm{m\,s^{-1}}$	**3**	**10**

(*iv*) The Doppler effect is also used to detect the red shift of galaxies. What does the red shift tell us about the universe?

Universe is expanding	**4**	**4**

(*speed of sound in air = 340 m s*$^{-1}$)

(*d*) In May of 2019 the definition of the ampere, the SI unit of current, was changed. It is now defined in terms of the value of *e*, the elementary charge.

(*i*) What is current?

The flow	**3**	
Of charge	**3**	**6**

(*ii*) Calculate the current flowing when one mole (6.0×10^{23}) of electrons passes a point in 30 minutes.

$Q = (6.0\ \times 10^{23})(1.6 \times 10^{-19}) = 96000\ \mathrm{C}$	**3**	
$I = \frac{Q}{t} = 53.3\ \mathrm{A}$	**3**	**6**

The previous definition of the ampere was based on the phenomenon of two current-carrying parallel conductors exerting a force on each other.

(*iii*) Explain why this phenomenon occurs.

Each current carrying wire has a magnetic field	**4**	
Each wire experiences a force in the other's magnetic field	**3**	**7**

(*iv*) Describe a laboratory experiment to demonstrate this phenomenon.

Power supply and U-shaped foil	**3**	
Allow current to flow	**3**	
Foil moves	**3**	**9**