1. (a) Figure 1 shows two stars, A and B, which form a binary star system. The two stars orbit their common centre of mass with the same period of rotation. The Earth is in the same plane as the orbits of the two stars.

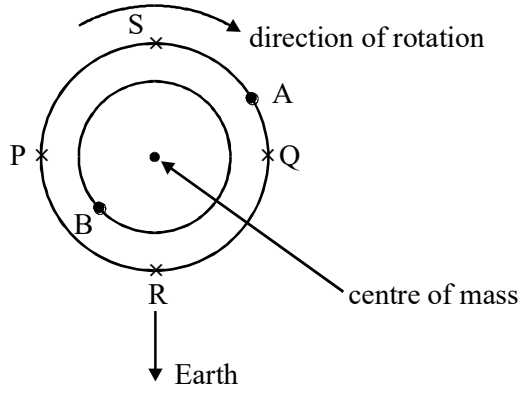


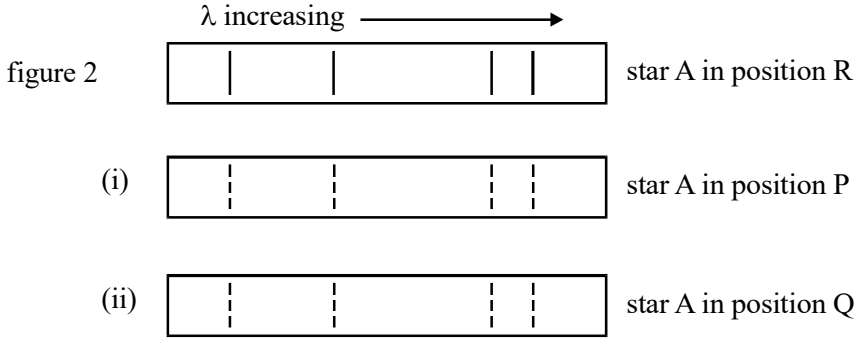
Figure 1

Figure 2 shows part of the spectrum of star A when it is in position R.

The spectrum of star A is observed when it is in position P and again when it is in position Q.

Explaining your reasoning, draw in the two boxes (i) and (ii) the same part of the spectrum of star A when it is at P and Q, respectively.

(for reference, the dotted lines in boxes (i) and (ii) show the same spectrum as in figure 2)



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(5)

(b) (i) The calcium K line from a laboratory source has a wavelength of 3.9342×10^{-7} m. The same line, when measured in the spectrum of star A, when A is in position S in figure 1, has a wavelength of 4.7804×10^{-7} m. Calculate the velocity of the binary system.

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(ii) The wavelength of the same calcium K line, when measured in the spectrum of star A as it orbits, varies from a maximum of 4.7936×10^{-7} m to a minimum of 4.7672×10^{-7} m over an interval of 120 days. Calculate the radius of the orbit.

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(7)
(Total 12 marks)

2. (a) (i) State what is meant by the *Doppler effect.*

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(ii) Explain how observing the spectrum of a star and applying the Doppler equation to the experimental observations enables the speed of recession of the star to be obtained.

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(iii) Give an example from astronomy of a situation where the double Doppler effect would have to be applied, explaining why it is necessary to apply the double effect.

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(6)

(b) One of the brightest galaxies in the Virgo cluster of galaxies is named M87 and is approximately 4.9×10^7 light years away.

(i) Use the value of the Hubble constant given in the Data Sheet to show that the speed of M87 relative to Earth is about $8 \times 10^5 \text{ms}^{-1}$.

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(ii) The wavelength of one particular line in the hydrogen spectrum measured in the laboratory is 6.5647×10^{-7} m. Use the result obtained in part (b)(i) to calculate the wavelength of the equivalent line observed in the spectrum of M87.

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(4)

(Total 10 marks)

3. Photographs of lines in the spectrum of the Sun show changes in wavelength due to the Doppler effect. Due to the rotation of the Sun about its axis, one edge of the Sun is approaching the Earth, and the other edge is receding.

(a) Give expressions for the observed change in the wavelength of a line of original wavelength, λ,

(i) for light coming from the edge which is moving away from the observer at speed v,

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(ii) for light coming from the edge which is moving towards the observer at speed v.

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(2)

(b) The apparent wavelength of a line of original wavelength 589 nm is measured from photographs showing opposite ends of the diameter of the Sun The difference between the readings is 78×10^{-3} nm.

Calculate

(i) the speed, v, of a point on the edge of the Sun,

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(ii) the angular speed of rotation of the Sun.
radius of Sun = 7.0×10^8 m

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(4)
(Total 6 marks)

4. Quasars are star-like objects whose spectra have very large red shifts.

(a) What property of quasars led to their discovery?

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(1)

(b) 3C 48 is a quasar which has one of the largest red shifts ever measured. A particular spectral line has a value of 279.8 nm when measured using a laboratory source. The equivalent line in the spectrum of this quasar is 382.5 nm.

(i) Calculate the speed of this quasar relative to the Earth, ignoring relativistic effects.

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(ii) Show that the distance to the quasar is approximately 2×10^9 pc. Assume the Hubble constant is 65 km s^{-1} Mpc^{-1}.

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(3)

(c) To have the same apparent magnitude as Quasar 3C 48, the Sun would have to be placed approximately 2×10^3 pc from the Earth.

(i) Assuming the distance to the quasar is 2×10^9 pc, use the inverse square law to estimate the ratio of the power output of Quasar 3C 48 to that of the Sun.

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(ii) A controversy exists concerning the nature of quasars. List the properties which give rise to this controversy.

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(4)

(Total 8 marks)

5. Describe the main features of the Big Bang theory and the evidence that supports it.
You may be awarded marks for the quality of written communication in your answer.

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(Total 4 marks)

6. (a) Describe the main features of black holes and quasars.

You may be awarded marks for the quality of written communication in your answer.

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(3)

(b) There is some evidence to suggest that there is a black hole of 3×10^9 solar masses at the centre of the galaxy M87. Calculate the radius of the event horizon for this black hole.

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(2)
(Total 5 marks)

7. HT Cas is an eclipsing binary system in the constellation Cassiopeia. **Figure 1** shows the variation in apparent magnitude (light curve) of the system over a period of time.

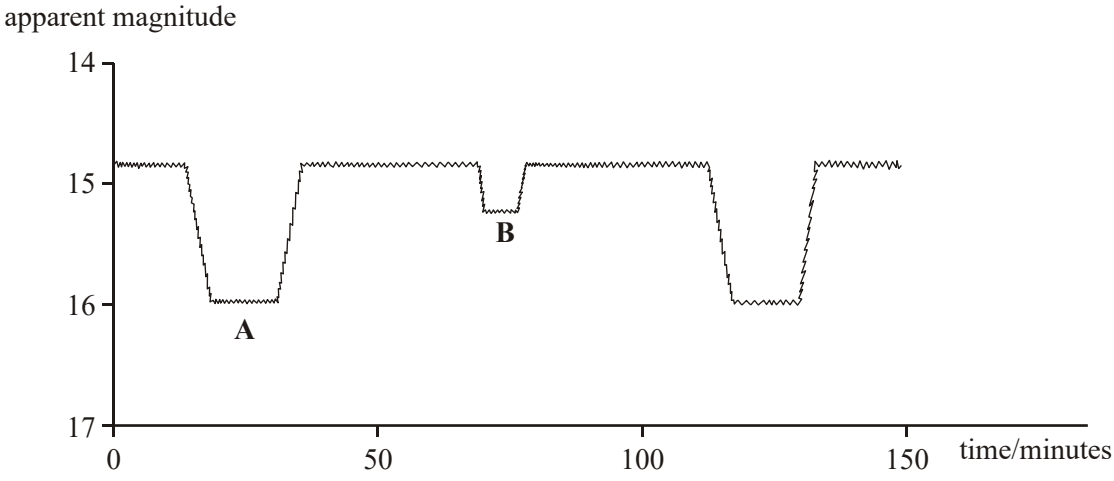

Figure 1

(a) Explain how the motion of the two stars produces the light curve in **Figure 1**.
Refer to regions **A** and **B** in your answer.

You may be awarded marks for the quality of written communication in your answer.

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(4)

(b) Analysis of the spectra produced by the system shows that one of the stars is moving with an orbital speed of 400 km s^{-1}.

(i) The wavelength of a hydrogen line in the spectrum of this star has an average value of 656.28 nm. Calculate the maximum and minimum values of the wavelength of this line due to the star's orbital motion.

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(ii) Use **Figure 1** to obtain a value of the period of the binary system, and calculate the radius of the orbit of this star.

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(6)
(Total 10 marks)

8. The red shift of a galaxy's spectrum can be used to determine its velocity, relative to the Earth.

(a) The wavelength of the hydrogen alpha line in the spectrum of the galaxy NGC 1357 is 660.86 nm. The wavelength of the same line from a laboratory based source is 656.28 nm. Calculate the velocity of galaxy NGC 1357.

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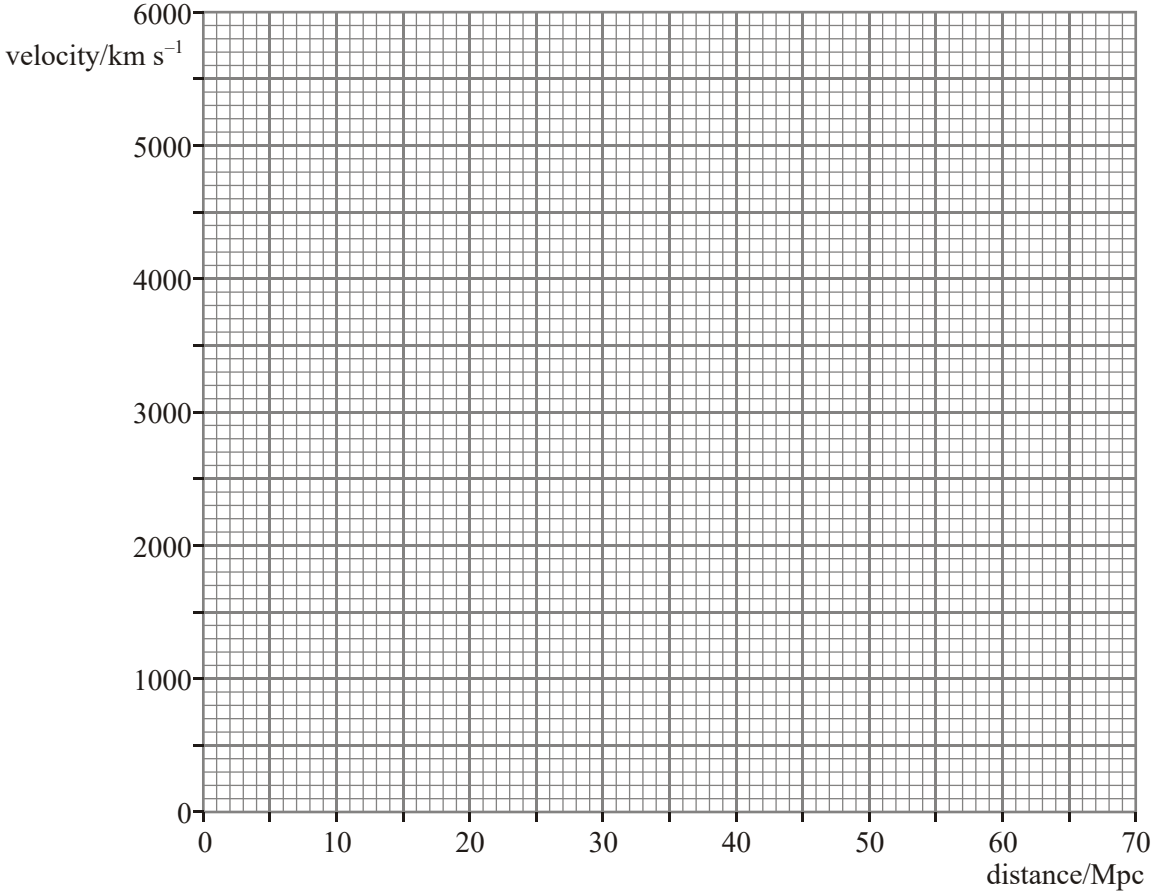
(2)

(b) Use the value obtained in part (a) to complete the table. Plot a graph of the data in the table below and use the graph to determine a value for the Hubble constant.

galaxy	velocity/km s^{-1}	distance/Mpc
NGC 1357		28
NGC 1832	2000	31
NGC 5548	5270	67
NGC 7469	4470	65



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(3)

(Total 5 marks)

9. The red shift of a galaxy's spectrum can be used to determine its velocity, relative to the Earth.

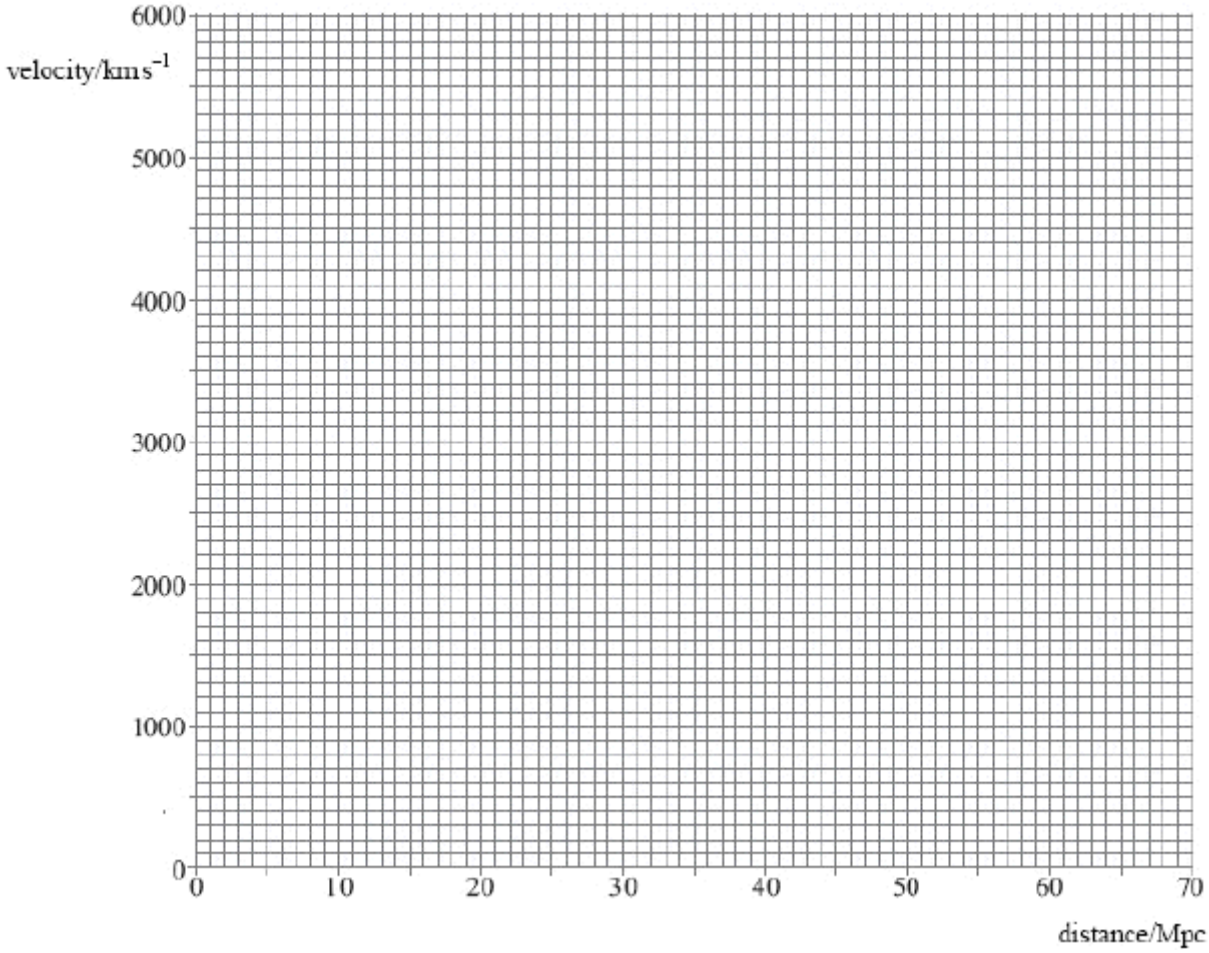
(a) The wavelength of the hydrogen alpha line in the spectrum of the galaxy NGXC 1357 is 660.86 nm. The wavelength of the same line from a laboratory based source is 656.28 nm. Calculate the velocity of galaxy NGC 1357.

Velocity = ...

(2)

(b) Use the value obtained in (a) to complete the table. Plot a graph of the data in the table and use the graph to determine a value for the Hubble constant.

galaxy	velocity/km s^{-1}	distance/Mpc
NGC 1357		28
NGC 1832	2000	31
NGC 5548	5270	67
NGC 7469	4470	65



Hubble constant .....

(3)

(c) Analysis of light from supernovae suggests that the expansion of the Universe is accelerating.

(i) Explain how the light from supernovae can be used to determine the distance to galaxies.

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(ii) What is the name given to the energy believed to be responsible for this accelerating expansion?

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(3)
(Total 8 marks)