

# Paper 3 Section 3B (Astrophysics)

## 3.9 Astrophysics

### 3.9.1 Telescopes

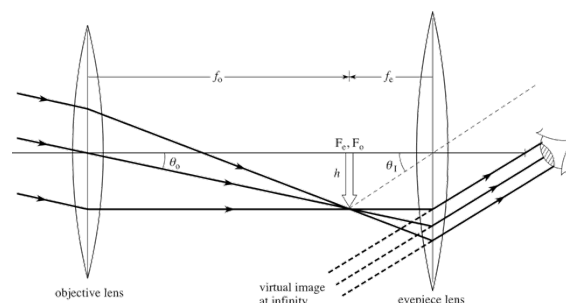
#### 3.9.1.1 Astronomical telescope consisting of two converging lenses

##### Content

- Ray diagram to show the image formation in normal adjustment.
- Angular magnification in normal adjustment.
- $$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$
- Focal lengths of the lenses.
- $$M = \frac{f_o}{f_e}$$

##### *Ray diagram to show the image formation in normal adjustment.*

The ray diagram for an astronomical telescope consisting of two converging lenses (refracting telescope) is shown below.



The three rays of light travel in parallel. The middle ray will continue on its path without changing direction, since it is passing through the centre of the objective lens, whereas the other two will refract to the common point  $f_o f_e$ . A parallel, dotted line from this point needs to be drawn so that it goes through the centre of the eyepiece lens. The three rays of light will then refract at the eyepiece lens, travelling to the parallel line that has been drawn in. The point  $f_o f_e$  must be drawn so that it is at least  $2/3$  of the way along the principal axis.

##### *Angular magnification in normal adjustment.*

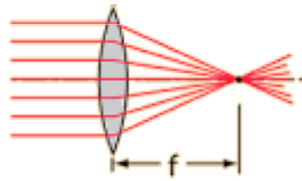
Angular magnification, in words, is the ratio of the angle subtended at the eye by the image formed by an optical instrument (telescope), to the angle subtended at the eye by an object when not being viewed through that instrument. The equation for angular magnification is

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

So if the angular magnification were 100, and the angle subtended by the image at the eye were  $2 \times 10^{-6}$  rad, then the angle subtended by the object at the unaided eye would be  $2 \times 10^{-8}$ .

### ***Focal length of the lens***

For a convex lens, the point at which all refracted rays of light will pass through is called the focal point. The diagram shows this point below.



$$M = \frac{f_o}{f_e}$$

Angular magnification can also be calculated using the equation shown above.

### 3.9.1.2 Reflecting telescopes

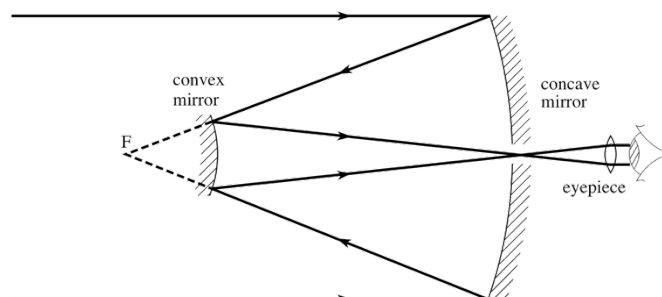
#### Content

- Cassegrain arrangement using a parabolic concave primary mirror and convex secondary mirror.
- Ray diagram to show path of rays through the telescope up to the eyepiece.
- Relative merits of reflectors and refractors including a qualitative treatment of spherical and chromatic aberration.

#### *Cassegrain arrangement using a parabolic concave primary mirror and convex secondary mirror.*

The Cassegrain arrangement is a type of reflecting telescope, it uses a parabolic concave primary mirror, with a convex secondary mirror that work as shown below.

#### *Ray diagram to show path of rays through the telescope up to the eyepiece.*

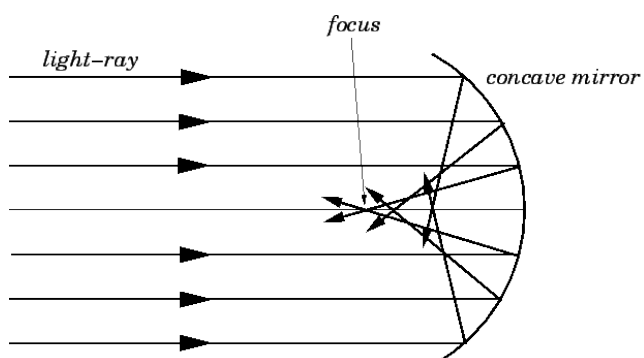


**ENSURE RAYS DO NOT CROSS BEFORE THEY LEAVE THE SECONDARY MIRROR! (SO, AS THEY LEAVE.)**

#### *Relative merits of reflectors and refractors including a qualitative treatment of spherical and chromatic aberration.*

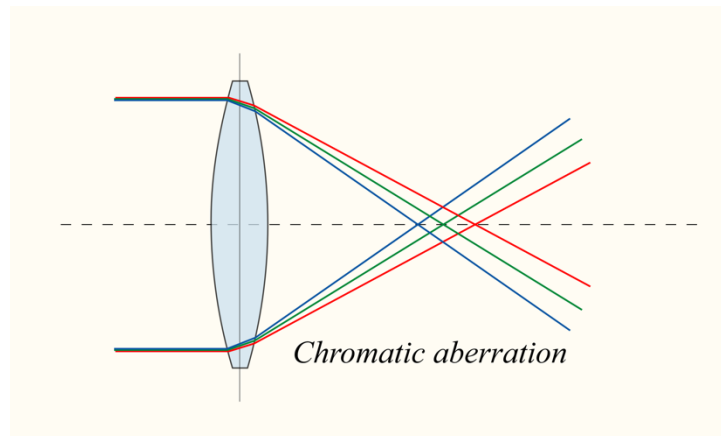
#### Spherical Aberration

Spherical aberration occurs when the concave mirror reflects rays of light coming in parallel to each other by different amounts. This defect would mean that the image formed, if this occurred in a Cassegrain telescope, would cause an unfocused image.



## Chromatic Aberration

This occurs when different wavelengths of light are refracted by different amounts. Since red has the longest wavelength (on the visible light spectrum), it is refracted the least. Blue has a shorter wavelength so is refracted more.



The advantages of reflecting telescopes are as follows:

1. They do not suffer from chromatic aberration as all wavelengths of light reflect in the same way, as opposed to a refracting telescope where for example blue will refract more than red.
2. You can provide support for the objective mirror along the back side of it, so they can be made very large, thus they can collect more light.

Disadvantages are as follows:

1. The reflector is open to the outside, so the optics need constant cleaning.
2. The secondary convex mirror blocks a certain amount of light so less light can be collected by the telescope.
3. The secondary mirror can produce diffraction effects.

Advantages of refracting telescopes:

1. The surfaces within the telescope are sealed, thus they will need cleaning very infrequently.
2. The tube will not be affected by changes in temperature or air currents, so images produced are usually sturdier and sharper than that of a reflector telescope.

Disadvantages of refracting telescopes:

1. Refracting telescopes suffer from chromatic aberration, this causes colour distortion, where there will be other blurred colours surrounding an image like the one shown below.



2. The objective lens can only be supported at its ends, so if the glass is too heavy it will distort under its own weight.
3. It is very difficult to make a glass lens with no imperfections, and to make a glass lens with perfect curvature.

## AQA June 2015 Unit 5 Q1c

### Question:

Discuss the level of detail the IRTF would be able to detect on the surface of Vesta, when Vesta is  $1.73 \times 10^{11}\text{m}$  from Earth. (We already know that the angular resolution of the IRTF is The smallest angle the telescope can resolve is  $3.3 \times 10^{-7}$  radian, and that Vesta subtends an angle of approximately  $3 \times 10^{-6}$  radian from Earth.)

### Answer:

- Minimum angular resolution is better/smaller than the size of the asteroid.
- Details of about 1/10 the angular size of Vesta/ 50km can be seen

### EXAM TIP:

**GIVE SPECIFIC DETAILS IE CALCULATIONS OR FIGURES TO PRESENT YOUR CONCLUSION!**

### 3.9.1.3 Single dish radio telescopes, I-R, U-V and X-ray telescopes

#### Content

- Similarities and differences of radio telescopes compared to optical telescopes. Discussion should include structure, positioning and use, together with comparisons of resolving and collecting powers.

*Similarities and differences of radio telescopes compared to optical telescopes. Discussion should include structure, positioning and use, together with comparisons of resolving and collecting powers.*

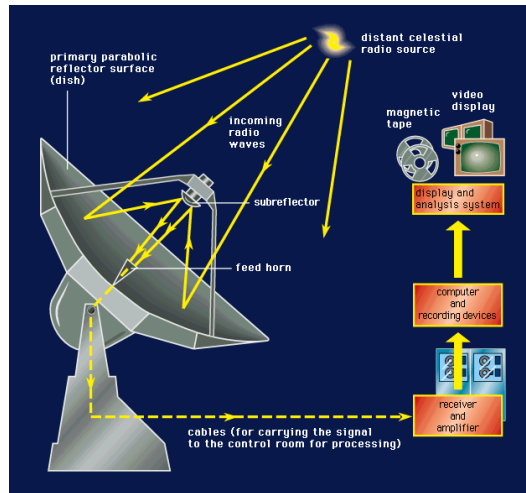
Radio telescopes have the structure shown below. They are similar to a reflecting telescope in that they use a primary parabolic surface to reflect the incoming radio waves towards a secondary sub reflector, obviously the reflector uses light waves instead. This then reflects the radio waves towards the feed horn, where it can be processed to produce an image.

Radio telescope are also usually much larger than optical telescopes, since radio waves have much larger wavelengths, a larger surface is required to capture more radio waves. The larger radio waves are pretty much stationary due to their vast size, so are relatively inefficient at tracking a source in the sky compared to an optical telescope. However smaller radio telescopes are able to track sources.

Radio telescopes tend to be located in remote areas, as they suffer from artificial interferences like those produced by mobile phones. Water vapour in the atmosphere can also interfere with the signal, absorbing the radio waves, thus to avoid this some are placed in space.

Radio telescopes have a much lower resolving power because the wavelength of electromagnetic radiation received by the radio telescope is much larger than the wavelength received by an optical telescope (roughly  $10^3\text{m}$  in a radio telescope, and  $0.5 \times 10^{-6}$  in an optical telescope). This is why the radio telescopes need to be so large. The Rayleigh Criterion tells us this (covered in the next topic), where resolving power  $\theta = \lambda/D$ , where  $D$  is equal to the diameter, and  $\lambda$  the wavelength.

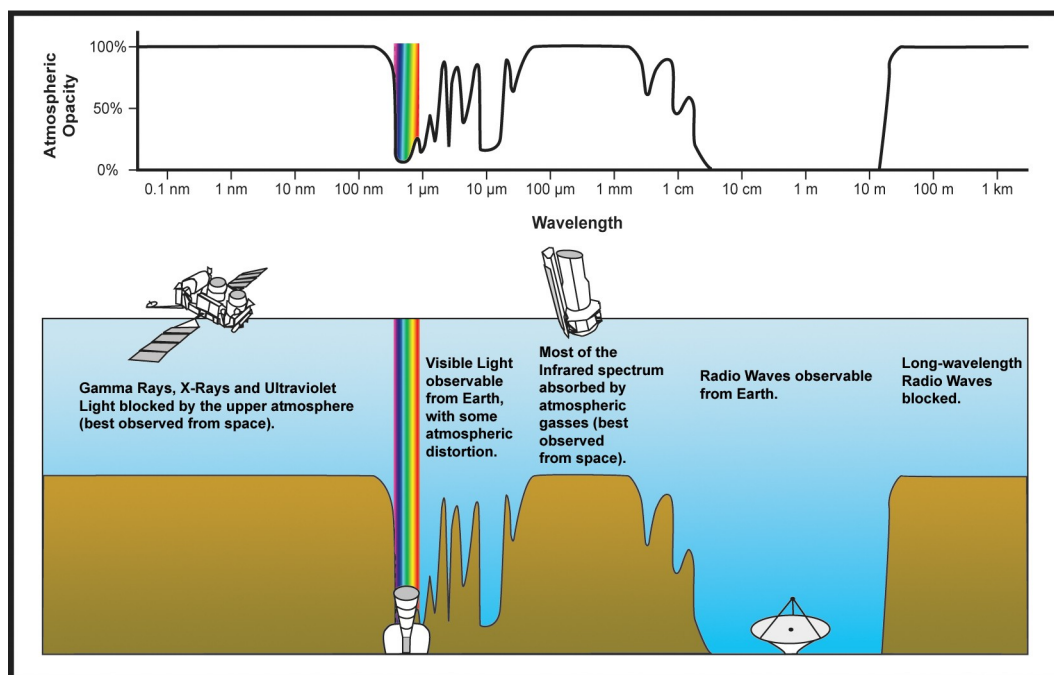
The collecting power of a telescope is proportional to its (objective) diameter<sup>2</sup>. Therefore the radio telescopes are able to collect much more radiation, as their diameters are much larger.



The types of telescope that we can use on the surface of the Earth are limited by the electromagnetic radiation that is able to pass through the atmosphere. Gamma rays, X rays and UV radiation are all blocked by the Earth's atmosphere. The UV radiation is absorbed by the ozone layer.

Incoming infrared radiation is partially blocked at certain wavelengths by water vapour in the atmosphere. Most radio wavelength pass through from the microwave region to early radio waves. However longer wavelength radio waves are all blocked by the atmosphere.

This limits the types of telescopes that we can use to detect electromagnetic radiation on the surface of the earth. Thus satellites in space are used typically to look at these other parts of the electromagnetic spectrum with telescopes.



### 3.9.1.4 Advantages of large diameter telescopes

#### Content

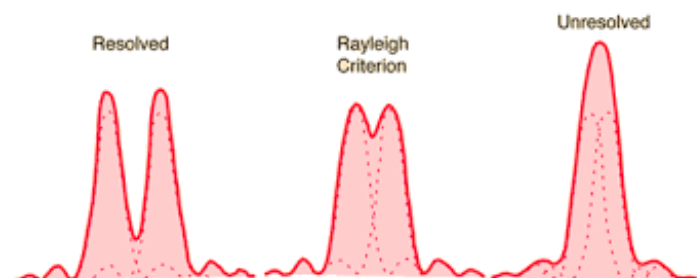
- Minimum angular resolution of telescope.
- Rayleigh criterion,  $\theta \approx \frac{\lambda}{D}$
- Collecting power is proportional to  $diameter^2$ .
- Students should be familiar with the rad as the unit of angle.
- Comparison of the eye and CCD as detectors in terms of quantum efficiency, resolution, and convenience of use.
- No knowledge of the structure of the CCD is required.

#### *Minimum angular resolution of telescope.*

The minimum angular resolution of a telescope is the minimum distance that two objects can be recognised as separate objects.

#### *Rayleigh criterion* $\theta \approx \frac{\lambda}{D}$

This is given by the equation shown above. It is simply that the minimum angular resolution of a telescope is equal to the wavelength of the radiation divided by the diameter. In words, the criterion states that an image will just be resolved if the first minimum of the diffraction pattern of one source coincides with the central maximum of another source. The image below shows different scenarios of interactions of diffraction patterns.



#### *Collecting power is proportional to diameter<sup>2</sup>.*

If asked to compare the collecting power of a telescope of diameter 26m, and a telescope of diameter of 13m, you would do  $26^2/13^2$ . This gives you that the collecting power of the 26m diameter telescope is 4 x larger.

#### *Students should be familiar with the rad as the unit of angle.*

One radian is equal to just under 57.3 degrees. The radian is the standard unit of the angle and is represented by the symbol 'rad'.



***Comparison of the eye and CCD as detectors in terms of quantum efficiency, resolution, and convenience of use.***

The CCD is a silicon chip divided into picture elements, called pixels. Photons of light hit the CCD and excite electrons, causing them to be released from the semiconductor. The number of electrons liberated (and therefore the charge) is proportional to the intensity of the light. These electrons are trapped in 'potential wells', and they produce an electron pattern which is identical to the image formed on the CCD. When exposure is complete the charge is processed to form an image.

Quantum efficiency is the ratio of the number of photons detected to the number of photons incident on a detector. It basically tells us how well a detector can capture photons and make them further available for amplification and imaging. To get a percentage you must multiply this ratio by 100.

The quantum efficiency of a CCD is typically 80%, whereas the quantum efficiency of our eye is less than 1%.

Defining the resolving power of a CCD can not be done using Rayleigh's criterion, like with optical systems. The resolving power is reliant on the number of pixels and their size, relative to the size of the image projected on it. If you have smaller pixels, the resolution will be clearer. On the other hand, the angular resolution of the eye can be found using the Rayleigh criterion. Typically, the angular resolution of the eye is between  $2.9 \times 10^{-4}$  rad and  $5.8 \times 10^{-4}$  rad.

CCD's are very convenient as the images can be stores digitally, and sent around the world instantly for review, and easy retrieval.

***No knowledge of the structure of the CCD is required.***

## 3.9.2 Classification of stars

### 3.9.2.1 Classification by luminosity

#### Content

- Apparent magnitude,  $m$ .
- The Hipparchus scale.
- Dimmest visible stars have a magnitude of 6
- Relation between brightness and apparent magnitude. Difference of 1 on magnitude scale is equal to an intensity ratio of 2.51
- Brightness is a subjective scale of measurement.

#### *Apparent magnitude, $m$ .*

Apparent magnitude is the brightness of an object as seen from earth. The lower the value of apparent magnitude, the brighter the star.

#### *The Hipparchus scale.*

In his scale of apparent magnitude, a smaller number means that the object is brighter. His scale was from 1 to 6, where 1 is the brightest.

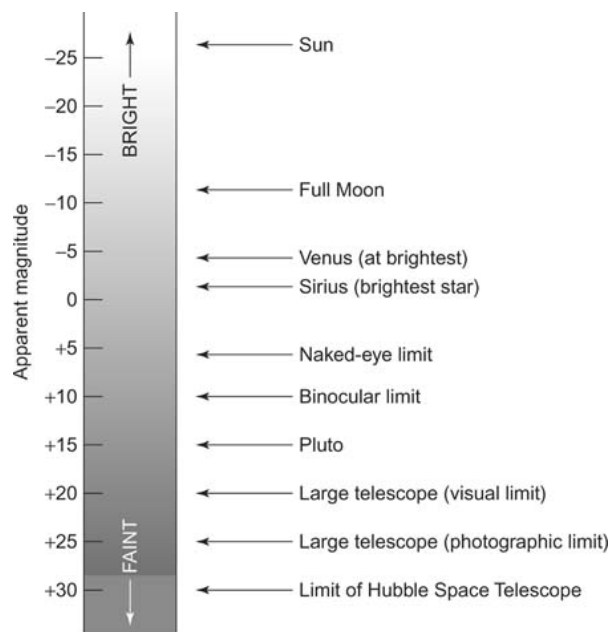
#### *Dimmest visible stars have a magnitude of 6.*

This follows on from the last point.

#### *Relation between brightness and apparent magnitude. Difference of 1 on magnitude scale is equal to an intensity ratio of 2.51.*

Because of the way light is perceived by an observer, it turns out that equal intervals in brightness are actually equal ratios of light intensity received. Therefore the scale is logarithmic, whereby an increase in one on the apparent magnitude scale corresponds to an increase in intensity by roughly 2.51. So a difference of two on the scale is  $2.51^2$  and so on. Another thing worth noting is that a difference of 5 on the scale ( $2.51^5$ ) is equal to an increase in intensity of 100. In summary, a second magnitude star is 2.51 times brighter than a third magnitude star, and 6.31 times brighter than a fourth magnitude star. The scale has now been adapted so that the brightest stars on the scale to the human eye can have an apparent magnitude of around -26 (the sun), and the faintest stars around 6. This is because when Hipparchus made the scale, a full definition on what a star actually was had not been made, so with new knowledge that the sun is a star, it has the highest apparent magnitude. Since our eyes have not developed, the dimmest stars of magnitude 6 are still the dimmest.

The diagram below shows the apparent magnitude scale.



***Brightness is a subjective scale of measurement.***

Brightness is subjective: if ten people were asked to place a number of stars in order, they would more than likely all give different orders. This is an important point to keep in mind as it comes up frequently in exam questions.

### 3.9.2.2 Absolute magnitude, $M$

#### Content

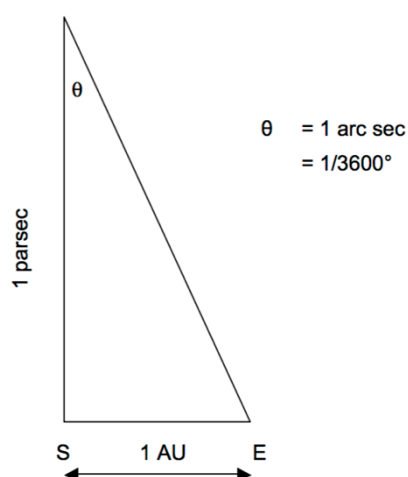
- Parsec and light year
- Definition of  $M$ , relation to  $m$ ,  $m - M = 5 \log \frac{d}{10}$

#### *Parsec and light year*

The light year is distance travelled by light in a vacuum in one year. It can be converted into metres by multiplying the speed of light in a vacuum ( $3 \times 10^8 \text{ ms}^{-1}$ ) by the time in one year ( $365 \times 24 \times 60 \times 60$ ), which gives  $9.46 \times 10^{15} \text{ m}$ .

The parsec is a unit of measurement equal to  $3.08 \times 10^{16} \text{ m}$ , or 3.26 light years. One parsec is the distance at which one astronomical unit subtends an angle of one arcsecond. One arcsecond is  $1/3600^\circ$ . One astronomical unit is the mean distance from the Sun to the Earth, which has the value  $1.5 \times 10^{11} \text{ m}$ .

The diagram below shows how the distance of one parsec is calculated.



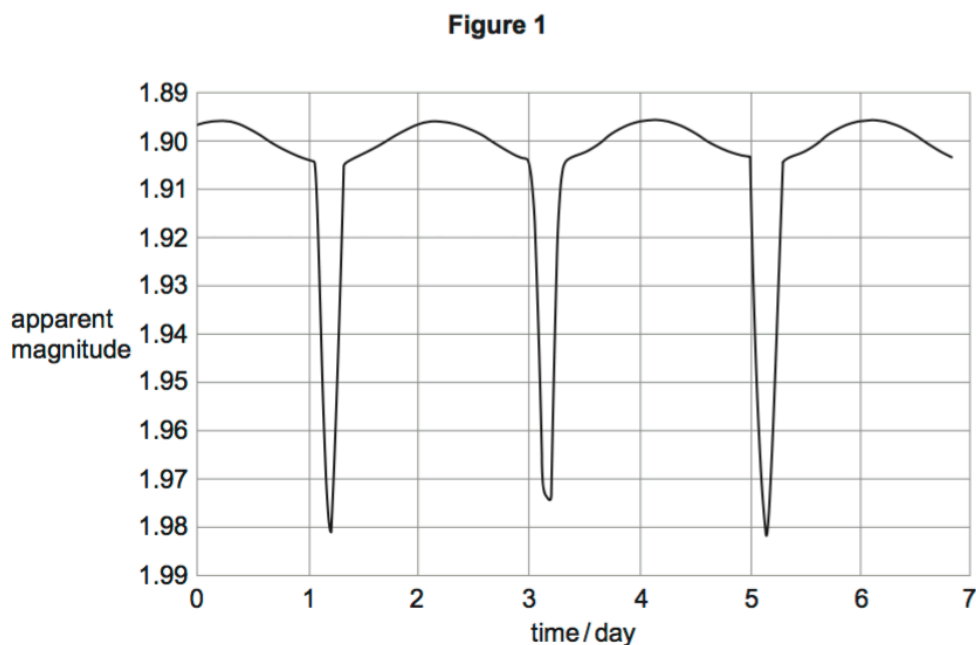
#### *Definition of $M$ , relation to $m$ ; $m - M = 5 \log \frac{d}{10}$*

The absolute magnitude of a star is the apparent magnitude it would have at a distance of 10 parsecs from an observer. The equation ' $m - M = 5 \log \frac{d}{10}$ ' relates  $m$  to  $M$ , where  $m$  is the apparent magnitude,  $M$  is the absolute magnitude and  $d$  is the distance measured in parsecs (pc).

Therefore, Stars which are closer than 10 pc have a brighter (more negative) apparent magnitude than absolute magnitude, and this is the opposite for stars further than 10pc away. If the apparent magnitude is equal to the absolute magnitude, then the star must be 10pc away.

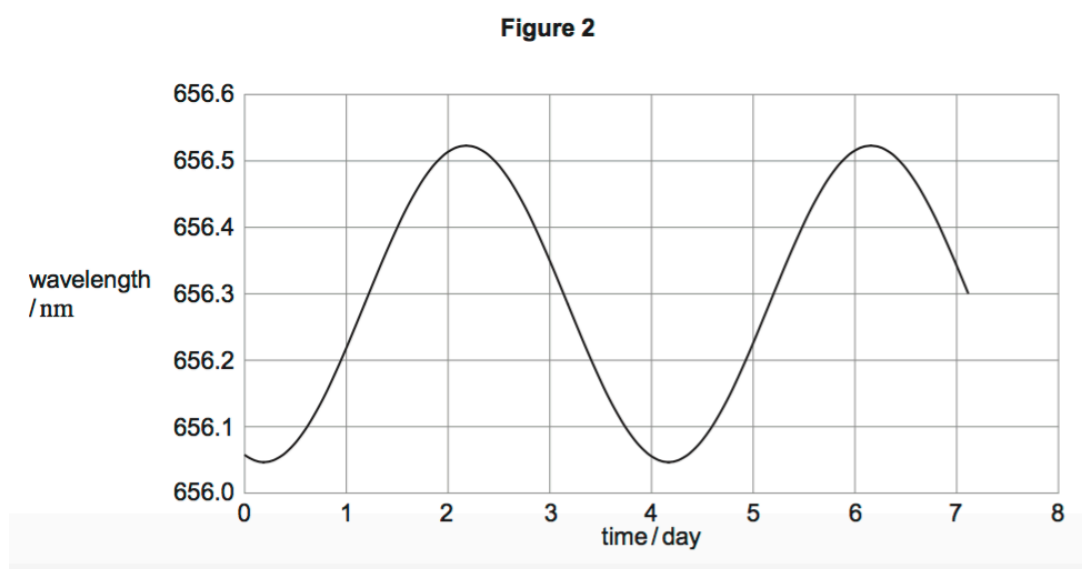
## AQA June 2015 Unit 5 Q2c

Menkalinan is an eclipsing binary star system in the constellation of Auriga. **Figure 1** shows the variation in apparent magnitude with time (light curve) for Menkalinan.



Analysis of the spectrum of one of the stars shows a periodic variation in wavelength

**Figure 2** shows the results for one of the spectral lines in the Hydrogen Balmer series. The wavelength for this line as measured for a source in a laboratory on the Earth is 656.28 nm.



**Question:**

The distance from the Earth to Menkalinan is  $7.7 \times 10^{17}$ .  
Calculate the value of the absolute magnitude of Menkalinan when it appears dimmest

**Answer:**

$$\begin{aligned} m - M &= 5 \log (d/10) \\ d \text{ (in parsec)} &= 7.7 \times 10^{17} / 3.08 \times 10^{16} = 25 \text{ pc} \quad \text{dimmest } m = 1.981 \\ \text{dimmest } M &= 1.981 - 5 \log(25/10) = -0.009 \end{aligned}$$

*Exam tips:*

**WHEN DEALING WITH  $m-M = 5\log(d/10)$  REMEMBER TO CONVERT DISTANCE INTO PARSECS!**

**ALSO, REMEMBER A LOWER VALUE ON THE APPARENT MAGNITUDE SCALE = BRIGHTER TO THE NAKED EYE AS SEEN FROM EARTH! THIS MEANS THAT AN APPARENT MAGNITUDE OF 1 IS BRIGHTER THAN AN APPARENT MAGNITUDE OF 2.**

## OCR (A) A Level Specimen 1 Q23a)c)

This isn't directly mentioned in the spec but questions have been asked before that test similar content.

### Question:

State and explain how stellar parallax is used to measure distances in space.

### Answer:

- Apparent motion or displacement of a star relative to the position of more distant stars
- Caused by the Earth's orbit around the Sun.
- An angle of parallax of 1 arcsecond when displacement of Earth is 1AU corresponds to distance 1 pc

### Question:

Suggest why hydrogen spectral lines might often be used to measure a star's velocity

### Answer:

Hydrogen is most common element in stars or Hydrogen has most intense (spectral) lines.

Intensity of light from other elements may be too low for accurate measurement

## AQA June 2015 Q2c

'The distance from the Earth to Menkalinan is  $7.7 \times 10^{17}$ m.

Calculate the value of the absolute magnitude of Menkalinan when it appears dimmest.'

- $M - m = 5 \log (d/10)$
- $D \text{ (in parsec)} = 7.7 \times 10^7 / 3.08 \times 10^7 = 25 \text{ pc}$
- Dimmest  $m = 1.981$
- Dimmest  $M = 1.981 - 5 \log(25/10) = -0.009$

### 3.9.2.3 Classification by temperature, black-body radiation

#### Content

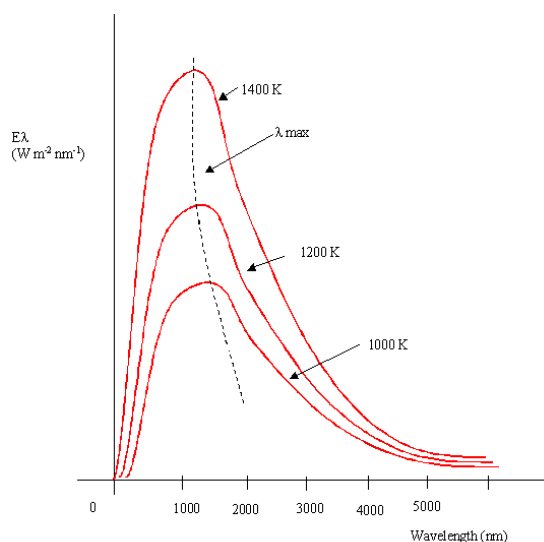
- Stefan's law and Wien's displacement law.
- General shape of black-body curves, use of Wien's displacement law to estimate black-body temperature of sources.
- Experimental verification is not required.
- $\lambda_{\text{MAX}}T = \text{constant} = 2.9 \times 10^{-3} \text{ mK}$ .
- Assumption that a star is a black body.
- Inverse square law, assumptions in its application.
- Use of Stefan's law to compare the power output, temperature and size of stars  $P = \sigma AT^4$ .

#### *Stefan's law and Wien's displacement law.*

**Stefan's law** states that the total thermal energy radiated by a blackbody radiator per second per unit area is proportional to the fourth power of the surface temperature. The equation for Stefan's law is  $P = \sigma AT^4$  where  $P$  is total energy radiation per second per unit area (power), with unit Watts (W),  $\sigma$  is Stefan's constant with units  $\text{W m}^{-2}\text{K}^{-4}$ ,  $A$  is surface area ( $\text{m}^2$ ) and  $T$  is surface temperature in Kelvin (K). **Wien's displacement law** states that  $\lambda_{\text{max}} T = \text{constant} = 0.0029 \text{ mK}$  where 'mK' is the unit of the constant.  $\lambda_{\text{MAX}}$  is the wavelength of maximum power output, with the unit metre (m), and  $T$  is surface temperature in Kelvin (K).

#### *General shape of black-body curves, use of Wien's displacement law to estimate black-body temperature of sources.*

A black-body is a body that absorbs all wavelengths of electromagnetic radiation and can emit all wavelengths of electromagnetic radiation. The area under a black-body curve is the total energy radiated per unit time per unit surface area.





The general shape of a black-body curve is shown above. As temperature of an object increases, the peak of the graph moves towards the shorter wavelengths

It can be used to calculate black-body temperature by taking the value of  $\lambda_{\max}$ , then doing  $0.0029 / \lambda_{\max}$  to find T, from the equation  $\lambda_{\max} T = 2.9 \times 10^{-3}$ .

*Experimental verification is not required.*

$$\lambda_{\max} T = \text{constant} = 2.9 \times 10^{-3} \text{ mK.}$$

$\lambda_{\max} T = \text{constant} = 0.0029 \text{ mK}$  where ‘mK’ is the unit of the constant.  $\lambda_{\max}$  is the wavelength of maximum power output, with the unit metre (m), and T is surface temperature in Kelvin (K).

*Assumption that a star is a black body.*

In calculations we assume that stars act as black body’s, sometimes questions will ask what assumptions have been made in calculations regarding black bodies.

*Inverse square law, assumptions in its application.*

Any source that spreads its influence equally in all directions without a limit to its range obeys the inverse square law. Therefore, if the source reduces to a quarter of its original value when distance is doubled, it obeys this law. This law can give information on the intensity of a light source at different distances, so if the sun is used to provide energy for solar cells on a space probe, the equation can be used to determine what happens as the probe gets further from the sun. It can also be used to determine the power output of different objects, for example Doppler shift information suggests some quasars are billions of light years away, then using the inverse-square law it can be shown that the power output of a quasar must be equivalent to that of a whole galaxy.

Assumptions in the inverse square law is that it assumes that no light is absorbed or scattered between the source, and that the observer and the source can be treated as a point.

*Use of Stefan’s law to compare the power output, temperature and size of stars  $P = \sigma AT^4$*

This law tells us that, if two stars have the same black body temperature, so are the same spectral class, the star with the brighter absolute magnitude has the larger diameter.

### 3.9.2.4 Principles of the use of stellar spectral classes

#### Content

- Description of the main classes:

Spectral class	Intrinsic colour	Temperature / K	Prominent absorption lines
O	blue	25 000 – 50 000	He <sup>+</sup> , He, H
B	blue	11 000 – 25 000	He, H
A	blue-white	7 500 – 11 000	H (strongest) ionized metals
F	white	6 000 – 7 500	ionized metals
G	yellow-white	5 000 – 6 000	ionized & neutral metals
K	orange	3 500 – 5 000	neutral metals
M	red	< 3 500	neutral atoms, TiO

- Temperature related to absorption spectra limited to Hydrogen Balmer absorption lines: requirement for atoms in an  $n = 2$  state.

#### *Description of the main classes*

When the light created within a star passes through its atmosphere absorption of particular wavelengths takes place. This produces gaps in the spectrum of the light from the star resulting in an absorption spectrum. The wavelengths are related to frequency ( $c = f \lambda$ ) and therefore to particular energies ( $\Delta E = hf$ ). Electrons in the atoms and molecules of the star's atmosphere are absorbing the light, and therefore jumping to higher energy levels. The difference in these energy levels are discrete and therefore the frequencies of the absorbed light are discrete

The relationship between temperature and spectra is due to the effect of energy (different temperatures), on the state of the atoms or molecules. At low temperatures the energy may not be high enough to excite atoms, or to break molecular bonds, so you get titanium oxide or just neutral atoms. At higher temperatures atoms may have too much energy to form molecules, to ionisation can take place. Then, the abundance of hydrogen and helium in the atmosphere of the hottest stars mean that their spectral lines dominate.

#### *Temperature related to absorption spectra limited to Hydrogen Balmer absorption lines: requirement for atoms in an $n = 2$ state.*

The electrons begin in the  $n = 2$  state, so must first be given enough energy, so must be very hot. To observe Balmer lines, electrons must be in this state, so at high temperatures many electrons are performing Balmer transitions. At very high temperatures, electrons may begin at  $n = 3$  or will be ionised, so there will be less transitions, but at low temperatures energy level changes are rare.

## AQA June 2015 Q2b

### Question:

‘The black body temperature of each star is approximately 9200 K.

Explain why a Hydrogen Balmer line was chosen for the analysis of wavelength variation.’

### Answer:

- The temperature (9200K) indicates that the star is in spectral class A.
- Hydrogen Balmer lines are strongest in A class stars and therefore would be more easily measured.

## Edexcel AS Paper 1 Specimen Q14b

### Question:

When the light from a star is dispersed to form a spectrum, dark lines are seen at a number of frequencies. This is known as an absorption spectrum and is caused by the presence of certain elements in the star.

Explain how the absorption spectrum is created.

### Answer:

- If photon energy is equal to an energy level difference (ground state to  $n=1$  for instance) in the elements present
- Then the photon can be absorbed by an electron and the electron is excited/moves to higher level
- So the absorption spectrum is created because the frequencies of the absorbed photons are missing from the continuous spectrum produced by the star.

## AQA June 2007 Unit 5

### Question:

Describe how Balmer absorption lines are produced.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

### Answer:

- 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 ( $e = hf$ )

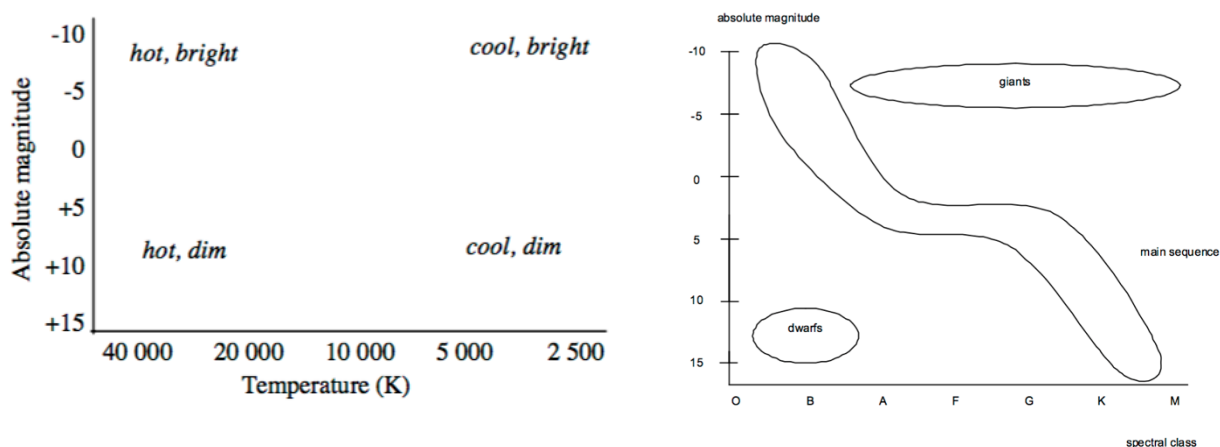
- When electrons return to lower energy states, energy released in all directions so reduced intensity in original direction (or different frequencies emitted as electrons can return to lower states in different steps)
- Producing gaps in spectra

### 3.9.2.5 The Hertzsprung-Russell (HR) diagram

#### Content

- General shape: main sequence, dwarfs and giants.
- Axis scales range from  $-10$  to  $+15$  (absolute magnitude) and  $50\,000\text{ K}$  to  $2\,500\text{ K}$  (temperature) or OBAFGKM (spectral class).
- Students should be familiar with the position of the Sun on the HR diagram.
- Stellar evolution: path of a star similar to our Sun on the HR diagram from formation to white dwarf.

*General shape: main sequence, dwarfs and giants.*



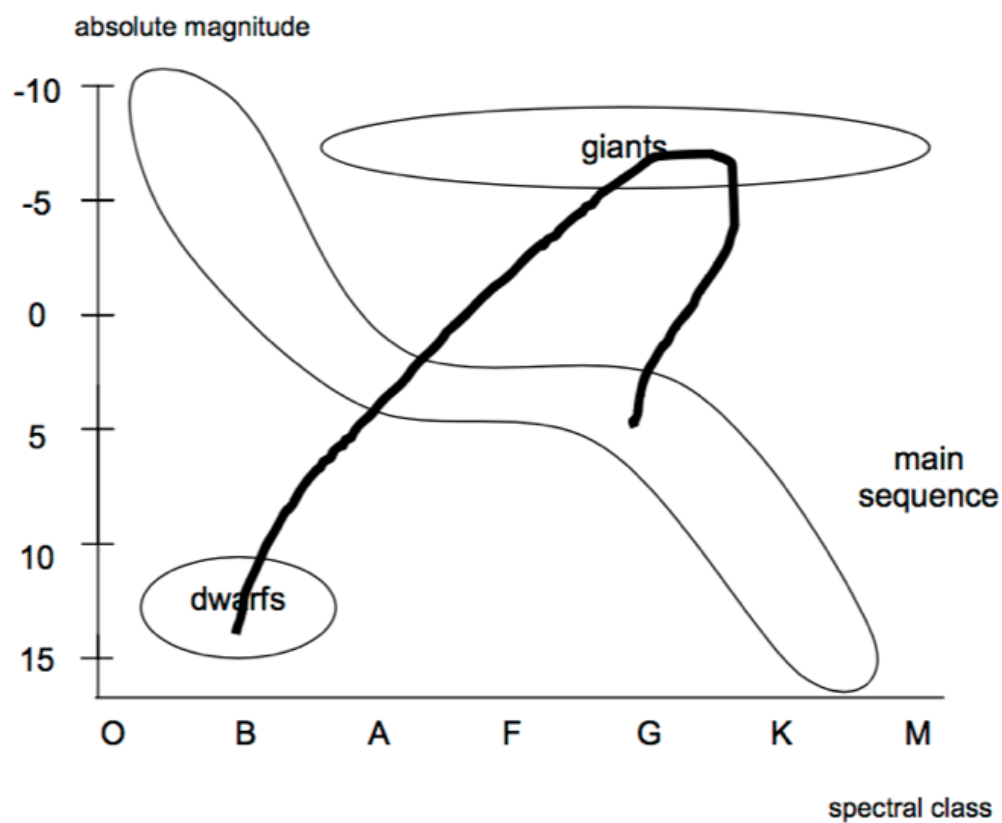
The Hertzsprung-Russell diagram has  $+15$  at bottom of y axis and  $-10$  at top, where the y axis is absolute magnitude. The graph is flat between the absolute magnitudes of  $0$  and  $5$ . The sun lies at G on the x axis, and a value of around  $+5$  on the y axis. The x axis will either be spectral class or absolute temperature in Kelvin. The x axis must begin at  $50,000\text{ K}$  at O, and finish on  $2,500\text{ K}$  on the far right of the axis, just further than M. The scale falls from  $50,000$  to  $20,000$ ,  $10,000$ ,  $5,000$  and then finally  $2,500$ . The value of  $20,000$  will be just to the right of B,  $10,000$  will be slightly closer to F than A,  $5,000$  will be just to the right of G (the star has a surface temperature of around  $6,000\text{ K}$  and so lies at G. The  $2,500$  will lie just to the right of M.

*Students should be familiar with the position of the Sun on the HR diagram.*

As already mentioned, the position of the star is at an absolute magnitude of  $+5$ , and spectral class G.

*Stellar evolution: path of a star similar to our Sun on the HR diagram from formation to white dwarf.*

The graph below shows the path of a star similar to our sun on the HR diagram.



## AQA June 2015 Unit 5 Q3bi)ii)

### Question:

Which of the following regions of the Hertzsprung-Russell diagram does 40 Eridani B belong to? (We already know its surface temperature to be approximately  $1.6 \times 10^4$  K, its radius is around  $9.5 \times 10^6$  and that its power output is around  $4.2 \times 10^{24}$  W)

### Answer:

- It has a high temperature
- But is relatively small, so it will have a low absolute magnitude

(This puts it into the bottom left region of the HR diagram)

Also when thinking about its 'relative size', its radius is comparable to that of the Earth, thus it is relatively small, compared to the Sun, for instance.

### 3.9.2.6 Supernovae, neutron stars and black holes

#### Content

- Defining properties: rapid increase in absolute magnitude of supernovae; composition and density of neutron stars; escape velocity  $> c$  for black holes.
- Gamma ray bursts due to the collapse of supergiant stars to form neutron stars or black holes.
- Comparison of energy output with total energy output of the Sun.
- Use of type 1a supernovae as standard candles to determine distances. Controversy concerning accelerating Universe and dark energy.
- Students should be familiar with the light curve of typical type 1a supernovae.
- Supermassive black holes at the centre of galaxies.
- Calculation of the radius of the event horizon for a black hole, Schwarzschild radius ( $R_s$ ),  $R_s \approx 2GM/c^2$ .

*Defining properties: rapid increase in absolute magnitude of supernovae; composition and density of neutron stars; escape velocity  $> c$  for black holes.*

One of the defining properties of **supernovae** is that they have a rapid increase in absolute magnitude, so a rapid increase of brightness of the star. The defining properties of neutrons stars are that they are extremely dense, with a density of nuclear matter (neutrons) and are relatively small i.e. only 12km in diameter. They have very strong magnetic fields so are powerful radio sources, and combined with their spinning produce pulsars. For black holes, their escape velocity is greater than the speed of light, so even light cannot escape black holes. The boundary at which the escape velocity is equal to the speed of light is called the Event Horizon. The radius of the event horizon is called the Schwarzschild radius,  $R_s$ . The density of black holes however, is not very large, and actually the more massive a black hole, the less dense it is.

*Gamma ray bursts due to the collapse of supergiant stars to form neutron stars or black holes.*

As a supergiant star runs out of nuclear fuel (in the form of Hydrogen), its mass begins to flood into its core. Eventually this results in a core far too heavy, such that the core cannot withstand its own gravitational force. An intense and incredibly bright gamma ray burst will follow, ejecting most of its mass in this process too. What you are left with will either be a neutron star or a black hole.

*Comparison of energy output with total energy output of the Sun.*

Energy output of a (type 1a) supernovae may be 10 billion times that of the sun.

*Use of type 1a supernovae as standard candles to determine distances. Controversy concerning accelerating Universe and dark energy.*

A type 1a supernovae is known as a standard candle, characterised by the fact their absolute magnitude always peaks at the same value and is always known. These types of supernovae



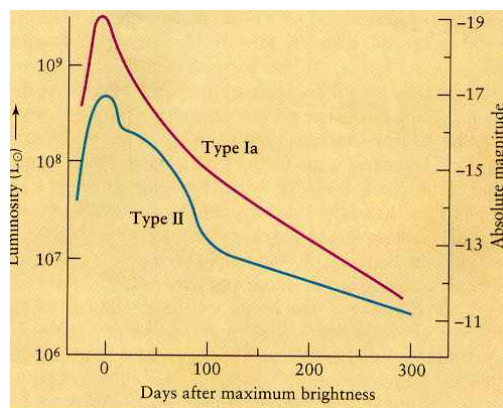
are also characterised by a massive increase in brightness and exhibit a rapid decrease in 'value' of absolute magnitude. Their apparent magnitude can also be measured, so the equation  $m - M = 5\log(d/10)$  can be used to calculate the distance in parsecs to the supernovae. The peak absolute magnitude value is -19.3, and it occurs after around 20 days.

Type 1a supernovae are due to an exploding white dwarf star which is part of a binary star system. The white dwarf increases in mass as it attracts material from its companion, and eventually reaches a size which allows fusion to start again, which causes the star to explode. This occurs when the star reaches a critical mass and produces a very consistent light curve.

However, there is some controversy regarding evidence that the universe seems to be accelerating at faster than the speed of light. This evidence comes from the red shift of galaxies, so 'dark energy' has been determined the culprit of this. There is however, another piece of controversy, as nothing is known about 'dark energy' as it could just be a fudge factor.

*Students should be familiar with the light curve of typical type 1a supernovae.*

The picture below illustrates a light curve for a typical type 1a supernovae, as well as a type II although you do not need to know about type II supernovae. The absolute magnitude peaks at around -19.3, usually occurring after approximately 20 days.



<http://www2.arnes.si/~gljsentvid10/snove.html> Supermassive black holes at the centre of galaxies.

It is said that there is a supermassive black hole at the centre of all galaxies. These black holes may have the mass several millions of times the mass of the sun.

*Calculation of the radius of the event horizon for a black hole, Schwarzschild radius ( $R_s$ ),  $R_s \approx 2GM/c^2$ .*

This equation gives the calculation of the radius of the event horizon for a black hole.

## Edexcel June 2010 Unit 6 Q3a

### Question:

In 2006 astronomers determined a new value for the Hubble constant. They calculated the velocity of recession  $v$  for a number of stars at a distance  $d$  from the Earth. They used units of  $\text{kms}^{-1}$  for  $v$  and Mpc (Megaparsecs) for  $d$ .

What might an astronomer actually measure to calculate a value for  $v$ ?

### Answer:

- Red shift
- OR Doppler shift
- OR frequency of electromagnetic radiation/light
- OR wavelength of electromagnetic radiation/light

## 3.9.3 Cosmology

### 3.9.3.1 Doppler effect

#### Content

- $\frac{\Delta f}{f} = \frac{v}{c}$  and  $z = \frac{\Delta \lambda}{\lambda} = -\frac{v}{c}$  for  $v \ll c$  applied to optical and radio frequencies
- Calculations on binary stars viewed in the plane of orbit.
- Galaxies and quasars.

$$\frac{\Delta f}{f} = \frac{v}{c} \text{ and } z = \frac{\Delta \lambda}{\lambda} = -\frac{v}{c} \text{ for } v \ll c \text{ applied to optical and radio frequencies}$$

The Doppler effect occurs in everyday life, for example when an ambulance passes you the change in pitch of the siren demonstrates this. As the ambulance travels towards you, the sound waves ‘bunch’ together, so essentially their wavelength decreases thus frequency increases as they travel at the same speed and  $c = f\lambda$ . The opposite occurs as the ambulance travels away from you.

This effect can also be applied to light, however in everyday situations the effect is not noticeable. An observer would be required to travel at very fast speeds, close to the speed of light, to observe these effects.

Redshift is a phenomenon that describes what occurs when the source of the light is moving away from the observer. This is because the wavelength appears to stretch out, ie increase, and red is at the longer wavelength end of the visible spectrum hence the name redshift.

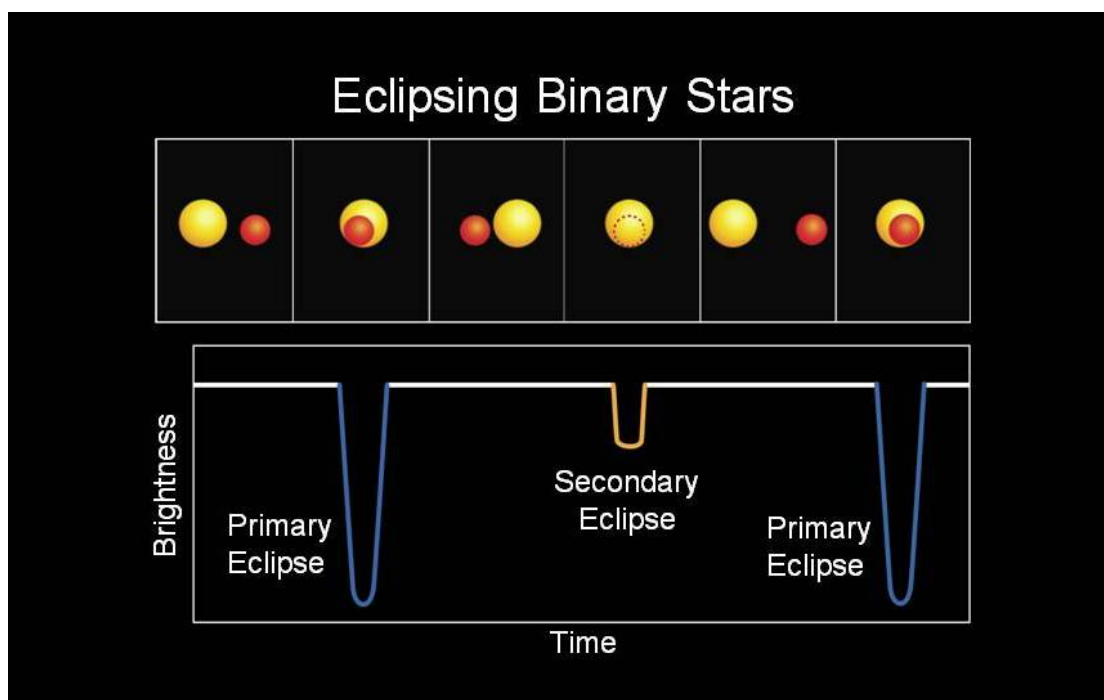
You can calculate redshift, denoted by the symbol  $z$ , by  $z = \Delta f/f = v/c$ , where  $v$  is the speed of the source, and  $\Delta f$  is the change in frequency both with their usual units. Redshift can also be calculated in terms of wavelength, by using the equation  $\Delta \lambda/\lambda = -v/c$ . Remember that velocity towards the observer is taken to be positive, so for objects moving towards you they will have a negative redshift. Redshift is the apparent shift to longer wavelengths, but for approaching sources the wavelength decreases so this is why there needs to be a negative sign. If the equation were to simply describe the Doppler shift, then this would not be necessary. Also, it is important to note that redshift has no units, as it is a ratio of two quantities with the same units.

#### *Calculations on binary stars viewed in the plane of orbit.*

A binary star system is a system of two stars rotating about a common centre of mass. The Doppler effect can be used in cosmology when studying an eclipsing binary star system, when one star passes in front of another, we can observe an eclipse, ie a dip in the brightness received (a higher value of apparent magnitude).

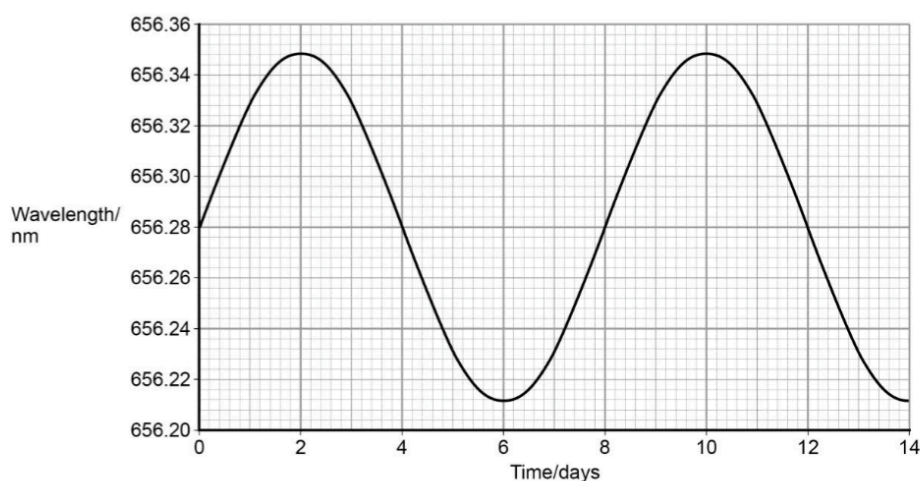
The example below shows two stars that emit different amounts of light (ie have a different surface temperature  $P = \sigma AT^4$ . When the apparent magnitude is at it lowest value, so

brightness is highest, both stars can be seen. This diagram below gives the apparent magnitude and corresponding positions of the stars.



[https://www.nasa.gov/mission\\_pages/kepler/news/kepler-34-35.html](https://www.nasa.gov/mission_pages/kepler/news/kepler-34-35.html)

The two stars A (orange) and B (red) are orbiting around a common centre of mass, thus each star will orbit around a given point. This means that you are able to observe a Doppler shift on each star. Take for example, star A, as it orbits around the common centre of mass. To an observer from Earth, at given times star A would appear to be retreating relative to the Earth, and at other times towards the Earth as it orbits. This observable change in wavelength can be measured and plotted on a graph of wavelength against time.



<http://filestore.aqa.org.uk/resources/physics/AQA-7407-7408-TG-A.PDF>

When the maximum wavelength is reached, the star is receding from the observer at its maximum velocity. At this point the two stars are next to each other. Also, the orbital period of the star would be 8 days (one full cycle). You can calculate the recessional velocity by using  $\Delta\lambda/\lambda = -v/c$ , with  $\Delta\lambda = (656.35 - 656.28) \times 3 \times 10^8 / 656.28 = 3.2 \times 10^4 \text{ ms}^{-1}$ .

If you also know the time period, you can calculate the diameter of the orbit using the circular motion equation  $\omega = v/r$ , which can be rearranged to  $2\pi r = vT$  (using  $\omega = 2\pi/T$ ). So  $3.2 \times 10^4 \times 8 \times 24 \times 3600 = 2.21 \times 10^{10}$  m. Thus diameter =  $7.04 \times 10^9$  m.

These calculations can only be applied to binary stars viewed in the same geometrical plane of orbit.

### *Galaxies and quasars*

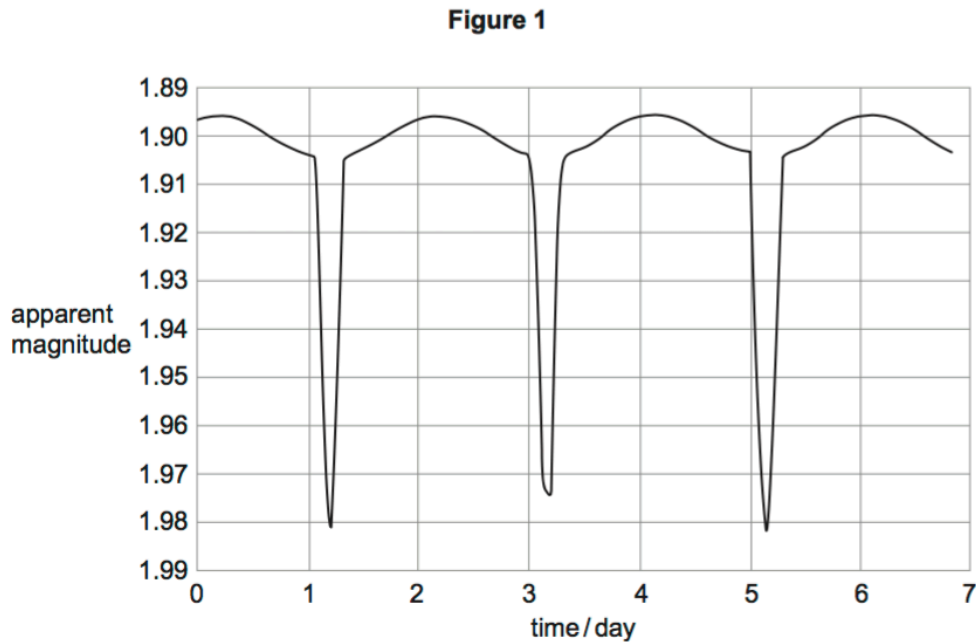
Some of the largest red shifts measured are those of the quasars. 'Quasi-stellar radio sources' are star-like objects with a very strong radio emission. This is where the name quasars came from. Although it was realised that the large majority of quasars were not predominantly radio emitters, so quasars are now referred to as 'quasi-stellar objects'. Tens of thousands of quasars have been discovered, with most predominantly emitting their energy in the infrared region of the electromagnetic spectrum. More detail on quasars is given in 3.9.3.3.

In terms of galaxies, the stars contained within very distant galaxies can not be resolved individually, thus only the behaviour of the galaxy can be studied. The spectrum of light absorbed on Earth from these galaxies are usually always significantly redshifted. This gives the indication that the universe is expanding.

The redshift of galaxies and quasars can be calculated as the ratio of the objects (ie the galaxy's) recession velocity to the speed of light. This is represented as  $z = v/c$ . The  $z$  is a positive number for redshifts because the recessional velocity is a negative number, making the equation positive.

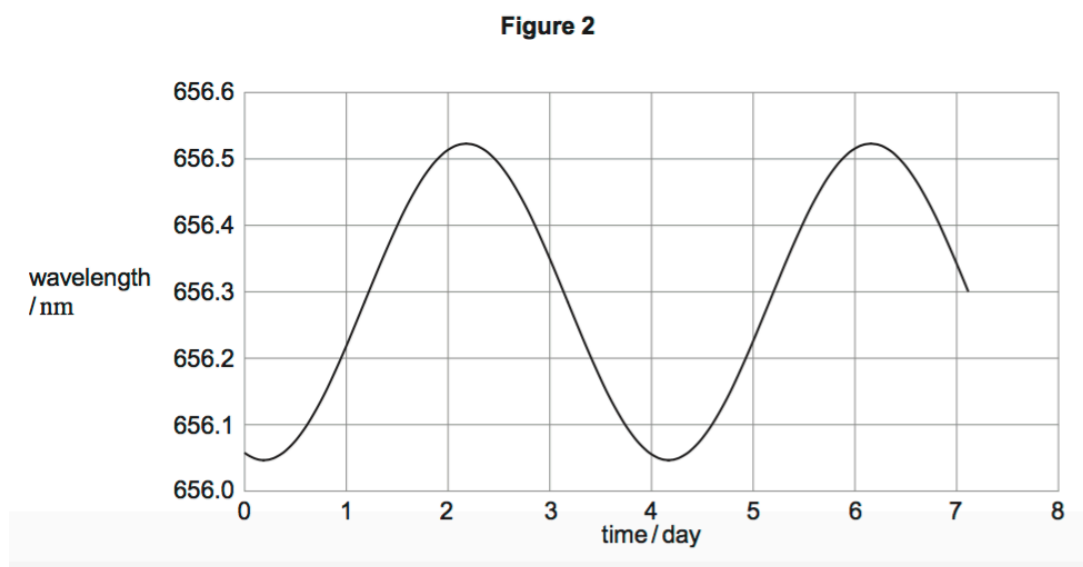
## AQA June 2015 Unit 5 Q2ab

Menkalinan is an eclipsing binary star system in the constellation of Auriga. **Figure 1** shows the variation in apparent magnitude with time (light curve) for Menkalinan.



Analysis of the spectrum of one of the stars shows a periodic variation in wavelength

**Figure 2** shows the results for one of the spectral lines in the Hydrogen Balmer series. The wavelength for this line as measured for a source in a laboratory on the Earth is 656.28 nm.



### Question:

Describe the physical processes that give rise to the shape of each graph. Go on to show how the information in the graphs can be used to determine properties, such as the speed and period, of the Menkalinan binary system. You should include appropriate calculations in your answer.

The quality of your written communication will be assessed in your answer.

### Answer:

‘The explanations expected in a good answer should include most of the following physics ideas’

- The time period,  $T$ , is the time from the first dip in the light curve to the third dip.
- This is approximately 4 days
- This is one full cycle for the wavelength graph.
- One full cycle is approximately 4 days.
- When one star passes in front of the other the amount of light received changes.
- The brightest (lowest value of) apparent magnitude occurs when both stars can be seen.
- The dips occur when one star is in front of the other.
- The similarity in the dips suggests that both stars have similar temperatures/sizes
- The variation in wavelength is due to the Doppler effect.
- The peaks and troughs occur when the stars are moving at their greatest velocity away from / towards us.
- The biggest change in wavelength is  $656.52 \text{ nm} - 656.28 \text{ nm} = 0.24 \text{ nm}$
- The orbital speed, is therefore  $\Delta\lambda \times c / \lambda$
- $= 0.24 \times 3 \times 10^8 / 656.28 = 1.1 \times 10^5 \text{ ms}^{-1}$
- The orbital radius is therefore  $v / (2\pi / T) = 6.1 \times 10^9 \text{ m}$

### Question:

The black body temperature of each star is approximately 9200 K.

Explain why a Hydrogen Balmer line was chosen for the analysis of wavelength variation

### Answer:

- The temperature (9200K) indicates that the star is in spectral class A.
- Hydrogen Balmer lines are strongest in A class stars and therefore would be more easily measured

### *Exam tip:*

**GIVE SPECIFIC DETAILS, FOR EXAMPLE, THAT 9200K IS ASSOCIATED WITH SPECTRAL CLASS A!**

## AQA June 2007 Unit 5 Q5

Explain what is meant by

**Question:**

A white dwarf,

**Answer:**

- collapsed core of giant star
- OB class, therefore hot (therefore white)
- high value of absolute magnitude, therefore dim (therefore small) star

**Question:**

Quasar,

**Answer:**

- Very large power output
- Large shift or very distant
- Small for its power output or rapid variations in power output



### 3.9.3.2 Hubble's law

#### Content

- Red shift  $v = Hd$
- Simple interpretation as expansion of universe; estimation of age of universe, assuming  $H$  is constant.
- Qualitative treatment of Big Bang theory including evidence from cosmological microwave background radiation, and relative abundance of hydrogen and helium.

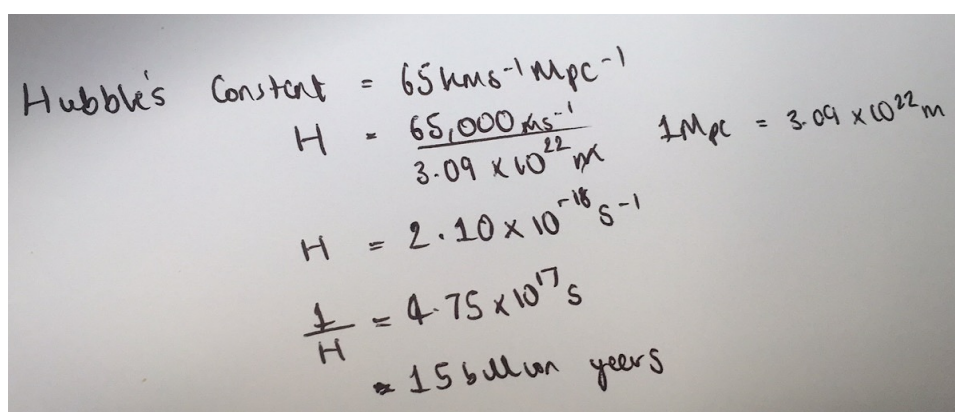
#### *Red shift $v = Hd$*

The equation  $v = Hd$  is referred to as Hubble's Law. It states the relationship with recessive velocity and distance to the galaxy.  $v$  is recessive velocity and  $d$  is distance to the galaxy.  $H$  is Hubble's constant, the currently accepted value is  $65 \text{ kms}^{-1} \text{ Mpc}^{-1}$ . Thus for this constant, the units used for velocity are  $\text{kms}^{-1}$  and for distance mega parsecs (Mpc). Drawing a graph of velocity against distance and calculating the gradient will give you Hubble's constant.

#### *Simple interpretation as expansion of universe; estimation of age of universe, assuming $H$ is constant.*

The basic interpretation of a graph of velocity against distance is that the universe is expanding. The further away the galaxy, the faster it moves, so for every distant galaxy it will seem as if the galaxy in front is moving away from it at a faster speed. This does suggest however, that the expansion rate is constant but recent observations suggest that the galaxies are accelerating away from each other. And so consequently, the rate of expansion of the universe is increasing.

The picture below illustrates how you can calculate an estimate for the age of the universe using Hubble's constant, and assuming  $H$  is in fact, constant. I have used  $H = 65 \text{ kms}^{-1} \text{ Mpc}^{-1}$ , other values may be used in other examples.



Handwritten calculations for the age of the universe using Hubble's constant:

$$\begin{aligned}\text{Hubble's Constant} &= 65 \text{ kms}^{-1} \text{ Mpc}^{-1} \\ H &= \frac{65,000 \text{ ms}^{-1}}{3.09 \times 10^{22} \text{ m}} & 1 \text{ Mpc} &= 3.09 \times 10^{22} \text{ m} \\ H &= 2.10 \times 10^{-18} \text{ s}^{-1} \\ \frac{1}{H} &= 4.75 \times 10^{17} \text{ s} \\ &\approx 15 \text{ billion years}\end{aligned}$$

Only if the universe has expanded at a constant rate  $H$  is a constant. Using Type 1a supernovae as standard candles, distant galaxies have been shown to be less bright than

originally predicted. The data suggest in fact, that the rate of expansion is not only increasing, but accelerating. The constant would therefore not hold true, and the actual age of the universe would be much older. Cosmologists have stipulated that '**dark energy**' is the cause of this expansion, and that the energy exerts a repulsive force within the universe that causes apparently void space to expand. Its influence must then grow as the universe expands.

*Qualitative treatment of Big Bang theory including evidence from cosmological microwave background radiation, and relative abundance of hydrogen and helium.*

Evidence comes from two main sources, outlined below:

1. One piece of evidence states that the high energy gamma electromagnetic radiation produced shortly after the Big Bang, should have over time been redshifted to wavelengths in the microwave region. This radiation should fill the universe, and was detected inadvertently in the 1960s. Later experiments showed that the black-body temperature was around 2.73K, which is what should be expected if the radiation were to be emitted in the gamma region soon after the Big Bang. Also, the distribution of the radiation is not completely uniform, which supports the idea that these variations in energy-density allowed for gravitational forces to act and go on to produce the galaxies we now see. From the evidence a more accurate age of the universe – 13.7 billion years, was put forward.
2. The universe is around 73% hydrogen and 25% helium, so the ratio of helium to hydrogen is around 3:1. These results are consistent with the predictions by the model. Helium is produced by nuclear fusion but this requires extremely hot temperatures, so as the temperature drops the ability to fuse elements is diminished, resulting in the relative abundance of 3:1, with around 2% of the universe being made of other elements. All other elements were produced within stars by later fusion-processes.

Other indirect evidence for the Big Bang is Hubble's relationship, which supports the idea of an expanding universe via red shift observations of distant galaxies.

## AQA June 2014 Section 5 Q2a

### Question:

‘The term Big Bang was first used in 1949 by the astronomer Fred Hoyle to refer to, what was then, a controversial theory describing the formation of the Universe.

Explain what is meant by the Big Bang theory. Your answer should include:

- A description of the main aspects of the theory
- An explanation of the different pieces of evidence that support the theory.

The quality of written communication will be assessed as part of your answer.’

### Answer:

#### For 6 marks:

- **Examples of the points made in the response:**
- The universe has expanded from a single hot dense point
- This expansion started approximately 13 billion years ago.
- Evidence comes from the Hubble relationship and observations of the red shift of distant galaxies.
- This shows that the galaxies are moving outwards from a single common point.
- (Conclusive) evidence comes from the cosmological microwave background radiation (which disproved the steady state theory)
- This follows a black body radiation curve which corresponds to a temperature of 2.7 K
- This can be interpreted as the left over “heat” of the big bang,
- Hydrogen and helium is present in the Universe in the ratio 3:1
- This supports the idea that a very brief period of fusion occurred when the Universe was very young, which is consistent with the Big Bang theory.

The information conveyed by the answer is clearly organised, logical and coherent using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate describes the big bang theory as the Universe expanding from an extremely dense and hot point over the past 13.6 billion years. The candidate also describes the evidence from, the relative abundances of H and He and the measurement of the microwave background radiation and states they support the big bang theory. Hubble’s Law may also be used to support the idea that the Universe is expanding

# OCR (A) A Level Specimen 1

## Question:

The Big Bang theory is an explanation for the start of the Universe.

Explain how the cosmic microwave background radiation supports the Big Bang theory for the start of the Universe. Comment on the relevance of the data in **Fig. 23.1** concerning the Big Bang theory

## Answer:

### Big Bang theory

- Predicts that all galaxies will be receding.
- Galaxy velocity proportional to distance from

### Red Shift

- Radiation from Virgo shows increase in wavelength or red shift  
Change in wavelength caused by motion of galaxy or reference to Doppler Effect
- Evidence that Virgo is receding from Earth.
- Support for Big Bang theory.

### Blue Shift

- Andromeda shows blue shift
- Andromeda approaching Earth
- Caused by gravitational attraction.

### CMBR

- Formed as gamma radiation at Big Bang
- Galactic red shift to microwave wavelength
- Intensity is uniform in all directions
- Corresponds to a temperature of 2.7K
- (Very small) ripples in intensity corresponding to formation of first stars or galaxies.

## AQA June 2015 Unit 5 Q4c

### Question:

NGC 3842 is  $3.3 \times 10^8$  light years from the Earth, and is receding at a velocity of  $6.3 \times 10^6 \text{ ms}^{-1}$

### Answer:

The easiest way to calculate this is to have  $v$  in the units ' $\text{ms}^{-1}$ ' and distance in ' $\text{m}$ ', as shown below.

Handwritten calculation for Hubble's constant  $H$ :

$$\text{so } H = \frac{v}{d} \text{ so } \frac{\text{ms}^{-1}}{\text{m}} = \text{s}^{-1}$$
$$\therefore H = \frac{6.3 \times 10^6 \text{ ms}^{-1}}{[(3.3 \times 10^8) \times (9 \times 46 \times 10^{15})] \text{ m}}$$
$$H = 2.02 \dots \times 10^{-15} \text{ s}^{-1}$$
$$\frac{1}{H} \approx 5.0 \times 10^{17} \text{ s}$$

### 3.9.3.3 Quasars

#### Content

- Quasars as the most distant measurable objects.
- Discovery of quasars as bright radio sources.
- Quasars show large optical red shifts; estimation involving distance and power output.
- Formation of quasars from active supermassive black holes.

#### *Quasars as the most distant measurable objects.*

We also now know that quasars are some of the most distant objects because of their very larger redshift. Applying the inverse-square law to the light enables predictions of the power output of quasars to be the equivalent to the power output of multiple galaxies.

#### *Discovery of quasars as bright radio sources*

Quasars were actually first discovered as extremely powerful radio sources; as optical telescopes were unable to resolve these objects.

#### *Quasars show large optical red shifts; estimation involving distance and power output*

Quasars show large optical redshifts; these suggest they are travelling at speeds of well above 0.1x the speed of light. One example is that of Quasar 3C 273, whose hydrogen Balmer lines measure at a wavelength of roughly 760nm, whereas the value on Earth of these same Balmer lines gives a value of 656nm. The redshift value is given at 0.16 and its distance is around 650Mpc away.

Their typical power output tends to be around  $10^{42}\text{W}$ .

#### *Formation of quasars from active supermassive black holes.*

Quasars are believed to come from active supermassive black holes present in young active galaxies. The supermassive black hole draws in a vast amount of matter in something called an accretion disc. Matter spins around in this disc and continually accelerates. As it spins faster, it will gain more kinetic energy and will heat up. As the matter warms, it rubs against other bits of matter to which there is friction between, and this gives us what we perceive to be visible light.

### 3.9.3.4 Detection of exoplanets

#### Content

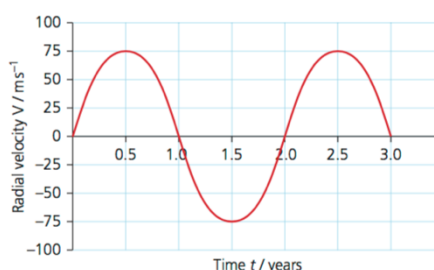
- Difficulties in the direct detection of exoplanets.
- Detection techniques will be limited to variation in Doppler shift (radial velocity method) and the transit method.
- Typical light curve.

#### *Difficulties in the direct detection of exoplanets.*

To begin, exoplanets are planets that orbit a star other than the Sun. What makes them difficult to detect is that, like our planet, they give off almost no light relative to the luminosity of the star they orbit. The only significant light that gives away their existence is light from the star that they orbit which reflects off them.

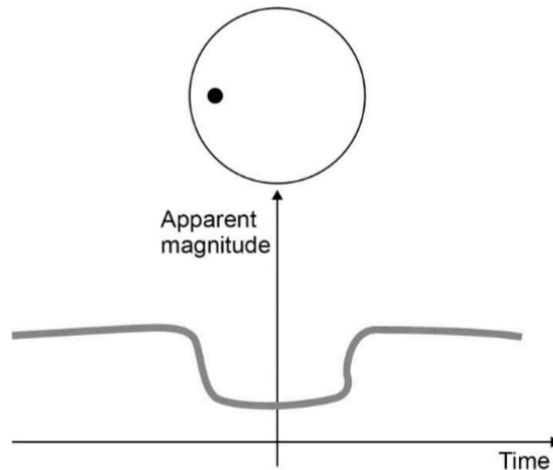
#### *Detection techniques will be limited to variation in Doppler shift (radial velocity method) and the transit method.*

- The **radial velocity method** relies on the fact both the star and planet orbit around a common centre of mass. For our solar system, the common centre of mass actually lies within the sun, so clearly the orbit of the sun around this point is not very visible. The Doppler shift can be measured in the light from the star as it ‘wobbles’ about this point, where differences in the spectral lines from usual values shows this shift.
- The radial velocity curve shows the velocity of the star; an example is given below. The period of the exoplanet will be the same as the period of the star on the curve.



[http://resources.collins.co.uk/Wesbite%20images/AQA/Physics/sb2module/9780007597642\\_Astrophysics.pdf](http://resources.collins.co.uk/Wesbite%20images/AQA/Physics/sb2module/9780007597642_Astrophysics.pdf)

- The **transit method** involves the dimming of its apparent magnitude (increase in value), as the brightness of a star decreases when an exoplanet travels across its face. When a planet passes in front of a star to an observer on Earth, the event is described as a ‘transit’.



<http://filestore.aqa.org.uk/resources/physics/AQA-7407-7408-TG-A.PDF>

- The graph above, of apparent magnitude against time is called a light curve. It illustrates the dimming of apparent magnitude as a planet transits a star.
- There will be a fractional drop in brightness, that will be in proportion to the size of the planet. You can find the area of the star that must be occupied for this fractional drop in brightness to occur.

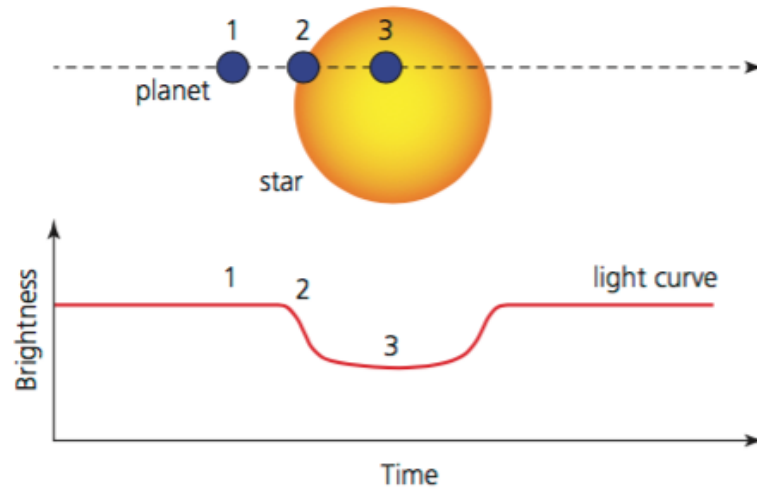
Example: A star of diameter  $10^{24}$  m dips in brightness by 0.001% when an exoplanet transits. Calculate the radius of the exoplanet.

• Area of star  $\pi \times (10^{12})^2 = 3.14 \times 10^{12} \text{ m}^2$   
 • Brightness dip of 0.001% so this means that 0.001% of the area is being blocked by the exoplanet.  
 •  $3.14 \times 10^{12} \times 0.001\% = \text{area of exoplanet}$   
 • So  $3.14 \times 10^7 \text{ m}^2 = \pi (\text{exoplanet})^2$   
 • So rearrange for exoplanet  $= 3.16 \times 10^3 \text{ m}$



### Typical light curve

A typical light curve is shown below, and the corresponding positions of the exoplanet whilst in the transit.



# AQA Paper 3B Section 'A' Specimen Paper 2014

## Q4.123

### Question 4.1

'In 1999 a planet was discovered orbiting a star in the constellation of Pegasus.

State one reason why it is difficult to make a direct observation of this planet.'

### Answer 4.1

- Star much brighter than reflected light from planet
- Planet very small and distant – subtends very small angle compared to resolution of telescopes

### Question 4.2

'The initial discovery of the planet was made using the radial velocity method which involved measuring a Doppler shift in the spectrum of the star.

Explain how an orbiting planet causes a Doppler shift in the spectrum of a star'

### Answer 4.2.

- Planet and star orbit around common centre of mass that means the star to moves towards/away from Earth as planet orbits
- Causes shift in wavelength of light received from star

### Question 4.3

'The discovery was confirmed by measuring the variation in the apparent magnitude of the star over a period of time.

Explain how an orbiting planet causes a change in the apparent magnitude of a star. Sketch a graph of apparent magnitude against time (a light curve) as part of your answer.'

### Answer 4.3

- Light curve showing constant value with dip □
- When planet passes in front of star (as seen from Earth), some of the light from star is absorbed and therefore the amount of light reaching Earth reduced
- Apparent magnitude is a measure of the amount of light reaching Earth from the star

## Sources:

<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>

<https://www.itp.uni-hannover.de/~zawischa/ITP/diffraction.html>

<http://www.cyberphysics.co.uk>

<http://www.bbc.co.uk/education>

<http://ibguides.com/physics/notes/measurement-and-uncertainties>

<http://www.doctrionics.co.uk/voltage.htm>

[http://homepages.engineering.auckland.ac.nz/~pkel015/SolidMechanicsBooks/Part\\_I/BookS\\_M\\_Part\\_I/08\\_Energy/08\\_Energy\\_01\\_Energy\\_in\\_Deforming\\_Materials.pdf](http://homepages.engineering.auckland.ac.nz/~pkel015/SolidMechanicsBooks/Part_I/BookS_M_Part_I/08_Energy/08_Energy_01_Energy_in_Deforming_Materials.pdf)

<https://www.kerboodle.com/app/courses/17892/modules/Home>

[http://www.met.reading.ac.uk/pplato2/h-flap/phys6\\_4.html](http://www.met.reading.ac.uk/pplato2/h-flap/phys6_4.html)

[http://abyss.uoregon.edu/~js/glossary/radio\\_telescope.html](http://abyss.uoregon.edu/~js/glossary/radio_telescope.html)

<http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/raylei.html>

<http://www.physicsclassroom.com/class/estatics/Lesson-4/Electric-Field-Intensity>

[https://en.wikipedia.org/wiki/Synchronous\\_orbit](https://en.wikipedia.org/wiki/Synchronous_orbit)

<http://hyperphysics.phy-astr.gsu.edu/hbase/electric/dielec.html>

<http://www.physbot.co.uk/capacitance.html>

<http://www.physbot.co.uk/gravity-fields-and-potentials.html>

[https://en.wikipedia.org/wiki/Magnetic\\_field#/media/File:Earths\\_Magnetic\\_Field\\_Confusion.svg](https://en.wikipedia.org/wiki/Magnetic_field#/media/File:Earths_Magnetic_Field_Confusion.svg)

<http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/cyclot.html>