GCE

Physics B

H557/01: Fundamentals of physics

Advanced GCE

Mark Scheme for Autumn 2021

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

1. Annotations available in RM Assessor

Annotation	Meaning
BOD	Benefit of doubt given
CON	Contradiction
✗	Incorrect response
ECF	Error carried forward
L1	Level 1
L2	Level 2
L3	Level 3
TE	Transcription error
NBOD	Benefit of doubt not given
POT	Power of 10 error
^	Omission mark
SF	Error in number of significant figures
✓	Correct response
?	Wrong physics or equation

2. Abbreviations, annotations and conventions used in the detailed Mark Scheme (to include abbreviations and subject-specific conventions).

Annotation	Meaning
/	alternative and acceptable answers for the same marking point
reject	Answers which are not worthy of credit
not	Answers which are not worthy of credit
Ignore	Statements which are irrelevant
Allow	Answers that can be accepted
( )	Words which are not essential to gain credit
__	Underlined words must be present in answer to score a mark
ECF	Error carried forward
AW	Alternative wording
ORA	Or reverse argument

Section A: MCQs

Question			Answer	Marks	Guidance
1			B	L	
2			D	L	
3			A	M	
4			B	L	
5			C	M	
6			D	M	
7			D	L	
8			B	L	
9			B	L	
10			B	M	
11			C	M	
12			A	M	
13			B	L	
14			A	L	
15			D	L	
16			D	M	
17			A	H	
18			C	H	
19			C	H	
20			A	M	
21			A	M	
22			B	H	
23			B	M	
24			B	H	
25			B	L	
26			A	H	
27			C	L	
28			B	H	
29			B	M	
30			A	H	
			Total	**30**	

Section B

Question			Answer	Marks	Guidance
31	(a)		method: diameter of atom = Circumference/[no. atoms + spaces] ✓ = πD / [2 x 19] OR = 3.5π / 38 (nm) ✓ evaluation: = 0.29 OR 0.3 (nm) ✓	**L** **M** **M**	correct counting to 38 [atoms + spaces] value of 0.58 nm (from using radius instead of diameter in circumference calculation) **max 1; not** 0.6 or 0.58 if scaling method used other methods acceptable including measuring diameter of circle and individual atom leading to evaluation in the range 0.23 to 0.29nm : • correct ratio of measured length of arrow / 3.5nm ✓ • measured diameter of atom / ratio ✓ • evaluation in range 0.23 to 0.29nm OR correctly rounded to 0.2 or 0.3nm ✓
			Total	**3**	

Question			Answer	Marks	Guidance
32	(a)		12½ waves per 1 ms means $f_{max} \approx$ 12500 Hz and need 2 samples per cycle ✓	L	**need** to identify f_{max} for mark do not allow 25kHz/2 = 12.5kHz for f_{max} **not** just "sampling needs to be at least double the highest frequency" or statements of Nyquist
32	(b)		$V_{total} / V_{noise} \approx 140 / 0.4 = 350$ ✓ $2^{bits} > 350$ $2^9 = 512$ suggest 9 bits sample^{-1} ✓	L M	**Allow** estimates in range 340 to 360 **need** to show $2^8 = 256$ or $2^9 = 512$ or $\log_2(350) = 8.45$ leading to 9 (bits sample^{-1}) for second mark **not** just quoting bits = $\log_2(V_{total}/V_{noise})$ from data booklet
			Total	3	

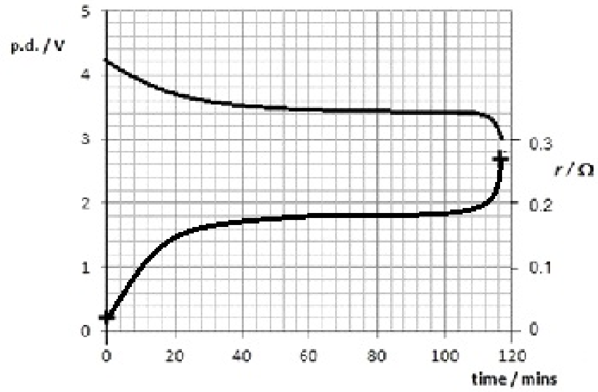
Question			Answer	Marks	Guidance
33	(a)		wavelengths are shortened OR they are blue-shifted ✓ because these galaxies are approaching (Milky Way) ✓	L L	**Must** have idea of change **Allow** emitted waves are bunched up **not** just "because of Doppler effect"
33	(b)	(i)	$1000/1.9$ / [$4 \times 10^4/660$] ✓ (= 526 / 60.6) = 8.7 ✓	M M	**Allow** first mark for correctly calculating both gradients – units not required for mark 1929 gradient in range 519 to 526 1998 gradient in range 60.6 to 61.5 **Allow** evaluation in range 8.4 to 8.7 **Allow** a valid comparison with completed calculation using 8 x 1998 gradient value or 1929 value / 8 for the second mark **Allow max 1** for a correct evaluation in the range > 8 , ≤ 9 using correct method but incorrect values from graphs.
33	(b)	(ii)	age = $1/H_0$ ✓ = $[660\times3.1\times10^{22}]/[4\times10^7]$ s = $5.1\times10^{17}/3.2\times10^7$ years = $16\ (\pm 2)\times10^9$ (years) ✓	H H	method **Allow** 1 / gradient OR in numbers **Allow** ecf from gradient in b(i) for this mark evaluation of show that.
			Total	**5**	

Question			Answer	Marks	Guidance
34	(a)		$N = A \times t_{1/2} / \ln 2$ OR $= 8.5\times10^6 \times 60 \times 24 \times 3600/0.693$ ✓ $= 6.4 \times 10^{13}$ ✓	L L	method evaluation
34	(b)		absorbed dose $= N_0/2 \times 35\times10^3\times1.6\times10^{-19}\times1/0.05$ ✓ = 3.6 (Sv) ✓	M M	method mark for using energy deposited per unit mass **Allow** 3.4 Sv using $N_o = 6 \times 10^{13}$ for 2 marks **Allow** ecf from **34(a)** when N_o rounds to >6 and <7 **Allow** 1 mark for 7.2 Sv for only ½ decay
34	(c)		cells nearer seed will receive higher dose than farther away / to give more even irradiation / dose will decay away from the seed by γ-ray absorption✓	L	any valid point e.g. spread over greater volume further away **Allow** spreads out over larger (surface) area further away **Allow** valid use of $1/R^2$ and / or exponentially
			Total	**5**	

Question			Answer	Marks	Guidance
35	(a)		e.g. lines on graph OR $e^{-1} = 0.37$ ✓ $T =$ 1300 (K) ✓	H H	evidence of finding f when $E = kT$ **accept** answers in range 1100 to 1500 (K) if first mark awarded
35	(b)		the average molecule has energy kT and so will be able to perform the process ✓ Boltzmann factor $e^{-20} \approx 2 \times 10^{-9}$ so only a small fraction of molecules have sufficient energy but make many attempts each second / high collision frequency giving a significant rate ✓	L M	completion : **allow** very few collisions occur with a pair of molecules with less than energy kT significant rate at $T / 20$: OR Boltzmann tail contains molecules that have much higher than average energy by “getting lucky” / gaining energy from multiple consecutive collisions by chance from the thermal chaos
			Total **Total section B**	**4** **20**	

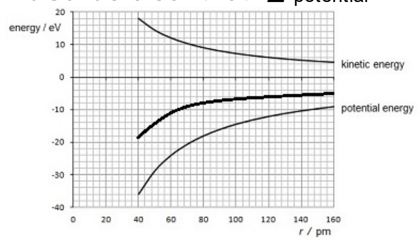
Section C

Question			Answer	Marks	Guidance
36	(a)	*	**Level 3 (5–6 marks)** Marshals argument in a clear manner and includes clear explanation of **all** strands including : • circuit diagram with scaled components and correct symbols • methodology of readings to be taken • analysis to find *r* *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Covers **all** strands at a superficial level and does not include enough depth for level 3. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)** Makes at least two independent points (possibly from only one strand), that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit	LL MM HH	**Allow** labelled diagrams or graphs **Indicative scientific points in the three strands may include:** **circuit diagram to include:** • cell and variable resistor in range 10-100 Ω / at least five discrete resistors to give range 10-100 Ω • series circuit, possibly with switch to rest cell • Voltmeter in parallel with the variable load resistor / cell range: up to 10V max • Ammeter in series range : mA up to 1Amp **methodology of readings** • measure *V* on open circuit no load current i.e. e.m.f. • rest cell with switch between readings • connect max load resistance measure *V*, I tabulate • decrease load resistance repeat *V*, I readings • adjust load so that readings in *V* / I roughly evenly spaced • repeat until load on cell is 0 Ω / cell is shorted to measure **analysis to find *r*** • plot *V* on y-axis vs I on x-axis • plot straight line of best fit • *r* = gradient of line or from $r = [\mathcal{E} - V] / I$ calculations • draw best fit lines of max and /or min gradient to estimate uncertainty in *r*

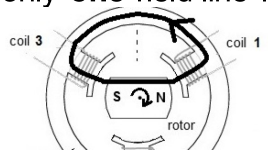
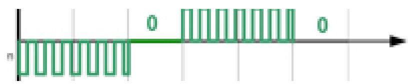
Question			Answer	Marks	Guidance
36	(b)	(i)	$Q = It$ so A × h = 1 A × 3600 s = 3600 A s or 3600 C ✓ OR charge = current × time ✓	L	**Not** just Q = It
36		(ii)	curving up to about 0.18 ± 0.2 Ω by about 60 mins ✓ levelling off then increasing again to 0.27 Ω ✓ If graph not drawn credit any **one** correct calculation based on r = [4.2 – V] /4.5 including [4.2 – 3.0] /4.5 = 0.27 Ω for final value	H H	
36	(b)	(iii)	$N = I\,t\,/\,[N_A \times e] = 4.5 \times 2 \times 3600/[6.0 \times 10^{23} \times 1.6 \times 10^{-19}]$ ✓ = 0.3(4) (moles) ✓ OR $N = I\,t\,/\,[N_A \times e]$ $= 4.5 \times 116 \times 60\,/\,[6.0 \times 10^{23} \times 1.6 \times 10^{-19}]$ ✓ = 0.33 (moles) ✓	S&C S&C	estimate method **Allow** approximation t = 2 hours evaluation
			Total	**11**	

Question			Answer	Marks	Guidance
37	(a)	(i)	(tilting the runway slightly so that) component (of gravity) down the slope balances friction ✓ OR so that there is no resultant force on the trolley at the experimental speed ✓	L	**Accept** (downward slope can ensure it) maintains constant speed
37	(b)	*	**Level 3 (5–6 marks)** Marshals argument in a clear manner and includes clear explanation of **all** strands including : • conservation of momentum check • conservation of kinetic energy check • forces acting on each trolley *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** covers **all** strands at a superficial level and does not include enough depth for level 3. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.*	L M HH H S&C	**Indicative scientific points may include:** **expect** measurements from tapes to be to $\pm$ 1 mm accuracy i.e. tape A before : 79 to 81; tape A after:39 to 41; tape B after 119 to 121. **Allow** use of less than 5 dot strip as long as measured length leads to evaluation in range. **conservation of momentum check** • momentum before = 0.9 × 0.8 = 0.72 kg m s^{-1} • after = [0.9 × 0.4 + 0.3 × 1.2] = 0.72 kg m s^{-1} sensibly conserved / to within the limits of uncertainty measurements comment that momentum is conserved in (all) collisions and should be conserved here. **conservation of kinetic energy check** • k.e. before = ½ × 0.9 × $[0.8]^2$ = 0.288 J • k.e. after = ½ × 0.9 × $[0.4]^2$ + ½ × 0.3 × $[1.2]^2$ = 0.072 + 0.216 = 0.288 J • sensibly conserved / to within limits of uncertainty measurements • so perfectly elastic collision • comment that kinetic energy is not always conserved in collisions • comment that kinetic energy is conserved in elastic collisions

Question			Answer	Marks	Guidance
			Level 1 (1–2 marks) Makes at least two independent points (possibly from only one strand), that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit		**forces acting on each trolley** • forces are equal and opposite OR • some version of **N3** backwards on **A**, forwards on **B** • $\rightarrow$ $F_{\mathbf{B}} = \Delta mv / \Delta t = 0.3 \times 1.23 / 0.06 = 6.2$ N to right OR • $\leftarrow$ $F_{\mathbf{A}} = 0.9 \times [0.41 - 0.82] / 0.06 = 6.2$ N to left
37	**(c)**	**(i)**	volume flow rate OR Av must remain constant ✓ by calculation for 1.0 s: $v_1 \pi [0.075]^2 / 4 = v_2 \pi [0.025]^2 / 4$ gives $9 v_1 = v_2$ ✓ OR at **F** diameter is $^1/_3$ of value at **E** so A is $^1/_9$	**M** **S & C**	**Allow** water is incompressible **expect** numerical argument completed OR $A \propto D^2$ OR $A \propto R^2$ with $[1/3]^2 = 1/9$
37	**(c)**	**(ii)**	$\pi D_1{}^2 v_1 /4 = 0.02$ OR $v_1 = 0.020 \times 4 / [\pi D_1{}^2]$ ✓ = 4.5(3) (m s^{-1}) ✓ OR $v_1 = 0.020 \times 4 / [9 \pi \times 0.025^2]$; = 4.5(3) (m s^{-1})	**S&C** **S&C**	method evaluation **Max 1** mark if diameter used for radius
37	**(c)**	**(iii)**	rate of change of momentum of water in nozzle=$\Delta mv/\Delta t$ ✓ = $20 \times (9-1)v_1 = 20\times8\times4.53 = 72(4)$ (N) ✓	**H** **S & C**	Method – no credit for just writing =$\Delta mv/\Delta t$ from formula sheet evaluation
			Total	**13**	

Question			Answer	Marks	Guidance
38	(a)	(i)	$E = ke / r^2$ = $8.98 \times 10^9 \times 1.6 \text{x} 10^{-19} / [40 \times 10^{-12}]^2$ ✓ = $0.90 \text{x} 10^{12}$ (V m^{-1}) ✓	L L	**Allow** just $E = ke / r^2$ OR correct substitution for method mark **allow** use of k = $9\text{x}10^9$ leading to $0.9 \text{ x} 10^{12}$ evaluation of show that : **allow** $0.898 \text{ x } 10^{12}$
	(a)	(ii)	**expect** two valid checks with 2 approx = numerical values ✓✓ OR 0.9 TV m^{-1} @ 40 pm becomes $0.9/2^2$ = 0.22 TV m^{-1} @ 80 pm two values here ✓✓	MM	check: $E r^2$ = sensibly constant in range [1.4 to 1.5] $\text{x}10^{-9}$ **Max 1** mark if one value just outside range **Max 1 mark only for general statement :** as r doubles E becomes x ¼ OR for 1 value of Er^2 **Allow** full credit for correct calculation without units
38	(a)	(iii)	area represents p.d. OR potential difference OR ΔV ✓ 1 big sq ≡ $0.2\text{x}10^{12}\text{x } 20\text{x}10^{-12}$ = 4 V and about 5 ± ½ big squares ≈ 20 ± 2 V ✓ OR = $\Delta\, ke / r$ = $9\text{x}10^9 \text{x} 1.6\text{x}10^{-19} \text{ x } [^1/52\text{x}10^{-12} - {}^1/160\text{x}10^{-12}]$ ✓ = [27.7 – 9] = 18.7 V ✓	H S&C	**not** unit of V **evaluation** by counting squares **allow** units not needed here if area ≡ voltage given already
38	(b)	(i)	method: $m v^2 / r = k e^2 / r^2 \rightarrow ½ m v^2 = k e^2 / 2 r$ ✓	H	**requires** algebraic argument
38	(b)	(ii)	E_{total} = $½ k e^2 / r - k e^2 / r = - ½ k e^2 / r$ ✓ graph is mirror image i.e. - E_{kinetic} ✓	M M	**must** be clear that $E_{\text{potential}} = - k e^2 / r$ 

Question			Answer	Marks	Guidance
	(b)	(iii)	otherwise orbits would decay by (radiative emission) / electron would spiral into proton ✓	M	any valid point: **Allow** without quantisation any energy or orbit radius would be allowed and there would be no specific energy levels OR no typical line spectrum
	(b)	(iv)	r = 53 pm ✓ requires 14 eV so 14 V is ionization potential ✓	S&C S&C	evaluation 5.3 x 10^{-11} m on total energy graph (to remove electron to ∞)
			Total	**12**	

Question			Answer	Marks	Guidance
39	(a)	(i)	flux loops want to shorten / magnet tries to align parallel to flux between coils **1** and **2** (at about θ = 30°) /flux lines leave **N** pole of rotor at an angle which exerts a turning moment to right ✓	L	**Allow** coil **1** is a S and will attract the N pole of the rotor (so this force will turn the rotor clockwise) **not** flux lines leave **S** pole of rotor radially which exerts no turning moment in this position
39	(a)	(ii)	anticlockwise path ✓ completed loop through the upper $^{1}/_{3}$ of stator ring ✓	L L	only **one** field line loop expected 
39	(b)		**1**: to make a stronger (stator) field / flux OR increase permeance (of flux path) ✓ **2**: to reduce eddy currents / heat losses ✓ **3**: to get more flux for the same (stator) coil current ✓ OR as air gaps reduce permeance (of magnetic circuit) / as air gaps reduce permeance (of magnetic circuit)	L M M	**Allow** reduce reluctance of flux path Must have correct technical term – e.g. permeance / reluctance
39	(c)		**1**: alter the frequency of switching (coils) ✓ **2**: alter magnitude of current (in stator coils) / (supply) voltage ✓	H H	**allow for second mark** pulse the switched supply voltage / current to stator coils by pulse width modulation PWM / on:off ratio will determine moment 
			Total	**9**	

Question			Answer	Marks	Guidance
40	(a)	(i)	$\boldsymbol{P} \propto 1/\boldsymbol{V}$ ✓ $\boldsymbol{V} \propto \boldsymbol{T}$ AND $\boldsymbol{P} \propto \boldsymbol{T}$ (OR θ + 273) ✓	L M	**Allow** in words e.g. just "inverse proportionality" **Allow** in words but response **must** either make reference to T or absolute temperature / Kelvin temperature
40	(a)	(ii)	e.g. $PV = c_1 = c_2 T = kNT = NkT$ ✓	M	**Must** have PV/T = constant OR PV=constant x T leading to pV=NkT **allow** ecf if correctly combined to an (incorrect) equation involving k
40	(a)	(iii)	$k = 101 \times 10^3 \times 22.4 \times 10^{-3} / [6.02 \times 10^{23} \times 273]$ $= \underline{1.377} \times 10^{-23}$ (J K^{-1}) $= \underline{1.38} \times 10^{-23}$ (J K^{-1}) ✓	M	evaluation to 4sf so that it shows correct conversions & subs rounded to 3sf for final answer **not** just quote the datasheet value alone for which no credit
40	(b)	(i)	$\sqrt{c^2} = \sqrt{[3NkT / m]}$ OR $\sqrt{c^2} = \sqrt{[3RT / m]}$ ✓ $= \sqrt{[3 \times 6.02 \times 10^{23} \times 1.38 \times 10^{-23} \times 300/4.0 \times 10^{-3}]}$ OR $= \sqrt{[3 \times 8.31 \times 300/4.0 \times 10^{-3}]}$ $=1.37 \times 10^3$ ✓	M M	method **Allow** in algebra or substituted numbers evaluation **accept** 1.4×10^3 (ms^{-1})
40	(b)	(ii)	Any **two** points : ✓✓ high collision frequency / $\approx 10^9$ s^{-1} OR small mean free path / $\approx 10^{-7}$ m random change in direction after collision OR random path gives slow diffusion or spread OR mean diffused distance = $\sqrt{N}\ x \approx$ few cm per minute	L M	not scent molecules more massive travel slower not sensitivity of nasal detection **Allow** diagram for full marks if clearly explained and annotated **Allow** reference to Brownian motion for one of two points
			Total	**8**	

Question			Answer	Marks	Guidance
41	(a)	(i)	Δm = [1.008665 - {1.007276+0.000549}] = 0.00084 u ✓ = 0.78(2) (MeV) ✓	L L	find mass defect in u convert to MeV
41	(a)	(ii)	"missing" energy / momentum was carried by an (anti)neutrino / a particle of tiny rest mass and zero charge ✓	M	**Allow** Energy (of beta particle) is shared with (anti)neutrino / a particle of tiny rest mass and zero charge
41	(a)	(iii)	$A = \lambda N = \ln 2 / t_{1/2} \times 10^4$ ✓ = 10 or 11 (10.7 s^{-1}) ✓	M M	Allow alternative method – e.g. calculate N remaining after 1 s (for 1 mark) and subtract from 10^4 (for second mark) evaluation do **not** penalise non-integer values
41	(a)	(iv)	d quark changes → u quark ✓	L	**Allow** udd → uud
41	(b)		stable neutrons exist in nuclei of light elements very close to $\boldsymbol{N} = \boldsymbol{Z}$ OR $\boldsymbol{N}/\boldsymbol{Z} = 1$ ✓	M	**Allow** vice-versa – e.g. unstable neutrons exist for nuclei where $\boldsymbol{N}/\boldsymbol{Z} > 1$ **Allow** worded explanation, for example with reference to concept of "neutron rich" **Allow** unstable nuclei become stable by beta emission which increases Z to become closer/equal to N Not just "they are stable"
			Total	**7**	
			Total section C **Total sections B & C**	**60** **80**	

OCR (Oxford Cambridge and RSA Examinations)
The Triangle Building
Shaftesbury Road
Cambridge
CB2 8EA

OCR Customer Contact Centre

Education and Learning
Telephone: 01223 553998
Facsimile: 01223 552627
Email: general.qualifications@ocr.org.uk

www.ocr.org.uk

Cambridge Assessment