A Level Physics A

H556/01 Modelling physics

Mark Scheme

Total marks: 100

Using this mark scheme

Mark codes used in this mark scheme:

B marks	Independent marks; awarded without reference to other marks.
M marks	Method marks; awarded for a correct method or use of a correct equation.
A marks	Accuracy marks; awarded for correct answer, but only if the corresponding M mark is awarded.
C marks	Consequential marks; awarded following on from a previous incorrect answer, provided the method remains correct.
ECF	Error carried forward. Follow through from a previous incorrect answer.
AW	Alternative wording accepted.
ORA	Or reverse argument.

Levels of Response (LoR) guidance

Questions marked with an asterisk (*) are assessed using Levels of Response marking. Award the level that best describes the overall quality of the response. Use the indicative scientific content as a guide; candidates do not need to include all points listed. Award the higher mark within a level if the response is closer to the description above it.

Section A – Multiple Choice

For each question award **1 mark** for the correct response only. If more than one option is indicated, or if the box is left blank, award **0 marks**.

Question	Answer	Question	Answer
1	B	9	C
2	B	10	B
3	B	11	B
4	B	12	A
5	D	13	C
6	A	14	B
7	B	15	A
8	B		

Total for Section A: 15 marks

Section B – Structured Questions

Question	Answer / Indicative content	Mark	AO	Guidance
(a)(i)	Curve from origin with decreasing gradient, approaching a horizontal asymptote (terminal / maximum speed).	**B1**	AO3	
	Suitable value marked on the v-axis, consistent with terminal speed $\approx 24\,\mathrm{m\,s^{-1}}$ (e.g. 24 or 25).	**B1**	AO2	
(a)(ii)	Resistive force increases with speed ($F \propto v^2$) / drag increases as speed increases.	**B1**	AO1	
	At maximum speed the resultant force along the slope is zero: component of weight down the slope equals the resistive force, so $a = 0$.	**B1**	AO3	
(a)(iii)	Component of weight down slope: $W \sin\theta = 820 \sin 4.0° \approx 57$ N.	**M1**	AO2	Allow 57 or 57.2 seen.
	Use $F = kv^2$ at terminal speed and rearrange to give $k = F/v^2$.	**M1**	AO2	
	$k = 57.2/(24)^2 = 57.2/576 \approx 0.099 \approx 0.10$.	**A1**	AO2	**ECF** on component of weight used.
(b)	Use $P = Fv$ with $F = kv^2$ so $P = kv^3$; rearrange to give $v = (P/k)^{1/3}$.	**M1**	AO2	
	Substitute $P = 320\,\mathrm{W}$ and their value of k.	**M1**	AO2	**ECF** on k.
	$v \approx 15\,\mathrm{m\,s^{-1}}$ (accept 14–17 depending on value of k used).	**A1**	AO2	
(c)	Since $P = kv^3$, speed scales as $v \propto P^{1/3}$.	**B1**	AO3	
	Therefore a 50% increase in P gives only $(1.5)^{1/3} \approx 1.14$ increase in v (approximately 14%), not 50%.	**B1**	AO3	
Total for Question 16		**12**		

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	Resultant (net) force on an object equals its rate of change of momentum / $F = \Delta p/\Delta t$ (or $F = \mathrm{d}p/\mathrm{d}t$).	**B1**	AO1	Accept equivalent wording.
(b)	Use $F = \Delta p/\Delta t$ with $\Delta t = 1$ s implied by $12\,\mathrm{kg\,s^{-1}}$.	**M1**	AO2	

Question	Answer / Indicative content	Mark	AO	Guidance
	Horizontal component of momentum changes from 12×25 to 0 (water deflected through 90°, all horizontal momentum removed).	**M1**	AO2	Only the horizontal component changes; vertical component was zero before and becomes 12×25 after – candidates may calculate the magnitude of the total change ($424\,\mathrm{N}$); award M1 only if horizontal component identified.
	$F = 12 \times 25 = 300\,\mathrm{N}$.	**A1**	AO2	
(c)	The water experiences a force from the wall that causes a change in its momentum (direction changes).	**B1**	AO3	
	By Newton's third law, the water exerts an equal and opposite force on the wall.	**B1**	AO1	
(d)	Horizontal force on water $= 300\,\mathrm{N}$ (from (b)); vertical force $= 12 \times 25 = 300\,\mathrm{N}$ (water acquires sideways momentum at $25\,\mathrm{m\,s^{-1}}$).	**M1**	AO2	
	Resultant $= \sqrt{300^2 + 300^2}$.	**M1**	AO2	
	Resultant $\approx 420\,\mathrm{N}$ (accept 424).	**A1**	AO2	**ECF** on force from (b).
Total for Question 17		**9**		

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	Loading points all plotted correctly (within half a small square of correct position).	**B1**	AO2	
	Unloading points all plotted correctly (within half a small square).	**B1**	AO2	
	Two smooth curves drawn through the respective sets of points (not straight line segments between points).	**B1**	AO2	
	Both curves clearly labelled (loading / unloading), consistent with the data in the table.	**B1**	AO2	Note: at the same force, the unloading curve shows greater extension than the loading curve.
(b)	Hooke's law does not apply over the whole range / F is not proportional to x / the loading curve is not a straight line through the origin / gradient is not constant.	**B1**	AO3	
	The loading and unloading paths are different (hysteresis occurs); energy is not fully recovered / cord shows plastic deformation / internal friction causes energy loss.	**B1**	AO3	
(c)(i)	Joule (J).	**B1**	AO1	*Reject: just the symbol J if the question asks for the name of the unit.*
(c)(ii)	The area represents the net energy dissipated (lost) per loading–unloading cycle (= difference between work done loading and work returned on unloading).	**B1**	AO3	
	Energy is converted to internal (thermal) energy in the cord due to internal friction between molecules / viscoelastic behaviour.	**B1**	AO3	
	A larger area between the curves means more energy lost per cycle / greater damping / less energy returned / better shock absorption.	**B1**	AO3	
Total for Question 18		**10**		

Question 19* (6 marks)

LEVELS OF RESPONSE MARK SCHEME Describe and discuss the observational evidence that supports the Big Bang theory, including the CMB radiation, recession of galaxies and Hubble's law.	
Level 3 (5–6 marks)	Clear and detailed discussion of both the cosmic microwave background (CMB) and galaxy recession / Hubble's law as evidence, with explanation of how each supports the Big Bang model. Line of reasoning is logically structured with a coherent narrative linking observations to the theory.
Level 2 (3–4 marks)	Some correct evidence described (e.g. CMB or recession but not both in detail), or both mentioned but the link to the Big Bang model is weak or incomplete. Reasoning has some structure but may lack clarity.
Level 1 (1–2 marks)	Limited description; may mention an expanding universe or CMB but with little detail or incorrect connection to the Big Bang model. Some attempt at structure.
0 marks	No creditworthy response.

Indicative scientific content (candidates need not include all points):

- **CMB radiation:** Uniform microwave radiation detected from all directions in space; its spectrum matches a black-body at approximately 2.7 K; this was predicted by the Big Bang theory as the remnant radiation from when the universe first became transparent ($\sim$380 000 years after the Big Bang).
- **Recession of galaxies:** Most distant galaxies show redshift in their spectra; Hubble's law ($v = H_0 d$) shows that a galaxy's recession speed is proportional to its distance; this implies the universe is expanding.
- **Link to Big Bang:** If the universe is expanding, extrapolating backwards implies it was once much smaller, denser and hotter – leading to the idea of an initial singularity / Big Bang; the CMB is the "afterglow" of when the hot, dense early universe cooled enough for atoms to form and photons to travel freely; its uniformity supports the idea of an initially uniform, dense, hot state.
- Additional evidence candidates may cite: relative abundance of hydrogen and helium consistent with Big Bang nucleosynthesis predictions; observed structure formation from density fluctuations in the CMB.

Total for Question 19: 6

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	Sum of the (random) kinetic energies of all the molecules / particles.	**B1**	AO1	
	For an ideal gas there is no intermolecular potential energy, so internal energy equals total kinetic energy.	**B1**	AO1	
(b)	Equate the two expressions: $\frac{1}{3}Nm\overline{c^2} = NkT$, giving $\frac{1}{3}m\overline{c^2} = kT$.	**M1**	AO2	
	Multiply both sides by $\frac{1}{2}$: $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$; hence average kinetic energy $\propto T$ (since k is constant).	**A1**	AO2	
(c)(i)	Use $c_{\mathrm{rms}} = \sqrt{\dfrac{280^2 + 360^2 + 410^2 + 520^2 + 600^2}{5}}$.	**M1**	AO2	
	Evaluate to give $c_{\mathrm{rms}} \approx 450\,\mathrm{m\,s^{-1}}$ (accept 440–460).	**A1**	AO2	
(c)(ii)	Use $\frac{1}{2}mc_{\mathrm{rms}}^2 = \frac{3}{2}kT$ or $c_{\mathrm{rms}}^2 = 3RT/M$.	**C1**	AO2	**ECF** on c_{rms} from (c)(i).
	Rearrange to give $M = 3RT/c_{\mathrm{rms}}^2$.	**C1**	AO2	
	$M \approx 3(8.31)(300)/(450)^2 \approx 0.037\,\text{kg mol}^{-1}$ (accept 0.035–0.040).	**A1**	AO2	
(d)	Use $p \propto T$ at constant V and n; $p_2/p_1 = T_2/T_1$.	**C1**	AO2	
	Substitute values: $p_2 = 95 \times (450/300)$.	**A1**	AO2	
	$p_2 = 143\,\mathrm{kPa}$ (accept 142–143).	**A1**	AO2	
Total for Question 20		**12**		

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	Use $\lambda_{\max} T$ = constant; apply ratio with Sun: $T_{\text{star}} = 5800 \times (500/480)$.	**M1**	AO2	
	$T \approx 6040\,\text{K}$ (accept 6000–6100).	**A1**	AO2	
(b)	Use Stefan–Boltzmann law: $L = 4\pi r^2 \sigma T^4$.	**M1**	AO1	
	Rearrange: $r = \sqrt{L/(4\pi\sigma T^4)}$.	**M1**	AO2	**ECF** on T from (a).
	Substitute $L = 6.0 \times 10^{28}$ W and $T \approx 6.0 \times 10^3$ K; $r \approx 8 \times 10^9$ m (accept answer consistent with T used; correct working required).	**A1**	AO2	
(c)	Use $I = L/(4\pi d^2)$.	**M1**	AO2	
	Rearrange: $d = \sqrt{L/(4\pi I)}$.	**M1**	AO2	
	Evaluate d in metres: $d \approx 1.8 \times 10^{18}$ m.	**A1**	AO2	**ECF** on L if candidate uses incorrect value.
	Convert to light years using $1\,\text{ly} \approx 9.46 \times 10^{15}$ m; $d \approx 190$ ly (accept 170–220 depending on rounding).	**A1**	AO2	
(d)	Any two from:			
• Uncertainty in the intensity measurement / detector calibration.	**B1**	AO3	Award one B1 per distinct, correct rea	
	• Interstellar extinction (absorption or scattering of light by dust and gas along line of sight) reduces observed intensity, so d is underestimated.	**B1**	AO3	
	• Luminosity estimate is uncertain (temperature from Wien's law has uncertainty; star may not be a perfect black body / emissivity $\neq 1$).	**B1**	AO3	
	• Assumption of isotropic emission may not hold / star may be variable.	**B1**	AO3	
(e)	Use $L = 4\pi r^2 \sigma T^4$; if T doubles, $L_{\text{new}} = 4\pi r^2 \sigma (2T)^4 = 16L$.	**M1**	AO2	
	$L_{\text{new}} = 16 \times 6.0 \times 10^{28} = 9.6 \times 10^{29}$ W (accept $\approx 10^{30}$).	**A1**	AO2	
Total for Question 21		**13**		

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	Any one of: orbital period equals 24 hours (one sidereal day); orbit is equatorial; orbits in the same direction as Earth's rotation; angular speed equals Earth's angular speed (appears stationary from Earth's surface).	**B1**	AO1	Any one correct condition.
(b)	Use $T^2 = \dfrac{4\pi^2}{GM} r^3$ (or $T = 2\pi\sqrt{r^3/GM}$).	**M1**	AO1	
	Substitute $T = 86\,400$ s, $M = 6.0 \times 10^{24}$ kg, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.	**M1**	AO2	
	$r \approx 4.2 \times 10^7$ m.	**A1**	AO2	
(c)	Apply Newton's second law to circular motion: $GMm/r^2 = mv^2/r$, giving $GMm/r = mv^2$.	**M1**	AO2	
	Hence $\frac{1}{2}mv^2 = \frac{1}{2}GMm/r = \frac{1}{2}\lvert U\rvert$ where $U = -GMm/r$, so $E_k = \frac{1}{2}\lvert E_p\rvert$.	**A1**	AO2	

(d)*   LEVELS OF RESPONSE – 6 marks

Evaluate advantages and limitations of launching satellites from aircraft compared to ground launches. Calculations must be used to support the answer.

Level 3 (5–6 marks): Correct quantitative comparison of the energies contributed by the aircraft altitude and speed (and/or Earth's rotation at equator), with a balanced evaluation of both advantages and limitations, supported by clear reasoning. Conclusions follow logically from the calculations.

Level 2 (3–4 marks): Some correct calculations and some evaluation, but either incomplete (e.g. only advantages considered) or lacking quantitative support for one aspect.

Level 1 (1–2 marks): Attempted calculation(s) with little or no evaluation, or largely descriptive points only.

0 marks: No creditworthy response.

Indicative calculations (per unit mass, using given data):

- Aircraft KE contribution: $\frac{1}{2}v^2 \approx \frac{1}{2}(230)^2 \approx 2.6 \times 10^4$ J kg^{-1}
- Aircraft GPE contribution: $gh \approx 9.81 \times 10^4 \approx 9.8 \times 10^4$ J k
- Rotational KE from equator: $\frac{1}{2}(460)^2 \approx 1.1 \times 10^5$ J kg^{-1}.
- Required orbital energy scale $\sim 3 \times 10^7$ J kg^{-1}: the aircra orbital energy required, so the benefit is small but not neglig

Indicative evaluation points:

Advantages: aircraft KE and altitude both reduce fuel requirement; can launch from closer to equator regardless of ground facilities; avoids dense lower atmosphere (less drag during initial ascent); more flexible launch direction (azimuth).

Limitations: aircraft payload capacity limits satellite mass; logistically complex and expensive; aircraft speed and altitude contribute only a small fraction of orbital energy, so savings are modest; safety and regulatory challenges.

Total for Question 22	**12**		

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	$\Delta E = (-0.58 - (-5.42)) \times 10^{-19} = 4.84 \times 10^{-19}$ J.	**M1**	AO2	Use levels X (-0.58) and Y (-5.42).
	$\lambda = hc/\Delta E \approx (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(4.84 \times 10^{-19}) \approx 4.11 \times 10^{-7}$ m $\approx 410\,\text{nm}$.	**A1**	AO2	**ECF** on ΔE.
(b)(i)	Photons of specific energies (matching the energy gap between levels) are absorbed by atoms in the stellar atmosphere, causing electrons to be excited to higher energy levels.	**B1**	AO1	
	Absorption occurs in the cooler gas in the outer atmosphere (or interstellar medium) along the line of sight to the observer.	**B1**	AO1	
(b)(ii)	Use $\Delta\lambda/\lambda \approx v/c$; $\Delta\lambda = 435 - 410 = 25$ nm (or candidate's λ_0).	**M1**	AO2	**ECF** on λ_0 from (a).
	$v \approx (25/410) \times 3.00 \times 10^{8} \approx 1.8 \times 10^{7}\,\text{m s}^{-1}$ (accept consistent **ECF** with candidate's λ_0).	**A1**	AO2	
(b)(iii)	Big Bang model / expanding universe / Hubble's law (as supporting evidence for Big Bang cosmology).	**B1**	AO1	
(b)(iv)	Use $d = v/H_0$; $d = 1.8 \times 10^{7}/2.2 \times 10^{-18}$.	**M1**	AO2	**ECF** on v from (b)(ii).
	$d \approx 8.2 \times 10^{24}$ m (accept $\approx 8 \times 10^{24}$).	**A1**	AO2	
(c)	Cosmic microwave background (CMB) radiation.	**B1**	AO1	Accept "microwave background radiation from all directions."
(d)	The CMB is uniform microwave radiation from all directions, consistent with the remnant heat from the very hot early universe predicted by the Big Bang model / its spectrum matches a black body at ∼2.7 K as predicted.	**B1**	AO3	
Total for Question 23		**11**		

TOTAL FOR PAPER: 100 MARKS