1 Cygnus A may be the nearest quasar yet discovered.

(a) Cygnus A has a redshift, z, of 0.057.
Calculate the distance to Cygnus A. State an appropriate unit.

answer = _____ unit = _____

(4)

(b) The first quasars were discovered in the 1950s. What property of quasars led to their discovery?

_____

_____

(1)

(Total 5 marks)

2 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.

_____

_____

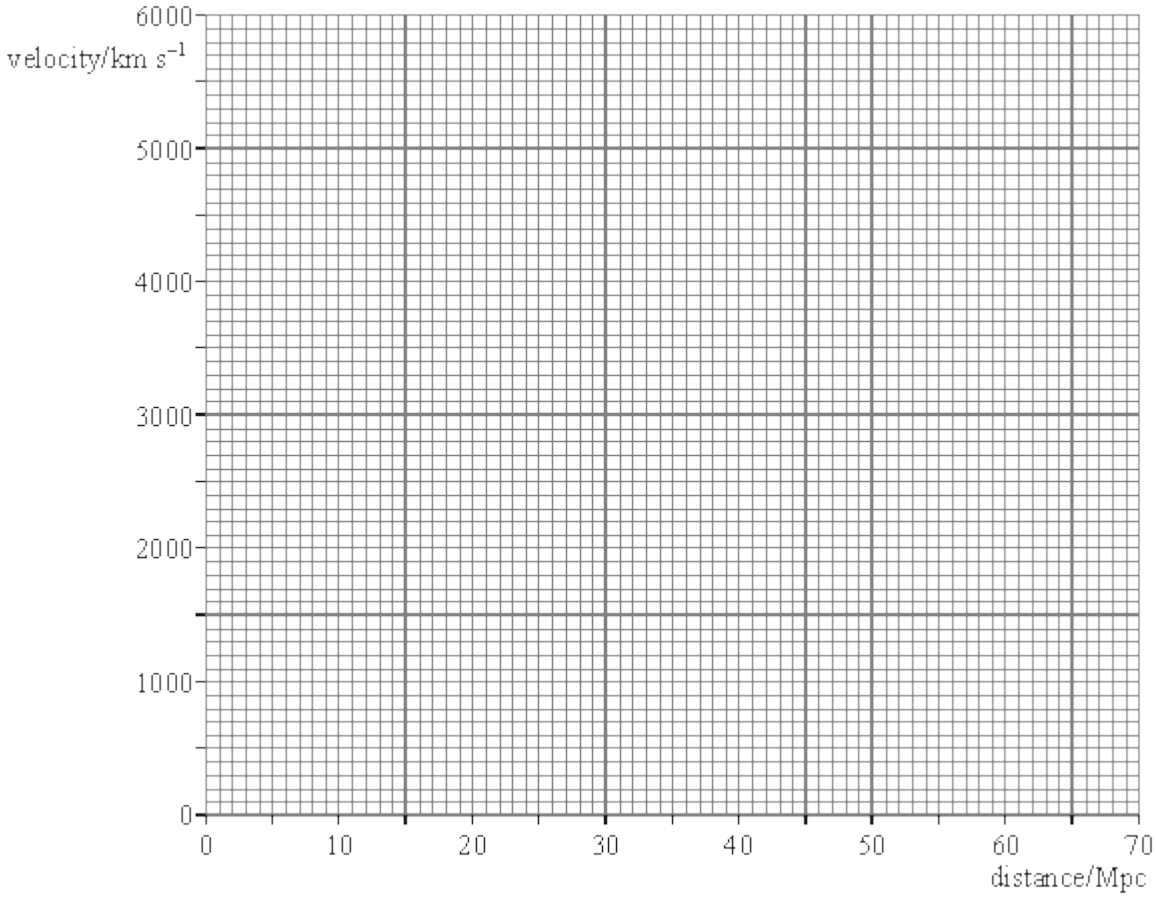
_____

_____

(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



_____

_____

_____

_____

(3)

(Total 5 marks)

3 (a) State which property of the first identified quasar led to its discovery.

_____

(1)

(b) 3C48 is a quasar in the constellation Triangulum. It is believed to have a power output 4×10^{11} times greater than that of the Sun. At the Earth, the Sun's intensity is 1.4×10^{17} times greater than that of the quasar.

(i) Calculate, using the inverse square law, the distance from Earth to this quasar in AU.

distance = _____ AU

(3)

(ii) Measurements of the red shift of the quasar suggest the expansion of the Universe has accelerated since the detected light left the quasar.
State the cause of this acceleration.

_____

(1)

(Total 5 marks)

4 Treated as a single source, the Andromeda galaxy has an apparent magnitude of 3.54 and an absolute magnitude of –20.62.

(a) Calculate the distance to the Andromeda galaxy.

_____

_____

_____

_____

_____

(2)

(b) The Andromeda galaxy is believed to be approaching the Milky Way at a speed of 105 km s^{-1}.
Calculate the wavelength of the radio waves produced by atomic hydrogen which would be detected from a source approaching the observer at a speed of 105 km s^{-1}.

wavelength of atomic hydrogen measured in a laboratory = 0.21121 m.

(2)

(c) Some astronomers believe the Andromeda galaxy may collide with the Milky Way in the distant future. Estimate a time, in s, which will elapse before a possible impact with the Milky Way.

(2)

(Total 6 marks)

5 NGC 3842 is a galaxy which contains one of the biggest black holes ever discovered.

(a) State what is meant by a black hole.

(1)

(b) The mass of the black hole in NGC 3842 is believed to be 1.0×10^{10} times greater than that of the Sun.

Calculate the radius of its event horizon.

radius = _____ m

(2)

(c) NGC 3842 is 3.3×10^{8} light years from the Earth, and is receding at a velocity of 6.3×10^{6} m s^{-1}.

Estimate, using these data, an age in seconds for the Universe.

age of Universe = _____ s

(3)

(Total 6 marks)

6 The Antennae Galaxies are a pair of colliding galaxies in the constellation Corvus.

(a) Measurements of the *red shift* of radio signals from the galaxies suggest they are approximately 25 Mpc from the Earth.

(i) Explain what is meant by red shift.

_____

_____

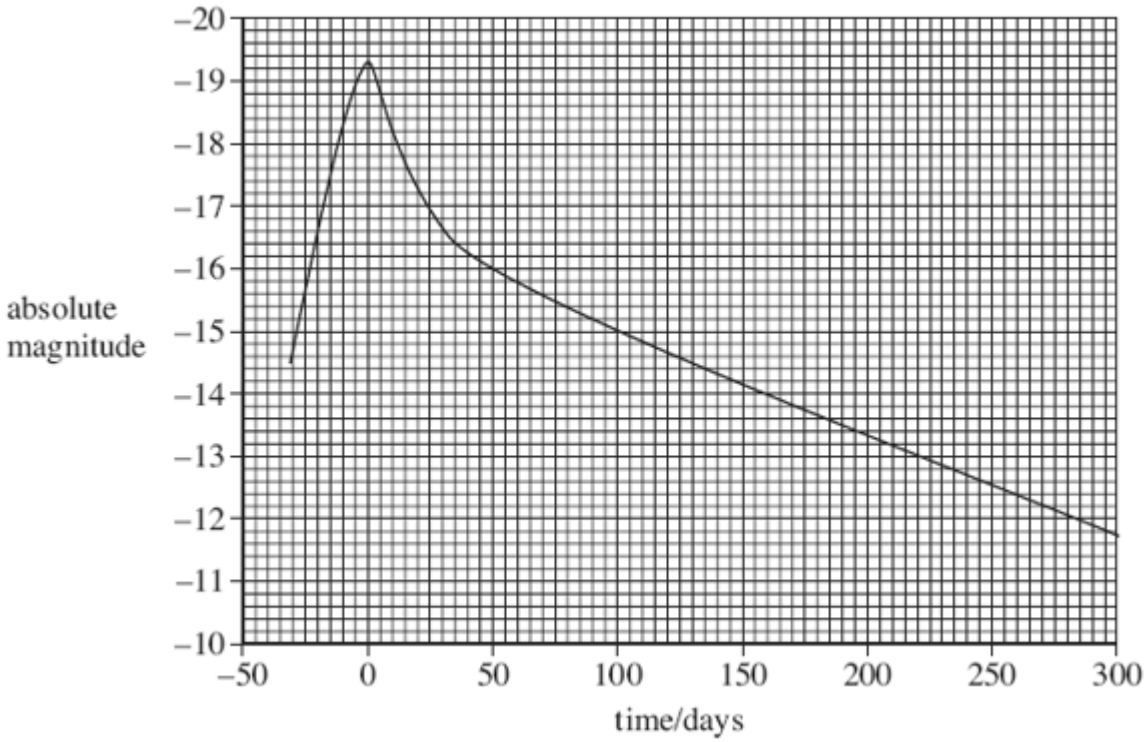
(1))

(ii) Calculate the recessive velocity of the Antennae Galaxies.

answer = _____km s^{-1}

(2)

(b) SN 2008sr was a type 1a supernova detected in the Antennae Galaxies. The figure below is the light curve of a type 1a supernova.



(i) With reference to the figure above, explain why type 1a supernovae can be used as standard candles to determine distances.

_____

_____

_____

_____

_____

(2)

(ii) The peak value for the apparent magnitude of this supernova was 12.9. Using this measurement and information from the figure above, calculate the distance to the Antennae Galaxies in Mpc.

answer = _____Mpc

(2)

(c) Why is it important for astronomers to have several independent methods of determining the distance to galaxies?

_____

_____

(1)

(Total 8 marks)

7 (a) The Sombrero Galaxy is 50 million light years away from the Earth.

(i) Calculate the distance to this galaxy in parsecs.

_____

(ii) Use Hubble's Law to show that this galaxy is receding at 1000 km s^{-1}.

_____

_____

(iii) One of the lines in the Hydrogen spectrum has a wavelength of 656.3 nm when measured in a laboratory on Earth. Calculate the wavelength of the same line in the observed spectrum of the Sombrero Galaxy.

(4)

(b) Show how Hubble's Law can be used to estimate the age of the Universe. State the assumption made.

(3)

(Total 7 marks)

8 (a) State what is meant by the Hubble constant.

(1)

(b) The recessional velocity of a galaxy 8.0×10^8 ly from Earth is measured to be 1.8×10^4 km s^{-1}.

Show that this suggests a value for the Hubble constant of 73 km s^{-1} Mpc^{-1}.

(2)

(c) (i) Using the value for the Hubble constant given in part (b), estimate the age of the Universe.
Give your answer in years.

age of the Universe _____ years

(3)

(ii) State **one** assumption that must be made to justify the estimate made in part (i).

_____

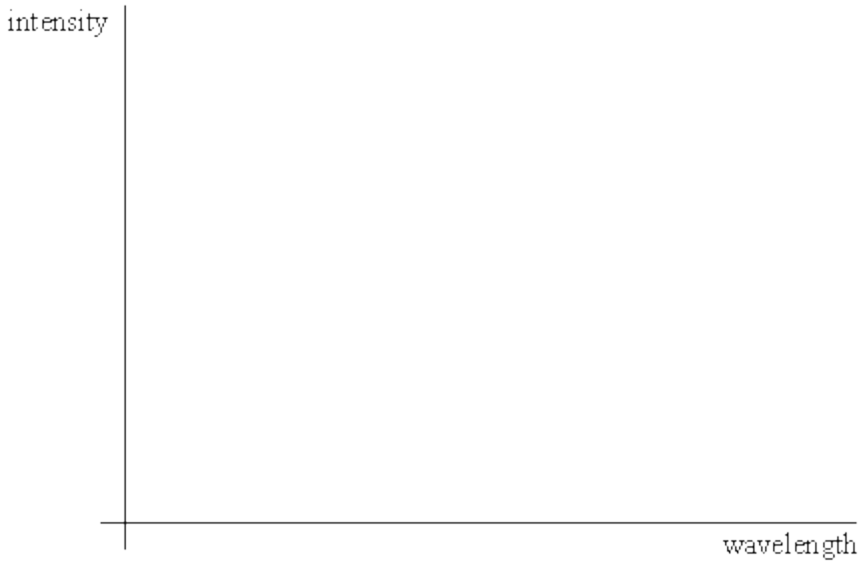
_____

(1)

(Total 7 marks)

9 The Earth's atmosphere absorbs electromagnetic radiation of certain wavelengths. Detectors on the surface of the Earth are largely restricted to the visible and radio regions.

(a) (i) On the axes below, draw the black body radiation curve for the Sun.



(ii) Mark on the wavelength axis the region affected by the atmosphere's absorption of ultra violet radiation.

(iii) What is responsible for this absorption?

_____

(iv) What effect can this absorption have on the measured temperature of a star? Explain your answer.

_____

_____

_____

_____

_____

(4)

(b) The atmosphere has little effect on radio waves between 30 MHz and 300 GHz. This radio window was first exploited in 1946 when a short pulse of radio waves of wavelength 2.7 m was transmitted from the Earth and reflected back by the Moon.

(i) Show that the frequency of the transmitted waves falls within the radio window.

_____

_____

(ii) The experimenters had to take into account the relative movement of the Earth and Moon when tuning the receiver. The maximum difference between the frequency of the detected and transmitted waves was 300 Hz.

What is the name of this effect?

_____

(iii) Calculate the relative velocity of the Earth and Moon when the frequency of the received signal was 300 Hz greater than the transmitted frequency.

_____

_____

_____

(5)

(Total 9 marks)

10 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,

_____

_____

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

_____

_____

(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,

_____

_____

_____

_____

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

_____

_____

_____

(4)

(Total 6 marks)

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

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

_____

_____

(1)

(b) 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.

_____

_____

_____

_____

(2)

(c) 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.

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 6 marks)

12 A galaxy is 4.5×10^{24} m from the Earth.

(a) Show that this galaxy is likely to be moving at a speed of about 1×10^{7} m s^{-1} relative to the Earth.

Hubble constant, H = 65 km s^{-1} Mpc^{-1}
1 parsec (pc) = 3.1×10^{16} m

(3)

(b) The galaxy emits light of wavelength 580.0 nm as it moves away from the Earth. This light is observed on the Earth.

(i) Calculate the change in wavelength of this light due to the movement of the galaxy.

[Hint: $\Delta\lambda/\lambda = \Delta f/f$]

Speed of light in a vacuum, $c = 3.0 \times 10^{8}$ m s^{-1}

Change in wavelength _____

(3)

(ii) Calculate the wavelength of the light from the galaxy when observed on the Earth.

Observed wavelength _____

(2)

(Total 8 marks)

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

_____

_____

_____

(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.

_____

_____

_____

(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.

_____

_____

_____

(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 booklet to show that the speed of M87 relative to Earth is about 8×10^5 m s^{-1}.

_____

_____

_____

(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.

_____

_____

_____

(4)

(Total 10 marks)

14 (a) The table summarises some of the properties of two stars in the constellation of Ursa Minor.

name	**apparent magnitude**	**<u>radius of star</u> radius of the Sun**	**spectral class**
Polaris	2.0	50	F
Kocab	2.0	50	K

(i) Using these data, describe and explain **one** similarity and **one** difference in the appearance of the two stars as seen with the unaided eye by an observer on the Earth.

similarity_____

_____

_____

difference_____

_____

_____

(2)

(ii) Deduce which of the two stars is further from the Earth.

_____

_____

_____

_____

_____

_____

(3)

(b) Ursa Minor also contains the galaxy NGC 6251. Measurements indicate that the light from the galaxy has a red shift, *z*, of 0.025 and that the galaxy is 340 million light years from Earth.

(i) Use these data to calculate a value for the Hubble constant.

value _____ k ms^{-1} Mpc^{-1}

(3)

(ii) Use your answer to part (b)(i) to estimate a value for the age of the Universe. State an appropriate unit for your answer.

age _____ unit _____

(3)

(Total 11 marks)

15 (a) (i) The wavelength of the calcium H line in the laboratory is 3.968×10^{-7} m. The wavelength of the same line in the spectrum of a distant galaxy is found to be greater by 0.198×10^{-7} m. Explain the reason for this increase.

_____

_____

_____

_____

(ii) The wavelength of the calcium K line from the same source is observed to be greater than the wavelength of the K line in the laboratory by a different amount. Explain why the respective increases in wavelength for the H line and K line are different.

If the wavelength of the K line is 3.934×10^{-7} m, calculate the increase in wavelength for the K line.

_____

_____

_____

_____

_____

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_____

(5)

(b) (i) Explain how this 'red-shift' in the wavelength can be used to measure the distance of the galaxy from Earth, provided the Hubble constant is known.

_____

_____

_____

_____

(ii) If the two measured values of the wavelength are 3.934×10^{-7} m and 4.733×10^{-7} m, calculate the speed of the galaxy with respect to the Earth.

_____

_____

_____

_____

_____

(iii) Hence calculate the distance in light-years of the galaxy from Earth.

Take the Hubble constant to be 65 km s^{-1} Mpc^{-1}.

_____

_____

_____

_____

_____

(6)

(Total 11 marks)

16 (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.

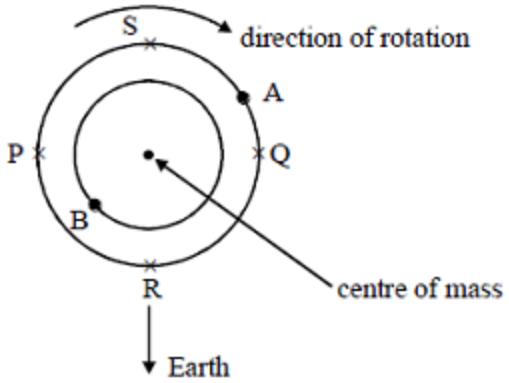


Figure 1

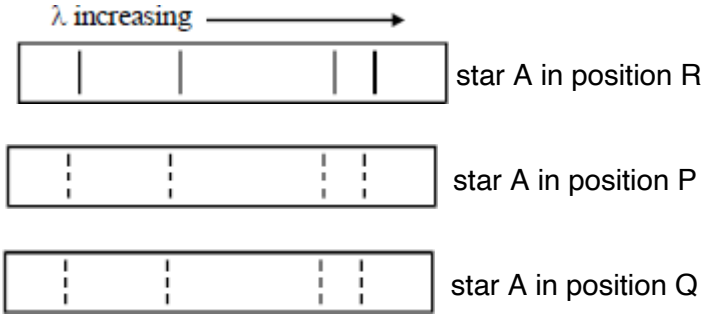
Figure 2 shows part of the spectrum of star A when it is in position R.

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**)

Figure 2



_____

_____

_____

(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.

_____

_____

_____

(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.

_____

_____

_____

_____

_____

(7)

(Total 12 marks)

17 (a) Light arriving at the Earth from a distant galaxy is observed to be *red shifted*.

(i) Explain, in terms of spectral lines, what the term *red shift* means.

_____

_____

(1)

(ii) Explain how the red shift is consistent with the movement of distant astronomical objects away from us.

Two of the 6 marks in this question are for the quality of your written communication.

_____

_____

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_____

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_____

(6)

(b) The wavelength of a given line in the spectrum is 5.40×10^{-7} m when measured using a light source in a laboratory on Earth. When the light from the distant galaxy is used for the measurement, the wavelength is found to be 5.61×10^{-7} m.

(i) Show that this wavelength change corresponds to a frequency shift of about 2.1×10^{13} Hz.

speed of light in a vacuum, $c = 3.0 \times 10^{8}$ m s^{-1}

Frequency shift _____

(3)

(ii) Calculate the speed of the galaxy relative to Earth.

Galactic speed _____

(3)

(iii) Estimate the distance, in m, between the galaxy and the Earth.

Hubble constant = 65 km s^{-1} Mpc^{-1}
1 pc (parsec) = 3×10^{16} m

Galactic distance _____

(3)

(Total 16 marks)