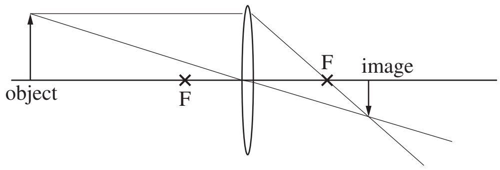
Answers to examination-style questions

Answers	Marks	Examiner's tips
1 (a) (i) For red light, $f = 0.98$ m $P = \frac{1}{f} = \frac{1}{0.98} = 1.02$ dioptres	1 1	Although this is a fairly straightforward calculation, it contains two aspects which caused many students to fail to get full marks. Choosing the right focal length requires an understanding that 'blue bends best', that is, that the shorter focal length is for blue (or violet) light, and therefore the longer (0.98m) is for red light. The formula for power is relatively easy, but, for full marks, the correct unit for power had to be given.
(ii) Chromatic aberration	1	Chromatic aberration occurs because a lens can act like a prism, splitting white light into its colours. The hint here is the word 'chromatic' – related to colour.
(b) Use of $M = \frac{\theta'}{\theta}$ $\theta' = \frac{30 \times 4.2 \times 10^5}{6 \times 10^8}$ $= 0.021$ rad	1 1	This is effectively a two step calculation. You need to work out the angular separation of Io and Jupiter without the telescope – this is found from dividing their distance apart by how far away they are. When you use the telescope the distance gets magnified – by a factor of 30 in this case. This is how the answer is obtained. Notice that the angular separation still needs a unit – the radian (or rad). This is the standard unit of angle used in A level Physics.
(c) Use of $M = \frac{f_o}{f_e}$ $f_e = \frac{0.95}{30} = 0.032$ length $= f_o + f_e = 0.98$ m	1 1	'In normal adjustment' just means 'with the image at infinity'. This is the standard set up for the specification. The ray diagram for the telescope needs to be learned. From that you get the idea that the separation of the lenses is the sum of the focal lengths ($f_o + f_e$), and the magnification is their ratio, $\frac{f_o}{f_e}$. Putting these two ideas together gives the answer.

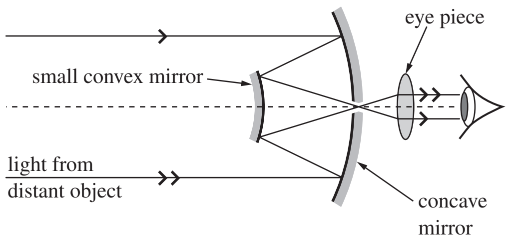
Answers to examination-style questions

Answers	Marks	Examiner's tips
2 (a) Ray parallel to principal axis through labelled principal focus	1	If the labels were missing, only 1 mark would have been awarded.
Ray through centre of lens to form diminished image	1	When drawing ray diagrams it is important to use a ruler and to make your labels clear. It is also helpful to include the direction of the rays. There are three possible rays which could be drawn – only two are needed however. Most commonly the ones drawn are: a ray entering the lens parallel to the principal axis passes through the principal focus; a ray travelling through the centre of the lens travels in a straight line. The image is found where these two cross, and is drawn from that point to the principal axis.
(b) (i) $\frac{1}{f} = 12.5$	1	This is a two stage question. The focal length of the lens is found from the power. This is then used in the lens formula. A problem encountered by using the lens formula is associated with the 'sign' of any distances. In this specification there is only one rule to follow – the distance is negative to a virtual image. In this example the image is real. This can be seen from the ray diagram, and from the fact that the answer is positive. Many candidates lost a mark because they failed to invert their final answer – that is, to change $\frac{1}{v}$ (9.64) into v (0.10 m)
Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ gives $12.5 = \frac{1}{0.35} + \frac{1}{v}$	1	
$\frac{1}{v} = 9.64$		
$v = 0.10(4)$ m	1	
(ii) diminished, inverted, real	1	There are three properties of an image – and each one has two alternatives. These are: real/virtual; magnified/diminished; upright/inverted. The question is not asking for properties like position or colour.



Answers to examination-style questions

Answers	Marks	Examiner's tips
3 (a) concave primary mirror convex secondary two correct rays	1 1 1	There are two optical telescope ray diagrams which need to be learned – the refracting telescope, and this one. The curvature of the mirrors causes the biggest problem for many students. The objective is concave and the secondary is convex. The secondary should not be draw as a plane mirror – and it is definitely wrong if drawn concave. The problem with the objective is more subtle. It should look like one continuous mirror, with a gap in the middle. It is quite commonly drawn as two separate concave mirrors.



Answers	Marks	Examiner's tips
(b) (i) Use of $\theta = \frac{\lambda}{d}$ = gives $\theta = \frac{570 \times 10^{-9}}{0.356} = 1.6 \times 10^{-6}$ rad	1	Problems with resolving power are often related to the use of powers – remembering that nm means 10^{-9} metres, and the unit. It is quite common to see 'watt' as the unit here, which is an obvious misunderstanding, rather than radians.
(ii) The size of the pixels	1	In the past, the CCD has often been tested in a whole question. This aspect of the operation of a CCD requires an understanding of both the structure of the CCD and what is meant by resolution. Each pixel of the CCD adds up the photons hitting it (it accumulates charge) over its whole area. Therefore the smaller the pixel, the greater the resolution (that is, the more detail which can be seen).
(iii) The ratio of the number of photons falling on a device that produce a signal to the total number of photons falling on the device	1	There are several definitions which need to be learned in this specification. This is just one of them. The most common error is caused when students miss out the last four words – i.e. they do not make it clear that it is the fraction of those photons falling on the device.

Answers to examination-style questions

Answers	Marks	Examiner's tips
4 **(a)** • Hydrogen (in atmosphere of star) has electrons in $n = 2$ state. • Light of particular frequencies (from star passing through atmosphere) is absorbed … corresponding to energy differences between orbits ($E = hf$). • When electrons return to lower energy states, energy released in all directions so reduced intensity in original direction (or lower frequencies emitted as electrons can return to lower states in steps) … producing gaps in spectra.	**max 4**	This is one of the few occasions where there is a significant overlap between the core content and the option. The need for the $n=2$ state is so that the spectrum is visible. There are several parts to the hydrogen spectrum but only the Balmer series needs to be understood for this option. It is also important to see that this is an absorption spectrum – that is, the whole spectrum is seen with gaps in it, corresponding to the Balmer series. It is quite common to answer in terms of the emission spectrum and so miss several marks. The reference to 'passing through the atmosphere' can be confusing. The answer is actually referring to the atmosphere of the star. There are five marking points here – you only need four for all four marks to be awarded. It is worth writing out the full answer however.
(b) **(i)** Temperature too low for hydrogen to have electrons in $n=2$ state	**1**	In order for hydrogen atoms to have electrons in the $n=2$ state (i.e. not in the ground state) the hydrogen needs to be 'energised'. This means the atmosphere of the star needs to be hot. F and G are much cooler stars than A or B.
(ii) (Ionized) metal absorption lines	**1**	The specification contains a lot of detail about spectral classes. This should be learned.

Answers to examination-style questions

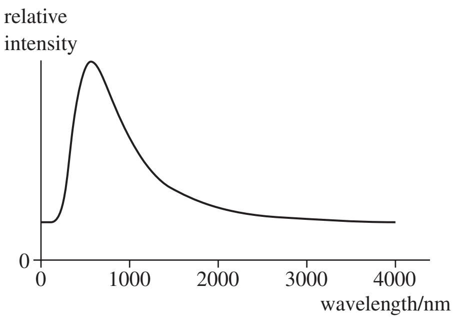
Answers | **Marks** | **Examiner's tips**

5 (a) (i) $\lambda_{max} = \dfrac{0.0029}{3500}$

$= 8.3 \times 10^{-7}$ m — **1**

(ii) Graph with correct shape wavelength axis labelled — **1**

with peak near 8×10^{-7} m. — **1**



Examiner's tips: This equation is unusual in that the constant is given in the specification rather than in the data list. Many students and teachers fail to recognise that the 'm' in the unit of the constant (0.0029 m K) refers to 'metres' rather than 'milli'. This means that they include an unnecessary factor of 0.001 in their answer.

The value of the temperature is now used to help label the temperature scale. The calculated value in **(i)** shows the position of the peak in the curve, rather than the largest value of wavelength. The shape of the curve is similar no matter what temperature is chosen – the line should be steeper on the left hand side.

(b) Use of $m - M = 5 \log \dfrac{d}{10}$ — **1**

$4.23 - (-6.81) = 5 \log \dfrac{d}{10}$ — **1**

$d = 1614$ pc $= 5.26 \times 10^3$ lyr.

Examiner's tips: This calculation is not straightforward and should be done in steps – with each step written down. This means that if a small mistake is made in any single step the error can be identified and carried forward so that the other marks can still be obtained. The log referred to in the equation is 'base 10'. It is important to know the difference between this and the '$\log_e$' or 'ln' button on a calculator. This problem requires the use of the antilog – sometimes shown as 10^x. The value obtained in the equation is in pc, and must be converted to light year.

(c) Use of $P = \sigma A T^4$ and $A = \pi r^2$ — **1**

$\dfrac{P_m}{P_s} = \dfrac{\sigma A_m T_m^{\ 4}}{\sigma A_s T_s^{\ 4}}$

$= \dfrac{r_m^{\ 2} T_m^{\ 4}}{r_s^{\ 2} T_s^{\ 4}}$ — **1**

$= 401\,000$

or:

$P = \sigma A T^4$ and $A = \pi r^2$

$P_s = \sigma A_s T_s^{\ 4}$

$= 5.67 \times 10^{-8} \times 2\pi(6.9 \times 10^8)^2\ (5800)^4$ — **1**

$= 1.8 \times 10^{26}$ (W)

$P_m = \sigma A_m T_m^{\ 4}$

$= 5.67 \times 10^{-8} \times 2\pi(1.2 \times 10^{12})^2\ (3500)^4$

$= 7.7 \times 10^{31}$ (W)

$\dfrac{P_m}{P_s} = \dfrac{7.7 \times 10^{31}}{1.8 \times 10^{26}}$ — **1**

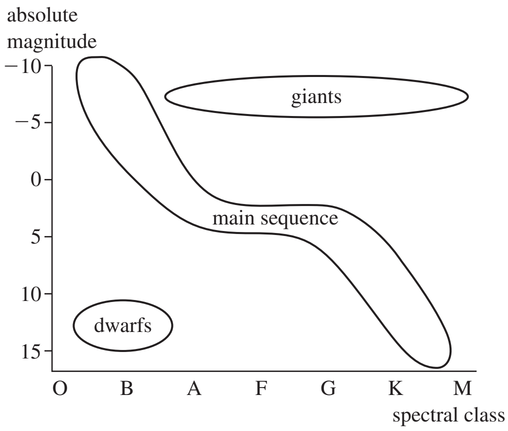
$= 430\,000$

Examiner's tips: The relationship between the power output of a star and its surface area has often been tested in this option in the past. It is important to make sure that the correct constant is chosen from the list on the data sheet. Notice there are two routes to the answer – choose whichever one you find more straightforward. The difference in the two answers is due to rounding errors. Both parts **(b)** an **(c)** of this question are quite difficult and should be studied carefully if you are thinking of obtaining a high grade on this paper.

Answers to examination-style questions

Answers	Marks	Examiner's tips
6 (a) (i) White dwarf: • relatively hot (therefore white) • but relatively dim (therefore small) star.	1 1	There are several astronomical objects which are on the specification. The properties asked for are related to the objects themselves rather than how they got to be there. In this case a white dwarf is hot and dim – both properties which can be remotely measured. Answers related to their formation – such as the core of a much larger star – would not gain credit. Similarly restating the properties in the question – for example, 'small' – would not gain the mark.
(ii) Quasar: • very large power output • large red shift therefore very distant • relatively small for power output.	1 1 1	The quasar properties are a little more controversial. Stating that it has a large red shift and is very distant gains only one mark as the first statement is a measurable property and the second is an inference from that property.
(b) (i) $0.366 = \frac{v}{c}$ $v = 0.366 \times 3 \times 10^8$ $= 1.1 \times 10^8\ \text{m s}^{-1}$.	1	The calculation of the recessional speed from the red shift is very straightforward. Careless errors can often be spotted if the answer is faster than the speed of light.
(ii) Use of $v = Hd$ and $H = 65\ \text{km s}^{-1}\ \text{Mpc}^{-1}$ $d = \frac{v}{H} = \frac{1.1 \times 10^5}{65} = 1.7 \times 10^3\ \text{Mpc}$	1 1	The use of Hubble's Law requires the velocity to be in km s^{-1} and the distance in Mpc. The value for Hubble's constant is provided on the data sheet. There is no need to convert the final answer into light year
7 (a) Rayleigh criterion: two sources can just be resolved. If the 1st minimum of the diffraction pattern of one source coincides with the centre of the diffraction pattern of the other. The Airy disc is the bright central maximum of the diffraction pattern of a point source.	1 1 1	This can be answered using a diagram. Sometimes it is much easier to draw what you mean rather than rely on just words. The important point here is that the two sources are *just* resolved for the Rayleigh criteria and that it is the central maximum of one that coincides with the first minimum of the other. Few students knew what was meant by the Airy disc.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(b) (i) (Light collecting power is proportional to area.) • Area of four telescopes of diameter $8.2\text{m} = 4\pi\left(\frac{d}{2}\right)^2 = 211\ \text{m}^2$ • Single telescope of this area has a diameter $= 2\sqrt{\frac{A}{\pi}} = 16.4$ m *or:* Light collecting power is proportional to area, area is proportion to diameter^2 therefore: • diameter^2 of four telescopes = diameter^2 of single telescope $4 \times (8.2)^2 = d^2$ • $d = 16.4$ m	1 1 1 1	Knowing that the collecting power is proportional to area is the significant point in this question. The answer then becomes a simple issue of calculating the areas of the two situations and showing that they are similar. The answers quoted are more rigorous in that they calculate the diameter of the single telescope objective.
(ii) Use of $\theta = \frac{\lambda}{d}$ gives $\theta = \frac{200 \times 10^{-9}}{100}$ $= 2.0 \times 10^{-9}$ rad	1	As it is the maximum angular resolution (i.e. the 'best'), it is the smallest angle that is wanted. Maximum resolution occurs when close together objects can be resolved. As the wavelength appears at the top of the equation, it is the smallest wavelength that is needed. Furthermore, you need to be familiar with the prefixes (nano, micro) and the unit of the final answer (radians).
(iii) Infrared	1	
8 (a)  Main sequence correct Dwarfs and giants OBAFGKM	 1 1 1	The HR diagram is a core aspect of this specification. It should be understood in terms of temperature and spectra. You should be able to interpret the properties of stars in different parts of the diagram in some detail.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(b) (i) Above G on spectral class, between 5 and 0 on absolute magnitude.	**1**	For this question, you need to know the position of the Sun on the HR diagram. The fact that Beta Hydri has the same temperature puts it in the same spectral class – that is, G. The '3.5 times brighter' means that its absolute magnitude is between 1 and 2 less than that of the Sun. This is because a difference of 1 on the magnitude scale is a factor of 2.5 in brightness – and the scale is inverted (smaller = brighter). The allowed values in the mark scheme are actually quite generous but many students over-estimate the difference and lose the mark.
(ii) $P = \sigma A T^4$ • Beta Hydri has a larger P (brighter), same T, therefore it must have a greater A. • Beta Hydri is larger. *or:* (argued from the HR diagram): • At same spectral class (temperature), larger stars are higher up the HR diagram. • Beta Hydri is above the Sun, therefore it is larger.	 **1** **1** **1** **1**	Being able to use Stefan's Law quantitatively in this way requires a clear understanding of what the equation tells you.
9 (a) (i) Quasar: two from: • very powerful/bright • radio source • large red shift/very distant • relatively small **(ii)** Black hole: • escape velocity greater than speed of light	**max 3**	The properties of quasars are controversial, and it is worth understanding the ones accepted within the specification. Notice that large red shift and distant are seen as only one answer. The black hole property is the only one acceptable. References to singularities etc are usually ignored as the significant property is related to the escape velocity.
(b) (i) $d = \dfrac{800 \times 10^6}{3.26}$ $= 2.454 \times 10^8$ pc $= 245$ Mpc use of $v = Hd$ and $H = 65$ km s^{-1} Mpc^{-1} $v = 65 \times 245 = 1.59 \times 10^4$ km s^{-1} $= 1.59 \times 10^7$ m s^{-1}	 **1** **1**	There are several opportunities to go wrong in this calculation. The important thing to do is take it one step at a time. The calculation of distance in Mpc requires knowledge of what the M stands for. The use of the correct value of H (given on the data sheet) leading to an answer in km s^{-1} can also cause problems.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(ii) use of $\frac{\Delta f}{f} = \frac{v}{c}$ gives $\Delta f = \frac{108 \times 10^9 \times 1.59 \times 10^7}{3 \times 10^8}$ $= 5.742 \times 10^9$ Hz	1	This question contains a unit prefix that you need to learn. Giga stands for 10^9.
measured frequency $= f - \Delta f$ $= 108 \times 10^9 - 5.74 \times 10^9$ $= 1.02 \times 10^{11}$ Hz	1	
(c) Use of $R = \frac{2GM}{c^2}$ $= \frac{2(6.67 \times 10^{-11})(10^8 \times 2 \times 10^{30})}{(3 \times 10^8)^2}$ $= 2.96 \times 10^{11}$ m.	1 1	There are two common errors which occur when the calculation of the radius of the event horizon is asked for. The mass of the black hole is often miscalculated: either the mass of the Sun is missed off altogether, or the mass of the Earth is substituted; the other is that students forget to square the speed of light.
10 (a) (i) Megrez, highest value of apparent magnitude.	1	This question you to know that the brightness is related to the apparent magnitude, and that the scale is inverted (smaller number = brighter star).
(ii) Alkaid, as it is in spectral class B	1	This question requires knowledge that spectral class is related to temperature and that the order (from hottest to coolest) is OBAFGKM.
(b) (i) Inherent brightness or brightness seen from 10 pc	1	There are a few definitions that need to be learned and this is one of them. References to just 'magnitude' fail to get the mark. Similarly luminosity and brightness are not the same thing.
(ii) Dubhe: it appears the brightest from Earth, and it is the furthest away	1	Something which looks brightest and is also furthest away, must actually be the brightest. It is time consuming but full credit was given to students who calculated all of the absolute magnitudes and showed that Dubhe was the brightest.
(c) (i) The distance from which the Earth and Sun would appear to be separated from one another by 1 second of arc	1	The most common mistake here is to simply state the parsec in light year or metres. The definition of the parsec is 'the distance at which 1 AU subtends an angle of 1 second of arc'. This is another example of where a diagram would make things much easier to describe.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(ii) $\frac{101}{3.26} = 31$ (parsecs)	**1**	Changing the distance into parsecs is necessary for the final part. To be given it to do separately here makes the final part much easier. This step may not always be given to the student to do like this.
(iii) Use of $m - M = 5 \log \frac{d}{10}$ to give $M = 1.9 - 5 \log \left(\frac{31}{10}\right)$ $= -0.56$	**1** **1** **1**	Common errors here include getting the *m* and the *M* the wrong way round. The use of the incorrect base for the logarithms was less common, but missing out the minus sign in the final answer did lose a mark.
11 (a) Neutron star: any two from: • extremely dense • small (typically 10 km diameter) • dim • (spinning) radio source Black hole: • object which has an escape velocity greater than speed of light	**max 3**	There are many aspects of neutron stars which are related to the theories about how they are formed or how they produce the phenomena which are detected (e.g. the pulsed radio waves). The properties quoted here are the ones currently accepted within this specification. Similarly, black holes are exciting phenomena which can stimulate a lot of interesting research. The fundamental property, however, is related to the escape velocity.
(b) Use of $R_s = \frac{2GM}{c^2}$ $= \frac{2(6.67 \times 10^{-11})(40 \times 2 \times 10^{30})}{(3 \times 10^{8})^2}$ $= 1.19 \times 10^{5}$ m.	 **1** **1**	This calculation of the Schwarzschild radius is relatively straightforward but is still prone to the same errors as seen before. i.e failing to use the correct mass – either missing out the mass of the Sun altogether, or using the mass of the Earth and forgetting to square the speed of light.

Nelson Thornes is responsible for the solution(s) given and they may not constitute the only possible solution(s).