Pearson
Edexcel

Mark Scheme (Results)

Summer 2025

Pearson Edexcel Level 3 Advanced GCE
In Physics (9PH0)
Paper 02: Advanced Physics II

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General Marking Guidance

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.

Mark scheme notes

Underlying principle

The mark scheme will clearly indicate the concept that is being rewarded, backed up by examples. **It is not a set of model answers.**

1. Mark scheme format

1.1 You will not see 'wtte' (words to that effect). Alternative correct wording should be credited in every answer unless the MS has specified specific words that must be present. Such words will be indicated by underlining e.g. 'resonance'

1.2 Bold lower case will be used for emphasis e.g. '**and**' when two pieces of information are needed for 1 mark.

1.3 Round brackets ( ) indicate words that are not essential e.g. "(hence) distance is increased".

1.4 Square brackets [ ] indicate advice to examiners or examples e.g. [Do not accept gravity] [ecf].

2. Unit error penalties

2.1 A separate mark is not usually given for a unit but a missing or incorrect unit will normally mean that the final calculation mark will not be awarded.

2.2 This does not apply in 'show that' questions or in any other question where the units to be used have been given, for example in a spreadsheet.

2.3 The mark will not be awarded for the same missing or incorrect unit only once within one clip in epen.

2.4 Occasionally, it may be decided not to insist on a unit e.g the candidate may be calculating the gradient of a graph, resulting in a unit that is not one that should be known and is complex.

2.5 The mark scheme will indicate if no unit error is to be applied by placing brackets around the unit.

3. Significant figures

3.1 Use of too many significant figures in the theory questions will not prevent a mark being awarded if the answer given rounds to the answer in the MS.

3.2 Too few significant figures will mean that the final mark cannot be awarded in 'show that' questions where one more significant figure than the value in the question is needed for the candidate to demonstrate the validity of the given answer.

3.3 The use of one significant figure might be inappropriate in the context of the question e.g. reading a value off a graph. If this is the case, there will be a clear indication in the MS.

3.4 The use of g = 10 m s^{-2} or 10 N kg^{-1} instead of 9.81 m s^{-2} or 9.81 N kg^{-1} will be penalised by one mark (but not more than once per clip). Accept 9.8 m s^{-2} or 9.8 N kg^{-1}

3.5 In questions assessing practical skills, a specific number of significant figures will be required e.g. determining a constant from the gradient of a graph or in uncertainty calculations. The MS will clearly identify the number of significant figures required.

4. Calculations

4.1 **use of** the formula means that the candidate demonstrates substitution of physically correct values, although there may be conversion errors e.g. power of 10 error.

4.2 If a 'show that' question is worth 2 marks, then both marks will be available for a reverse working. If the question is worth 3 marks then only 2 marks will be available.

4.3 The mark scheme will show a correctly worked answer for illustration only.

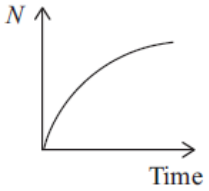
5. Quality of Written Expression

5.1 Questions that asses the ability to show a coherent and logically structured answer are marked with an asterisk.

5.2 Marks are awarded for indicative content and for how the answer is structured.

5.3 Linkage between ideas, and fully-sustained reasoning is expected.

Question Number	Answer	Mark
1	**The only correct answer is B,** kg m s^{-2} A is not correct because these are the base units of force C is not correct because N is not a base unit D is not correct because Pa is not a base unit	1
2	**The only correct answer is C,** photoelectric effect A is not correct because this is a wave effect B is not correct because this is a wave effect D is not correct because this is a wave effect	1
3	**The only correct answer is B,** when v is greater than c, then no light is transmitted. A is not correct because all light is reflected C is not correct because some light is reflected D is not correct because some light is transmitted	1
4	**The only correct answer is A,** a closed universe because a closed universe reaches a maximum size and then contracts B is not correct because scientists do not define a 'critical universe' C is not correct because a flat universe reaches a maximum size D is not correct because an open universe keeps expanding forever	1
5	**The only correct answer is C,** Y is twice as far away as X. A is not correct because $I = \frac{L}{4\pi x^2}$ and L is the same for each star B is not correct because $I = \frac{L}{4\pi x^2}$ and L is the same for each star D is not correct because $I = \frac{L}{4\pi x^2}$ and L is the same for each star	1
6	**The only correct answer is B,** E_k is a maximum **and** E_p is a maximum A is not correct because E_p is a maximum when displacement is a maximum C is not correct because E_k is a maximum at the equilibrium position D is not correct because E_k is a maximum at the equilibrium position, and E_p is a maximum when displacement is a maximum	1

7	**The only correct answer is C,** viscosity of liquid decreases **and** terminal velocity of ball bearing increases A is not correct because viscosity decreases with increasing temperature B is not correct because viscosity decreases with increasing temperature D is not correct because terminal velocity increases when the viscosity decreases	1
8	**The only correct answer is B**  A is not correct because the number of lead atoms increases over time C is not correct because the number of lead atoms must increase at a decreasing rate D is not correct because the number of lead atoms increases over time	**1**
9	**The only correct answer is C,** rotation of P_1 is $\pi/2$ rad and rotation of P_2 is π rad A is not correct because this has a net rotation of the filters of 45° B is not correct because this has a net rotation of the filters of 135° D is not correct because this has a net rotation of the filters of 180°	**1**
10	**The only correct answer is A,** X leads Y by 90° B is not correct because X reaches a maximum displacement a quarter of a cycle ahead of Y C is not correct because X reaches a maximum displacement a quarter of a cycle ahead of Y D is not correct because X reaches a maximum displacement a quarter of a cycle ahead of Y	**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
11	• Use of $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$ **(1)** • $v = (-)\ 1.8 \times 10^5\ \text{m s}^{-1}$ **(1)** • Towards the Earth (dependent upon correct numerator in Doppler equation) **(1)**	Example of calculation $\frac{(655.88 - 656.28)\ \text{nm}}{656.28\ \text{nm}} \approx \frac{v}{3.0 \times 10^8\ \text{m s}^{-1}}$ $v = \frac{(-)0.4\ \text{nm}}{656.28\ \text{nm}} \times 3.0 \times 10^8\ \text{m s}^{-1} = -1.83 \times 10^5\ \text{m s}^{-1}$	**3**

(Total for Question 11 = 3 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
12	• Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$, with $n_1 = 1$ and $\theta_1 = 45$ **(1)** • Use of $n = \frac{c}{v}$ **(1)** • Ratio of speeds = 0.69 Or angle for red light = 22.2° **(1)** • 0.69 is less than 0.99, so angle is not accurate. **Or** 22.2° is less than 33 degrees, so angle is not accurate. **Or** Comparison of calculated value with value in question and consistent conclusion **(1)**	Example of calculation $n = \frac{c}{v}$, so $\frac{n_{\text{red}}}{n_{\text{violet}}} = \frac{v_{\text{violet}}}{v_{\text{red}}} = 0.99$ $n_{\text{air}} \sin 45^{\text{o}} = n_{\text{violet}} \sin 22^{\text{o}}$ $n_{\text{air}} \sin 45^{\text{o}} = n_{\text{violet}} \sin(22^{\text{o}} + 11^{\text{o}})$ $n_{\text{red}} \sin 33^{\text{o}} = n_{violet} \sin 22^{\text{o}}$ $\frac{n_{\text{red}}}{n_{\text{violet}}} = \frac{\sin 22^{\text{o}}}{\sin 33^{\text{o}}} = 0.688$ For MP4 allow a conclusion based on candidate's calculated value of refractive index ratio [Alternative method: Use sin 45° / sin 22° to calculate n_{violet} 1.89 Using ratio of velocities = 0.99, n_{red} 1.87 Then calculated angle for red = 22.2° The red and violet lines would be very close together as the angular dispersion is negligible so diagram is incorrect" If students use this method and round to 2 sf then they will just get the angle for violet 22° ie same as red]	**4**

(Total for Question 12 = 4 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
13	An explanation that makes reference to the following points: • Work function is the minimum (photon) energy for an electron to be emitted **Or** For an electron to be emitted, the frequency must be above a (minimum) value **Or** For an electron to be emitted, the wavelength must be below a (maximum) value **Or** At the threshold for emission kinetic energy of electrons is zero **(1)** • Use of $c = f\lambda$ **(1)** • Use of $E = hf$ **(1)** • Conversion between eV and J **(1)** • Comparison of λ / f / E for visible light with value for threshold case **and c**omparison of λ / f / E for UV radiation with value for threshold **(1)**	<u>Example of calculation</u> $\phi = 3.74 \times 1.6 \times 10^{-19}\ \text{J} = 5.98 \times 10^{-19}\ \text{J}$ $f_0 = \dfrac{5.98 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 9.03 \times 10^{14}\ \text{Hz}$ $\lambda_{\text{max}} = \dfrac{3.00 \times 10^{8}\ \text{m s}^{-1}}{9.03 \times 10^{14}\ \text{s}^{-1}} = 3.32 \times 10^{-7}\ \text{m} = 332\ \text{nm}$ Visible light wavelength is 420 nm > 332 nm and UV radiation wavelength is 320 nm < 332 nm $\phi = 3.74 \times 1.6 \times 10^{-19}\ \text{J} = 5.98 \times 10^{-19}\ \text{J}$ $f_0 = \dfrac{5.98 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 9.03 \times 10^{14}\ \text{Hz}$ Visible light, $f = \frac{3.00\times10^{8}\ \text{m s}^{-1}}{4.2\times10^{-7}\text{m}} = 7.14 \times 10^{14}\ \text{Hz}$ $7.14 \times 10^{14}\ \text{Hz} < 9.03 \times 10^{14}\ \text{Hz}$ UV radiation, $f = \frac{3.00\times10^{8}\ \text{m s}^{-1}}{3.2\times10^{-7}\text{m}} = 9.38 \times 10^{14}\ \text{Hz}$ $9.38 \times 10^{14}\ \text{Hz} > 9.03 \times 10^{14}\ \text{Hz}$ Visible light $f = \dfrac{3.00 \times 10^{8}\ \text{m s}^{-1}}{4.2 \times 10^{-7}\text{m}} = 7.14 \times 10^{14}\ \text{Hz}$ $E = hf_0 = 6.63 \times 10^{-34}\ \text{J s} \times 7.14 \times 10^{14}\ \text{Hz}$ $E = 4.73 \times 10^{-19}\ \text{J}$ $E = \frac{4.73\times10^{-19}}{1.6\times10^{-19}\ \text{J}} = 2.96\ \text{eV} < 3.74\ \text{eV}$ UV radiation $, f = \dfrac{3.00 \times 10^{8}\ \text{m s}^{-1}}{3.2 \times 10^{-7}\text{m}} = 9.38 \times 10^{14}\ \text{Hz}$ $E = hf_0 = 6.63 \times 10^{-34}\ \text{J s} \times 9.38 \times 10^{14}\ \text{Hz}$ $E = 6.22 \times 10^{-19}\ \text{J}$ $E = \frac{6.22\times10^{-19}}{1.6\times10^{-19}\ \text{J}} = 3.89\ \text{eV} > 3.74\ \text{eV}$	**5**

(Total for Question 13 = 5 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*14</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning.
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
Indicative content:
IC1 (Average) distance travelled by molecules between collisions with piston/walls decreases
Or Time between collisions between molecules and the piston/walls decreases

IC2 Rate/frequency of collision of molecules with piston/walls increases

IC3 (Mean) velocity (of molecules) stays constant
Or change in momentum per collision stays constant

IC4 Rate of change of momentum (during collisions with piston) increases

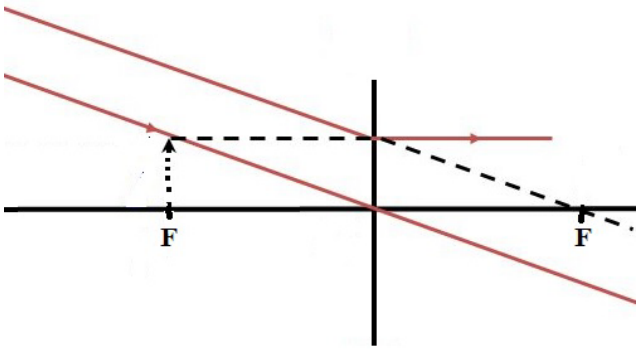
IC5 Force on piston/walls increases

IC6 $p = F/A$ so pressure exerted (by gas) increases
</td>
<td>
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
<table>
<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

(Total for Question 14 = 6 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
15(a)	• Conversion from eV to J **(1)** • Use of $E = hf$ **(1)** • Use of $c = f\lambda$ **(1)** • $\lambda = 6.2 \times 10^{-20}$ m **(1)**	Example of calculation $E = 2.0 \times 10^{13}\ \text{eV} \times 1.60 \times 10^{-19}\ \text{J eV}^{-1} = 3.2 \times 10^{-6}\ \text{J}$ $3.2 \times 10^{-6}\ \text{J} = 6.63 \times 10^{-34}\ \text{J s} \times f$ $f = \frac{3.2 \times 10^{-6}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 4.83 \times 10^{27}\ \text{Hz}$ $\lambda = \frac{3.0 \times 10^{8}\ \text{m s}^{-1}}{4.83 \times 10^{27}\ \text{Hz}} = 6.22 \times 10^{-20}\ \text{m}$	**4**
15(b)	• The speed of the pulsar is negligible compared with the speed of light **(1)**	Attempt at calculation may result in this conclusion and so should gain mark Accept idea of speed being much smaller Accept comment that red shift is negligible/very small, if based on a calculation	**1**

(Total for Question 15 = 5 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
16(a)	• Virtual **(1)**		**1**
16(b)	• Use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ **(1)** • Use of $P=\frac{1}{f}$ **(1)** • $P = 2.5$ (D) **(1)**	Ignore use of sign convention for MP1 and MP2 Example of calculation $\frac{1}{0.25\text{ m}}+\frac{1}{-0.65\text{ m}}=\frac{1}{f}$ $\therefore \frac{1}{f}=4.00-1.54=2.46\text{ m}^{-1}$ $\therefore P = 2.46$ D	**3**
16(c)	• One correct ray drawn **(1)** • Two correct rays drawn for a distant object **(1)** • Image upright and on same side of lens as object **(1)**	Accept diagram with rays drawn parallel to principal axis for MP1 and MP2 	**3**

(Total for Question 16 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
17(a)(i)	• Use of $V = \frac{4}{3}\pi r^3$ **(1)** • Use of $\rho = \frac{m}{V}$ **(1)** • $m = 7.76 \times 10^{10}$ (kg) **(1)**	Example of calculation $V = \frac{4}{3}\pi(245\text{ m})^3 = 6.16 \times 10^7\text{ m}^3$ $1.26 \times 10^3\text{ kg m}^{-3} = \frac{m}{6.16 \times 10^7\text{ m}^3}$ $m = 1.26 \times 10^3\text{ kg m}^{-3} \times 6.16 \times 10^7\text{ m}^3$ $\therefore m = 7.76 \times 10^{10}\text{ kg}$	**3**
17(a)(ii)	• Use of $F = \frac{Gm_1m_2}{r^2}$ **(1)** • $F = 5.5 \times 10^7$ N (ecf m from (a)(i)) **(1)**	Example of calculation $F = \frac{6.67 \times 10^{-11}\text{ N m}^2\text{ kg}^{-2} \times 5.98 \times 10^{24}\text{ kg} \times 7.76 \times 10^{10}\text{ kg}}{(7.49 \times 10^8\text{ m})^2}$ $\therefore F = 5.53 \times 10^7\text{ N}$	**2**
17(b)	• Use of $T = \frac{2\pi}{\omega}$ **Or** use of $v = \frac{2\pi r}{T}$ **(1)** • Use of $F = m\omega^2 r$ **Or** Use of $F = \frac{mv^2}{r}$ **(1)** • Use of $F = \frac{Gm_1m_2}{r^2}$ **(1)** • $M = 2.1 \times 10^{30}$ kg **(1)**	Example of calculation $\omega = \frac{2\pi}{T} = \frac{2\pi\text{ rad}}{1.17 \times 3.15 \times 10^7\text{ s}} = 1.70 \times 10^{-7}\text{ rad s}^{-1}$ $F = m\omega^2 r = 7.8 \times 10^{10}\text{ kg} \times (1.70 \times 10^{-7}\text{ rad s}^{-1})^2 \times 1.70 \times 10^{11}\text{ m}$ $\therefore F = 3.83 \times 10^8\text{ N}$ $M = \frac{Fr^2}{Gm} = \frac{3.83 \times 10^8\text{ N} \times (1.70 \times 10^{11}\text{ m})^2}{6.67 \times 10^{-11}\text{ N m}^2\text{ kg}^{-2} \times 7.8 \times 10^{10}\text{ kg}}$ $\therefore M = 2.14 \times 10^{30}\text{ kg}$	**4**

(Total for Question 17 = 9 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
18(a)	• Top line correct **(1)** • Bottom line correct **(1)**	Example of equation $^{137}_{55}\text{Cs} \rightarrow {}^{137}_{56}\text{Ba} + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\bar{\nu}_{e}$	**2**
18(b)(i)	• Use of $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ **(1)** • Use of $A = -\lambda N$ **(1)** • $N = \frac{2.5 \times 10^4 \text{ Bq}}{7.30 \times 10^{-10} \text{ s}^{-1}} = 3.4 \times 10^{13}$ **(1)**	Example of calculation $\lambda = \frac{\ln 2}{9.5 \times 10^8 \text{ s}} = 7.30 \times 10^{-10} \text{ s}^{-1}$ $N = \frac{2.5 \times 10^4 \text{ Bq}}{7.30 \times 10^{-10} \text{ s}^{-1}} = 3.42 \times 10^{13}$	**3**
18(b)(ii)	• Use of $N = N_0 e^{-\lambda t}$ **(1)** • $t = 1.4 \times 10^8$ s **(1)** (ecf λ from (b)(i))	Example of calculation $0.9\ \text{N}_0 = \text{N}_0 \text{e}^{-7.30 \times 10^{-10} \text{ s}^{-1} \times t}$ $\therefore t = \frac{\ln 0.9}{-7.30 \times 10^{-10} \text{ s}^{-1}} = 1.44 \times 10^8 \text{ s}$	**2**

(Total for Question 18 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
19(a)	• Use of $\rho = \frac{m}{V}$ **and** volume of a cuboid **(1)** • $m = 2.21 \times 10^5$ (kg) **(1)**	Example of calculation $V = 25.0\text{ m} \times 3.10\text{ m} \times 3.10\text{ m} = 240\text{ m}^3$ $m = 920\text{ kg m}^{-3} \times 240\text{ m}^3 = 2.21 \times 10^5\text{ kg}$	**2**
19(b)(i)	• Use of $I = \frac{P}{A}$ **(1)** • Use of $E = mL$ • Use of $E = mc\Delta\theta$ **(1)** • Use of 1% **(1)** • Use of $P = \frac{W}{t}$ **(1)** • Energy needed (8.3 x 10^8 J) is greater than energy arriving (5.6 x 10^8 J), so claim is incorrect. (ecf for mass from (a)) **Or** t = 18 hours > 12 hours, so claim is incorrect **(1)**	Example of calculation $P = 1350\text{ W m}^{-2} \times (3.1\text{ m})^2 = 13\,000\text{ W}$ $E = 0.01 \times 2.21 \times 10^5$ $\times\ 2.09 \times 10^3\text{ J kg}^{-1}\text{K}^{-1} \times 20K = 9.24 \times 10^7\text{J}$ $E = 0.01 \times 2.21 \times 10^5\text{ kg} \times 3.34 \times 10^5\text{ J kg}^{-1}$ $= 7.38 \times 10^8\text{J}$ $Etotal = 8.31 \times 10^8\text{ J}$ $t = \frac{8.31 \times 10^8\text{ J}}{13\,000\text{ W}} = 6.39 \times 10^4\text{ s}$ $t = \frac{6.39 \times 10^4\text{ s}}{3600\text{ s hour}^{-1}} = 18\text{ hours}$ For MP6 allow their value compared to the reference value.	**6**
19(b)(ii)	**MAX 2** • Energy will transfer to the ice sculpture from the surroundings **(1)** • Radiation from the sun is not continuously incident on the statue **(1)** • The Sun will not always be directly overhead **(1)** • Some incident radiation will be reflected **(1)**	Accept the model is idealised, as sculpture is not cuboid	**2**

(Total for Question 19 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
20(a)	• Use of $W = mg$ **(1)** • Use of $A = \pi r^2$ **(1)** • Use of $\sigma = \frac{F}{A}$ **(1)** • Use of 16 **(1)** • $\sigma = 4.1 \times 10^7$ Pa **(1)**	Example of calculation $W = 3.0 \times 10^8 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 2.94 \times 10^9 \text{ N}$ $F = \frac{2.94 \times 10^9 \text{ N}}{16} = 1.84 \times 10^8 \text{ N}$ $A = \pi \times (1.2 \text{ m})^2 = 4.52 \text{ m}^2$ $\sigma = \frac{1.84 \times 10^8 \text{ N}}{4.52 \text{ m}^2} = 4.07 \times 10^7 \text{ Pa}$	**5**
20(b)(i)	• Use of $\omega = 2\pi f$ **(1)** • Use of $v = (-)A\omega \sin \omega t$ **(1)** • $v = (-)0.96 \text{ m s}^{-1}$ **(1)**	Allow $(-)0.48 \text{ m s}^{-1}$ if *A/2* used Example of calculation Use of $\omega = 2\pi \times 0.17 \text{ Hz} = 1.07 \text{ rad s}^{-1}$ Use of $v = (-)\ 0.9 \text{ m} \times 1.07 \text{ rad s}^{-1} \times 1 = 0.961 \text{ m s}^{-1}$	**3**
20(b)(ii)	**MAX 3** • There is a maximum displacement for each tower when forced into oscillation at its natural frequency **(1)** • This is an example of resonance **(1)** • The linked towers have a reduced displacement at (a lower) natural frequency **(1)** • There is (more) damping when the towers are linked **(1)**		**3**

(Total for Question 20 = 11 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
21(a)	• The temperature at which the (mean) molecular kinetic energy is zero **(1)**	Accept The lowest temperature possible	**1**
21(b)	An explanation that makes reference to the following points: • The peak of the curve is higher **(1)** • The rate at which energy is radiated is proportional to temperature to the power of 4. **(1)** • The peak of the curve is displaced to the left **(1)** • The wavelength at which maximum rate of energy radiated occurs is inversely proportional to the temperature **(1)**	MP1 and MP3 allow correct sketch on graph MP2 allow reference to Stefan's law MP4 allow reference to Wien's law	**4**
21(c)	• Use of $\lambda_{\max}T$ with data for one star **(1)** • Use of $\lambda_{\max}T$ with data for all three stars **(1)** • Statement that values are similar/constant for each star AND comparison with Wein's Law constant **(1)**	<u>Example of calculation</u> $\lambda_{\max}T = 132\ \text{nm} \times 21500\ \text{K} = 2.838 \times 10^6\ \text{nm K}$ $\lambda_{\max}T = 245\ \text{nm} \times 11600\ \text{K} = 2.842 \times 10^6\ \text{nm K}$ $\lambda_{\max}T = 287\ \text{nm} \times 9940\ \text{K} = 2.844 \times 10^6\ \text{nm K}$	**3**

21(d)	• Use of $L = 4\pi r^2 \sigma T^4$ **(1)** • Luminosity and temperature of Sirius A read from graph **(1)** • Use of Luminosity of Sirius A with luminosity of the Sun. **(1)** • $\frac{r_{Sirius\ A}}{r_{Sun}} = 1.84$ **Or** r $= 1.28 \times 10^9$ m **(1)** • Comparison between candidate's ratio and given ratio with valid conclusion **Or** Comparison between $2 \times r_{Sirius}$ *and* r_{Sun} with a valid conclusion **(1)**	Example of calculation $L = 4\pi(6.96 \times 10^8 \text{m})^2 \times 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4} \times (5800)^4$ $\therefore L = 3.91 \times 10^{26}$ W Luminosity of Sirius = 30 L_{Sun} **and** T = 10 000 K $r = \sqrt{\dfrac{30 \times 3.91 \times 10^{26}\ \text{W}}{4\pi \times 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4} \times (10\,000\ \text{K})^4}}$ $\therefore r = 1.28 \times 10^9$ m $\frac{r_{Sirius\ A}}{r_{Sun}} = \frac{1.28 \times 10^9\ \text{m}}{6.96 \times 10^8 \text{m}} = 1.84$ $1.84 \approx 2$, therefore claim is correct	**5**

(Total for Question 21 = 13 marks)

TOTAL FOR PAPER = 90 MARKS

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