Astrophysics and Cosmology

1 (a). A group of students are conducting an experiment to determine the wavelength of monochromatic light from a laser.
Fig. 24.1 shows the laser beam incident normally at a diffraction grating.

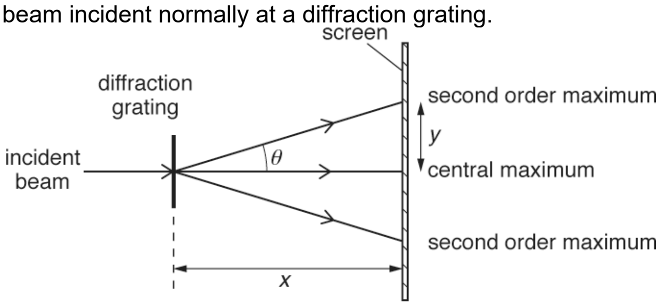


Fig. 24.1

The students use a diffraction grating with 600 lines mm^{-1}. They vary the distance *x* between the grating and the screen from 1.000 m to 2.000 m. They measure the distance y from the *central* maximum to the *second order* maximum.

The students decide to plot a graph of *y* against $\sqrt{x^2 + y^2}$.

Show that the gradient of the graph is equal to sin *θ*, where *θ* is the angle between the central maximum and the *second* order maximum.

[1]

(b). Fig. 24.2 shows the graph plotted by the students.

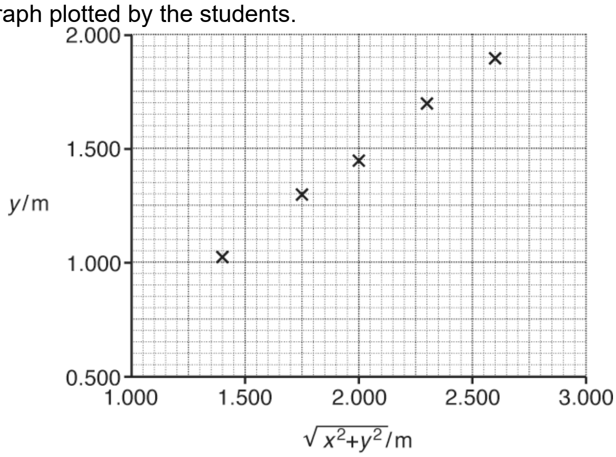


Fig. 24.2

i. Use Fig. 24.2 to determine an accurate value of the wavelength λ of the light from the laser.

λ = m **[2]**

ii. Suggest why there are no error bars shown in Fig. 24.2.

[1]

iii. Suggest how the precision of this experiment may be affected by using a protractor to measure the angle θ.

---

[1]

2. Which is the most likely evolution of a star which is 10 times more massive than our Sun?

A. main sequence star → red supergiant → white dwarf → black dwarf

B. main sequence star → supernova → red supergiant → neutron star

C. main sequence star → red supergiant → supernova → neutron star

D. main sequence star → red giant → neutron star → black hole

Your answer

[1]

3. Describe the **Doppler effect**

---

[1]

4. Other than matter, state what else may be present in the Universe that may affect its density.

---

[1]

5. An astronomer claims to have discovered a white dwarf with a mass twice that of our Sun.
Suggest why this claim must be incorrect.

---

[1]

6. State *Hubble's law.*

---

[1]

7. Fig. 19 is an incomplete Hertzsprung−Russell (HR) diagram of stars in our galaxy.

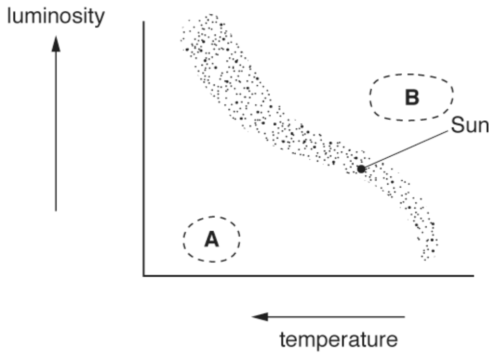


Fig. 19

The position of the Sun on the HR diagram is shown in Fig. 19.

State the type of stars found in regions **A** and **B**.

A ______________ **B** ______________ **[1]**

8. Fig. 22 shows the elliptical orbit of a planet around the Sun.

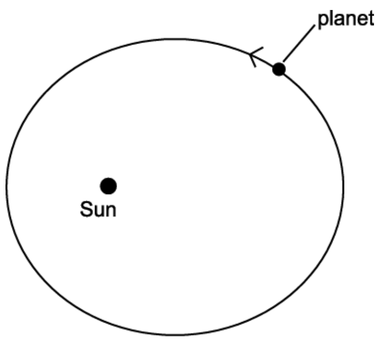


Fig. 22

Draw the gravitational force acting on the planet at the position shown in Fig. 22.

[1]

9. The parallax angle for a star is 0.015 seconds of arc.

What is the distance in parsecs (pc) of the star from the Earth?

A 67 pc
B 133 pc
C 220 pc
D 2.1×10^{18} pc

Your answer [1]

10. A spectral line corresponds to a wavelength λ1 in the laboratory.
The same spectral line observed in the spectrum of a receding galaxy corresponds to a wavelength λ2.
The distance of the galaxy from the Earth is d. The speed of light in a vacuum is c.

What is the correct expression for the Hubble constant H_0?

A $H_0 \approx \frac{c(\lambda_2 - \lambda_1)}{d\lambda_1}$

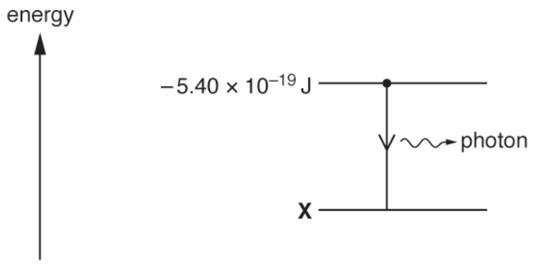
B $H_0 \approx \frac{c\lambda_1}{d(\lambda_2 - \lambda_1)}$

C $H_0 \approx \frac{c\lambda_2}{d\lambda_1}$

D $H_0 \approx \frac{c\lambda_1}{d\lambda_2}$

Your answer [1]

11. An electron makes a transition between the two energy levels shown below.



This transition produces a photon of frequency 4.10×10^{14} Hz.

What is the value of the energy level **X**?

A -2.68×10^{-19} J
B -2.72×10^{-19} J
C -5.40×10^{-19} J
D -8.12×10^{-19} J

Your answer [1]

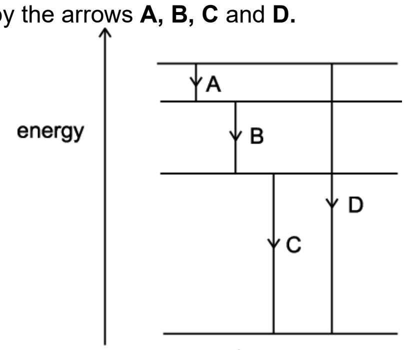
12. Which of the following is the greatest astronomical distance?

A. 1.0 pc
B. 2.0 ly
C. 3.0×10^5 AU
D. 4.0×10^{13} km

Your answer

[1]

13. The four energy levels of an atom are shown below.
Four electron transitions are shown by the arrows **A, B, C** and **D.**



Which electron transition will give the longest wavelength of electromagnetic radiation?

Your answer

[1]

14. In astronomy, distance can be measured in different units.

Which one of the following distances is the **largest**?

A 4.22 × 10^{16} m
B 1.91 pc
C 3.42 ly
D 593AU

Your answer

[1]

15. A hot metal emits a black-body spectrum. The luminosity of the metal at 800 °C is *L*.

What is the luminosity of the metal when at 1000 °C?

A. 1.2*L*
B. 1.3*L*
C. 2.0*L*
D. 2.4*L*

Your answer

[1]

16. According to the Cosmological principle, the Universe is isotropic, homogeneous and the laws of physics are universal.

State what is meant by the term *homogeneous*.

--- **[1]**

17. When the light from a star is passed through a diffraction grating it forms a spectrum.

Which of the following statements is / are correct?

1. Light emitted from the surface of a star would form a continuous spectrum.
2. Light received from the Sun has dark lines across its spectrum which correspond to the absorption of certain wavelengths by atoms in the Earth's atmosphere.
3. A photon in an emission spectrum occurs when an electron moves from a low to a higher energy level within an atom.

A. 1, 2 and 3
B. Only 1 and 2
C. Only 2 and 3
D. Only 1

Your answer ☐

[1]

18. Which column **A**, **B**, **C** or **D**, shows the correct sequence for the evolution of the Universe between the Big Bang and the formation of stars?

A	B	C	D
Universe starts to expand ↓ quarks and leptons form ↓ hadrons form ↓ nuclei form ↓ atoms form	Universe starts to expand ↓ hadrons form ↓ quarks and leptons form ↓ nuclei form ↓ atoms form	quarks and leptons form ↓ nuclei form ↓ Universe starts to expand ↓ atoms form ↓ hadrons form	quarks and leptons form ↓ hadrons form ↓ Universe starts to expand ↓ nuclei form ↓ atoms form

Your answer ☐ **[1]**

19. Some stars will evolve into white dwarfs.
The mass of the Sun is 2.0×10^{30} kg.

Which of the following **cannot** be the mass of a white dwarf?

A 1.2×10^{30} kg
B 2.0×10^{30} kg
C 2.7×10^{30} kg
D 3.2×10^{30} kg

Your answer **[1]**

20. An astronomer analyses the light from a distant galaxy.
One of the spectral lines in the spectrum observed from the galaxy has wavelength 610 nm.
The same spectral line has a wavelength of 590 nm when measured in the laboratory.

What is the speed of this galaxy?

A 9.8×10^{6} ms^{-1}
B 1.0×10^{7} ms^{-1}
C 2.9×10^{8} ms^{-1}
D 3.0×10^{8} ms^{-1}

Your answer **[1]**

21. Laser light of wavelength of 640 nm is incident normally at a diffraction grating. The separation between adjacent lines (slits) is 3.3×10^{-6} m.

What is the **total** number of bright spots that can be observed in the diffraction pattern?

A 5
B 6
C 10
D 11

Your answer **[1]**

22. Stars emit electromagnetic radiation. A graph of intensity against wavelength λ for a main sequence star is shown.

Which statement is correct as the main sequence star evolves into a red giant?

A. the peak wavelength does not change
B. the peak wavelength moves towards the origin
C. the peak wavelength moves to the left
D. the peak wavelength moves to the right

Your answer

[1]

23. Betelgeuse is a star in the constellation of Orion which astronomers think could undergo a supernova explosion.

What could Betelgeuse evolve into following the supernova stage?

A. main sequence star
B. neutron star
C. planetary nebulae
D. red giant star

Your answer

[1]

24. A star has surface temperature 3000 °C and luminosity *L*. Another star of identical size has a surface temperature of 2500 °C.

What is the luminosity of this second star in terms of *L*?

A. 0.48*L*
B. 0.52*L*
C. 0.83*L*
D. 0.85*L*

Your answer

[1]

25. The intensity against wavelength graph of an object at 750°C peaks at a wavelength of λ. The temperature of the object is raised to 960°C.

What is the wavelength now at the new peak intensity in terms of λ?

A 0.78 λ

B 0.83 λ

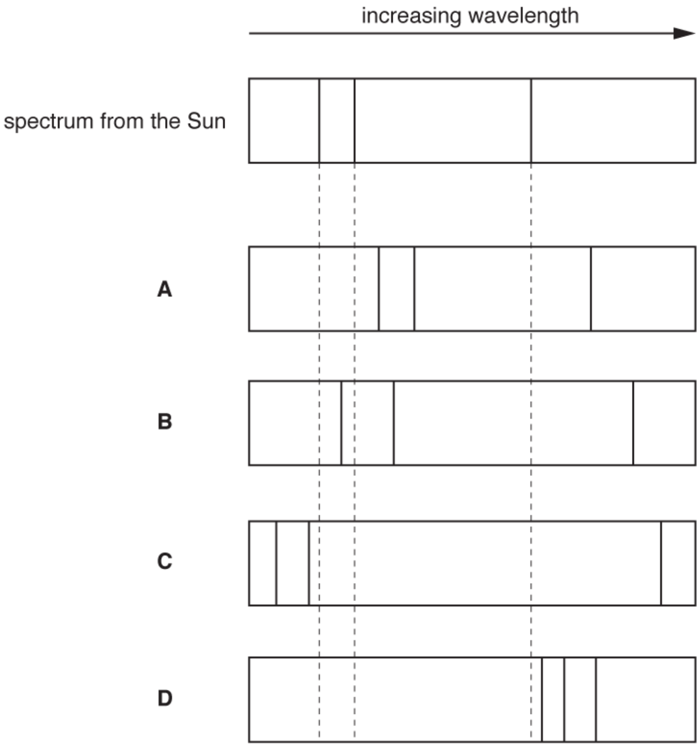
C 1.2 λ

D 1.3 λ

Your answer **[1]**

26. Part of the line spectrum for light from the Sun is shown below.

Which spectrum best shows light from a similar star to the Sun?



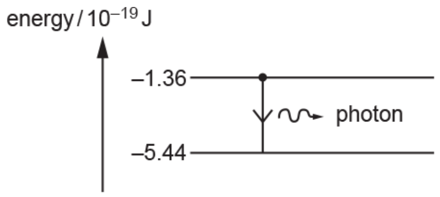
Your answer **[1]**

27. Which two quantities are related in Hubble's law?

A Distance and mass of galaxies.
B Velocity and intensity of galaxies.
C Distance and velocity of galaxies.
D Distance and red shift of stars in our galaxy.

Your answer **[1]**

28. The diagram below shows two energy levels for the electron in the hydrogen atom.



The electron makes the transition shown by the arrow.

What is the wavelength of the photon emitted?

A 293 nm
B 366 nm
C 488 nm
D 1460 nm

Your answer **[1]**

29. Recent analysis of the data collected from the Hubble and Gaia telescopes gave the Hubble constant a value of 73.5 km s^{-1} Mpc^{-1}.

What is this value, written to 2 significant figures, in s^{-1}?

A 2.4×10^{-21} s^{-1}
B 2.4×10^{-18} s^{-1}
C 2.4×10^{-12} s^{-1}
D 2.4×10^{21} s^{-1}

Your answer **[1]**

30. Algol is a triple-star system, with stars Aa1, Aa2 and Aa3 orbiting each other.
This triple-star is 90 light-years from the Earth.

The Aa1 star could evolve into a black hole.

State two ways in which the black hole would differ from the Aa1 star.

1.

2.

[2]

31. An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star. The light is incident normally on the grating.

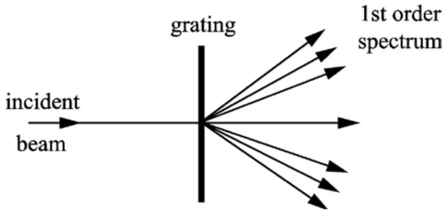


Fig. 6.1

First order diffraction maxima are observed at angles of 12.5°, 14.0° and 19.0° to the direction of the incident light as shown in **Fig. 6.1.**
Two of the wavelengths are 4.33×10^{-7} m and 4.84×10^{-7} m.
Calculate the wavelength of the third line.

wavelength = ... m **[2]**

32. Hubble's law can be used to estimate the age of the universe. Fig. 23 shows some of Hubble's early measurements of nearby galaxies plotted on a *v* against *d* graph, where *v* is the recessional speed of a galaxy and *d* is its distance from us. Measurements of distant galaxies taken over the last 85 years have refined the value of H_0 to be 68 km s^{1} Mpc^{-1}.

i. Suggest why measurements for our nearest galaxies can deviate from the current Hubble's law trend line.

[1]

ii. Suggest why measurements for galaxies at the largest distances deviate from the Hubble's law trend line.

[1]

33. A group of students have gathered data on four stars from the Internet. The information is shown in the table below.

Star	*T* / K	λ_{max} /µm
Antares	3.1×10^3	9.4×10^{-1}
Zeta	3.0×10^4	9.7×10^{-2}
Vega	9.3×10^3	3.1×10^{-1}
OTS-44	2.3×10^3	1.3×10^0

The surface temperature of the star in kelvin is *T* and λ_{max} is the wavelength of the emitted electromagnetic radiation at which the intensity is maximum.

Analyse and evaluate this data to show whether or not Wien's displacement law is obeyed.

[2]

34.

i. Show that the energy of a photon of wavelength 486 nm is 4.09×10^{-19} J.

[1]

ii. Fig. 5.4 shows some of the energy levels of an electron in a hydrogen atom.

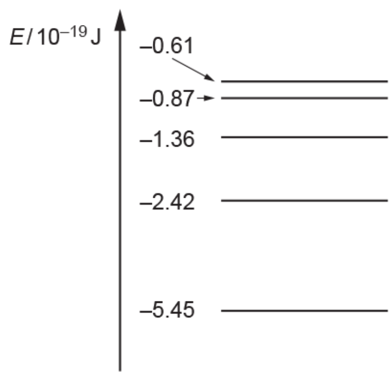


Fig. 5.4 (not to scale)

Draw an arrow on Fig. 5.4 to show an electron transition which would cause the **emission** of a photon of wavelength 486 nm.

[2]

35. Fig. 19 is an incomplete Hertzsprung−Russell (HR) diagram of stars in our galaxy.

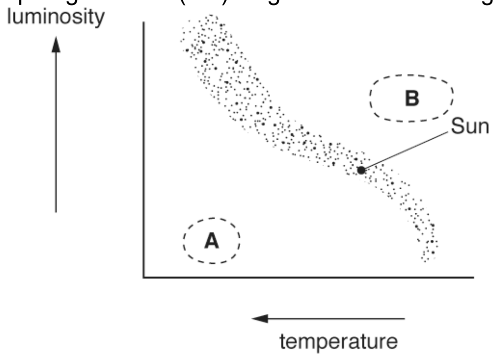


Fig. 19

The position of the Sun on the HR diagram is shown in Fig. 19.

The Sun is a main sequence star. Its surface temperature is 5800 K. The wavelength of the emitted light at maximum intensity is 550 nm.

Beta Pictoris is also a main sequence star. The wavelength of the emitted light at maximum intensity from this star is 370 nm.

i. Calculate the surface temperature of Beta Pictoris.

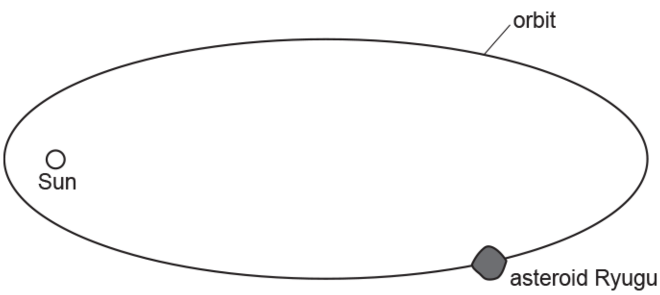
temperature = K **[2]**

ii. On Fig. 19, mark the likely position of Beta Pictoris with a letter **P**.

[1]

36 (a). In June 2018, the spacecraft Hayabusa2 arrived at an asteroid called Ryugu.

The asteroid orbits the Sun in an elliptical orbit as shown below.



The diagram is **not** drawn to scale.

i. Indicate with a letter **X** on the orbit where the asteroid would be moving at maximum speed.

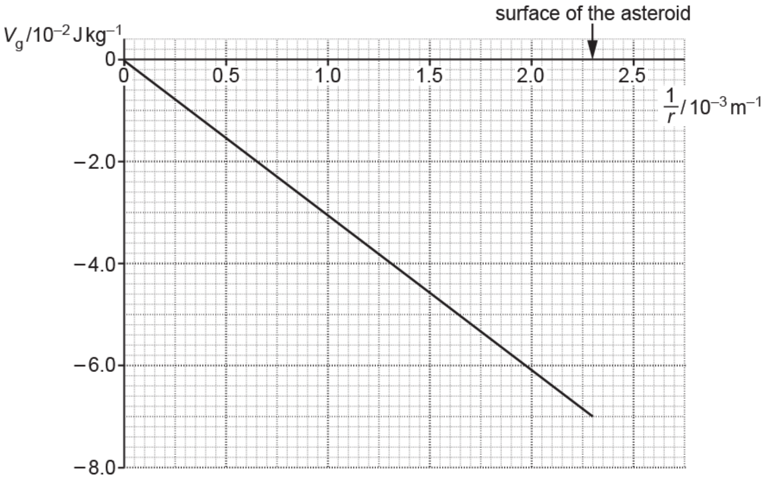
[1]

ii. Use Kepler's **second law** to explain your answer to **(a)(i)** .

---

[2]

(b). The gravitational potential at a distance *r* from the centre of the asteroid Ryugu is *V*g. The graph of *V*g against $\frac{1}{r}$ for the asteroid is shown below.



i. Define **gravitational potential** .

---

[1]

ii. Show that the magnitude of the gradient of the graph is equal to *GM*, where *M* is the mass of the asteroid and *G* is the gravitational constant.

[1]

iii. Use the gradient of the graph to show that the mass *M* of the asteroid is about 4.6×10^{11} kg.

M = ... kg **[2]**

(c). In October 2018, the probe Mobile Asteroid Surface Scout (MASCOT) was released from **rest** from the Hayabusa2 spacecraft from a distance of 600 m from the centre of the asteroid.

Assume that the spacecraft was stationary relative to the asteroid when MASCOT was dropped.

Use information from **(b)** to calculate the speed of the impact *v* when MASCOT landed on the surface of the asteroid.

v = ... m s^{-1} **[3]**

37 (a). Light from a distant galaxy is passed through a diffraction grating. Fig. 21.2 shows the part of the spectrum of light that shows a strong hydrogen-alpha emission line.

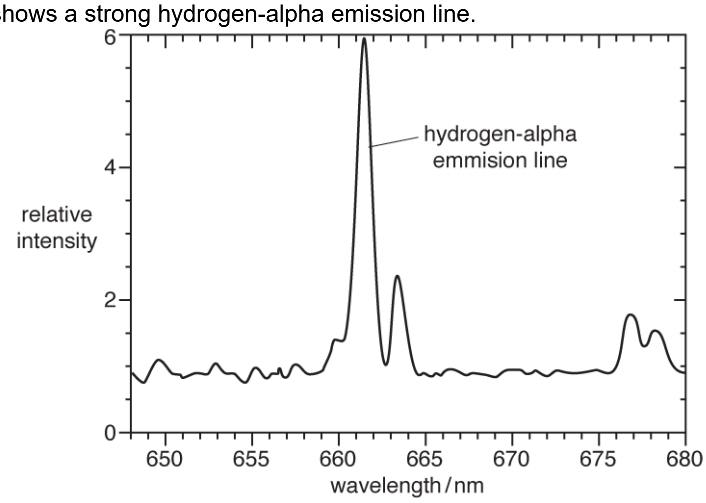


Fig. 21.2

i. State how an emission line is produced.

---

[1]

ii. State an adjustment that could be made to the experimental arrangement that would space the emission lines more widely.

---

[1]

iii. In the laboratory, the wavelength of the hydrogen-alpha emission line is 656.3 nm. Use Fig. 21.2 to determine the recession velocity of the galaxy.

recession velocity = ... m s^{-1} **[3]**

iv. Suggest why hydrogen spectral lines play an important role in determining red shift of galaxies.

[1]

(b). Light from a similar star is viewed in a galaxy **further** away. The star is part of a pair of stars which orbit a common centre of mass.
Describe and explain how the equivalent spectrum might appear.

[3]

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

[3]

39. An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star. The light is incident normally on the grating.

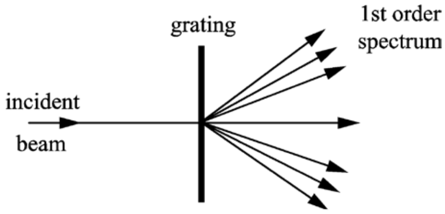


Fig. 6.1

In order to increase the accuracy of the values for wavelength, the student decides to look for higher order diffraction maxima.

i. State how this increases the accuracy.

---

[1]

ii. Calculate how many orders n can be observed for the shorter wavelength given in **(a)**.

n = ... **[2]**

40. Our Sun will eventually become a red giant.
Describe and explain the next stages of evolution of our Sun.

---

[4]

41. Astronomers often use absorption spectral lines to determine the relative velocity of distant galaxies. The wavelength of a specific absorption spectral line observed in the laboratory is 280 nm.

The galaxy RXJ1242-11 is 200 Mpc away from the Earth and it has a massive black hole at its centre.

i. Calculate in nm the wavelength λ of the same spectral line from RXJ1242–11 when **observed** from the Earth. Assume the Hubble constant is 68 km s^{-1} Mpc^{-1}.

λ = nm **[3]**

ii. State one of the characteristics of a black hole.

---

[1]

42. Rigel is a blue giant star in the constellation of Orion.
The table below shows some data about Rigel and about our Sun.

	Rigel	**Sun**
Surface temperature / K		5.8×10^3
Luminosity / W	4.62×10^{31}	3.85×10^{26}
Wavelength of emitted light at peak intensity / nm	240	500

i. Show that the surface temperature of Rigel is 12 000 K.

[2]

ii. Calculate the radius of Rigel.

radius = ... m **[2]**

43. The Universe evolved from the Big Bang.

Describe the evolution of the Universe up to the formation of the first nuclei.

---

[4]

44. An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star. The light is incident normally on the grating.

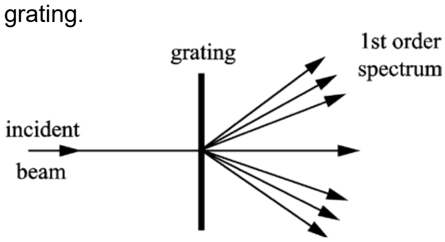


Fig. 6.1

These three emission lines all arise from transitions to the same final energy level. The part of the energy level diagram of hydrogen relevant to these transitions is shown in **Fig. 6.2**.

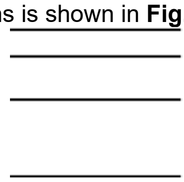


Fig. 6.2

i. Draw lines between the energy levels to indicate the transitions which cause the three emission lines and label them with their wavelengths.

[1]

ii. There are other possible transitions between the energy levels shown in **Fig. 6.2**. The least energetic of these produces photons of 4.8×10^{-20} J.

Calculate the wavelength of these photons.

State in which region of the electromagnetic spectrum this wavelength is found.

wavelength .... m

region: ....

[3]

45 (a). The galaxies in the Universe may be assumed to be distributed uniformly through space.

In this model, the separation between two neighbouring galaxies is 1.4×10^{23} m and each galaxy occupies a cube of space of volume 2.7×10^{69} m3 as shown in Fig. 24.2.

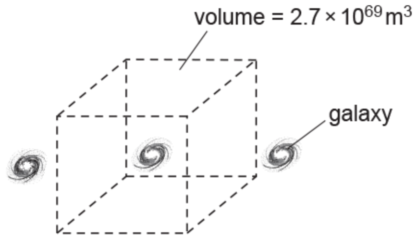


Fig. 24.2

There are on average 10^{11} stars in each galaxy and the mass of an average star is about 2.0×10^{30} kg.

i. Estimate the gravitational force between two neighbouring galaxies.

force = ... N **[2]**

ii. Show that the mean density of the Universe is about 7×10^{-29} kg m^{-3}.

[1]

iii. Suggest why the actual mean density of the Universe is different from the value calculated in (ii).

----

[1]

(b). Proxima Centauri is the closest star to Earth.
Fig. 24.1 shows the apparent positions of this star against the background of very distant stars as seen from the Earth over a period of exactly 6 months.

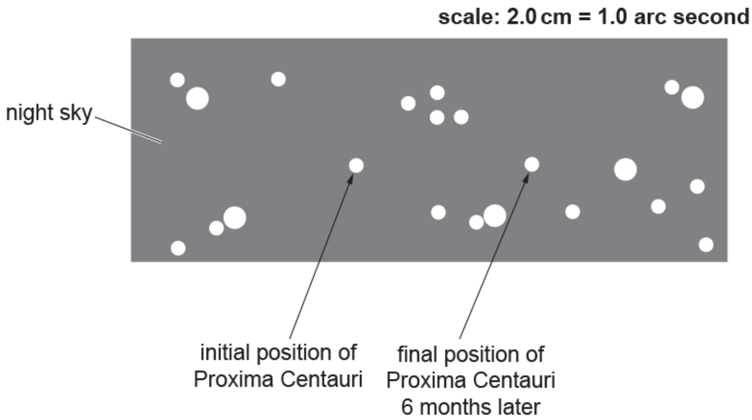


Fig. 24.1

The parallax angle for Proxima Centauri can be determined from Fig. 24.1 using the scale provided.

i. Show that the parallax angle *p* for Proxima Centauri is about 0.8 arc second.

[2]

ii. Use your answer in (i) to calculate the distance *d* of Proxima Centauri from the Earth in light-years (ly).

1 pc = 3.26 ly

d = ... ly **[2]**

46. This question is about the Sun and its radiation.

i. Use the data below to show that the luminosity of the Sun is about 4 × 10^{26} W.

- radius of Sun = 7.0 × 10^8 m
  surface temperature of Sun = 5800 K

[1]

ii. Sirius, the brightest star in the night sky, has a luminosity 25 times greater than that of the Sun. It has diameter 1.7 times greater than that of the Sun.

Calculate the surface temperature *T* of Sirius.

T = ... K **[3]**

47. Fig. 23.1 gives some data on the wavelength of a hydrogen spectral line for light received from the Andromeda galaxy and the Virgo cluster of galaxies.

	wavelength of hydrogen line from galaxy / nm	wavelength of hydrogen line on Earth / nm
Andromeda galaxy	485.6	486.1
Virgo cluster	489.8	486.1

Fig. 23.1

i. The Virgo cluster is 16.5 Mpc from the Earth.

Estimate the age of the Universe using data from **Fig. 23.1**.

age = ... s **[3]**

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

---

[2]

48. Fig. 21.1 shows some of the energy levels of electrons in hydrogen gas atoms.
The energy levels are labelled **A**, **B**, **C** and **D**.

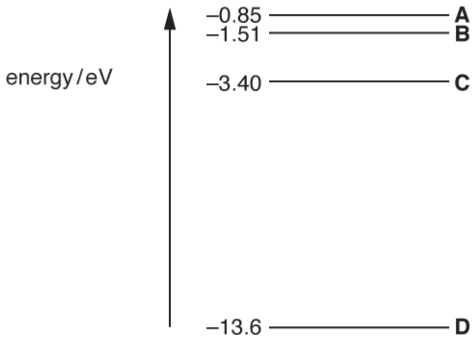


Fig. 21.1 (not to scale)

i. Explain why the energy levels are negative.

---

[1]

ii. An electron makes a transition (jump) from level **C** to level **A**.

1. Calculate the energy gained by this electron.

energy = ... eV **[1]**

iii.

1. Calculate the wavelength in nm of the photon absorbed by this electron.

wavelength = ... nm **[3]**

49. The Big Bang theory explains the origin and the evolution of the early Universe.
The table below shows the distance *d* and recession velocity *v* of some galaxies close to our own galaxy.

Galaxy	*d* / Mpc	*v* / km s^{-1}
NGC-5357	0.45	200
NGC-3627	0.90	650
NGC-4151	1.7	960
NGC-4472	2.0	850

The chemical composition of the stars in our galaxy can be determined by analysing in the laboratory the absorption spectral lines for these stars.
The closest star to us is the Sun. The wavelength of the hydrogen-beta spectral line from the Sun is 486 nm.

i. Use the information from the table to calculate the **observed** wavelength λ of the hydrogen-beta spectral line from a star in the galaxy NGC-4151.

λ = ... nm **[3]**

ii. A diffraction grating with 800 lines per mm is used to observe and analyse the light from the Sun in the laboratory.
A narrow beam of light from the Sun is incident normally at the diffraction grating.
Calculate the angle θ between the central beam of light through the grating and the hydrogen-beta spectral line in the **second** order spectrum.

θ = ... ° **[2]**

50. In cosmology, the Doppler effect can be observed with light from distant galaxies. The Doppler effect can also be observed with sound waves.

Two students use sound waves to investigate the Doppler effect.
In an open space, one student swings a loudspeaker at constant speed in a horizontal circle of radius 0.60 m.
The other student stands a large distance away and holds a microphone. The microphone is connected to a data logger and computer.

Fig. 6.1 shows the situation, viewed from above.

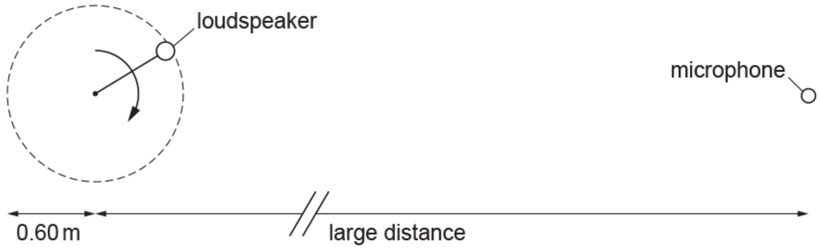


Fig. 6.1

The loudspeaker emits sound in all directions at a single frequency f_0 = 1700 Hz.

Fig. 6.2 shows the variation with time *t* of the frequency f received by the microphone.

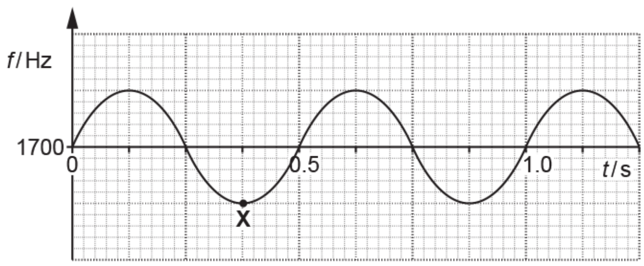


Fig. 6.2

i. Use Fig. 6.2 to show that the speed of the loudspeaker is 7.5 m s^{-1}.

[2]

ii. The speed of sound in this experiment is 330 m s^{-1}.

Calculate the maximum change in frequency Δ*f* of the sound detected by the microphone.

Δ*f* = ... Hz **[2]**

iii. Hence complete the scale on the y-axis of Fig. 6.2.

[1]

iv. Mark with an **X** on Fig. 6.1 the position of the loudspeaker which corresponds to the point **X** on Fig. 6.2.

[1]

51. * In 2017, an ultra-cool star TRAPPIST-1 was discovered with at least five of its own orbiting planets. Astronomers are interested about the possibility of finding life on some of the planets orbiting TRAPPIST-1.

The table below shows some data.

	TRAPPIST-1	**Sun**
Luminosity *L* / *W*	2.0×10^{23}	3.8×10^{26}
Surface temperature *T* / *K*	2500	5800
Radius of star / m	*R*	7.0×10^{8}
Distance between Earth and Sun / m		1.5×10^{11}
Distance between planets and TRAPPIST-1 / m	1.6×10^{9} to 9.0×10^{9}	

The temperature T in kelvin of a planet, its distance d from the star and the luminosity L of the star are related by the expression

$$\frac{T^4 d^2}{L} = \text{constant.}$$

- The average temperature of the Earth is about 290 K. Explain how life may be possible on some of the planets orbiting TRAPPIST-1.
- Use your knowledge of luminosity to show that the radius R of TRAPPIST-1 is smaller than the Sun.
- Support your answers by calculations.

---

[6]

52. * 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.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

.... **[6]**

53. This question is about the brightest wavelength (590 nm) of light from a sodium lamp.

Analysis of the light from the sodium lamp using a diffraction grating shows that there are photons of two different energies at wavelengths 589.0 nm and 589.6 nm.

i. Calculate the energy difference ΔE between these two photons.

ΔE = ... J **[3]**

ii. The light at these wavelengths can be seen as two separate lines when viewed through a diffraction grating. In order to be distinguishable from each other, the angular separation between the lines must be at least 0.02°.

Show that the lines will appear separated in the **second order** spectrum when the sodium lamp is viewed through a grating with 300 lines per millimetre.

[3]

54. The Big Bang theory explains the origin and the evolution of the early Universe.
The table below shows the distance *d* and recession velocity *v* of some galaxies close to our own galaxy.

Galaxy	*d* / Mpc	*v* / km s^{-1}
NGC-5357	0.45	200
NGC-3627	0.90	650
NGC-4151	1.7	960
NGC-4472	2.0	850

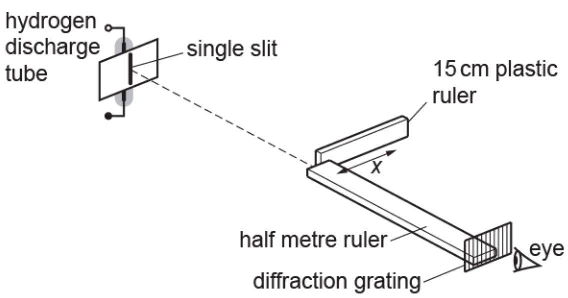
*Discuss the evidence for the Big Bang theory of the Universe. Use data in the table and your knowledge of electromagnetic radiation in your answer.

1 pc = 3.1×10^{16} m

[6]

55. Hydrogen atoms excited in a discharge tube only emit four different discrete wavelengths of visible photons.

*In a semi-darkened room, a single slit is placed in front of the discharge tube. A student holds a diffraction grating which has 300 lines per millimetre.
The student looks through the grating at a 15 cm plastic ruler placed 0.50 m away, as shown in Fig. 5.1.
The paths of the different colours of light from the slit to the student's eye are shown in Fig. 5.2.



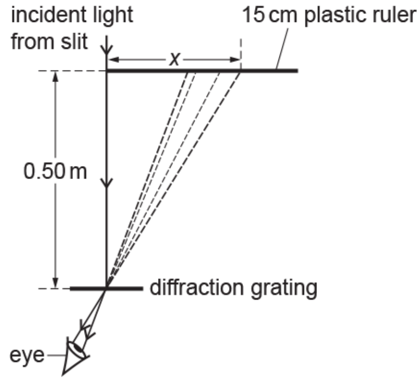


Fig. 5.1 (not to scale) **Fig. 5.2 (not to scale)**

Four **first** order images of the slit, one at each photon wavelength, are observed as vertical lines against the background of the plastic ruler, as shown in Fig. 5.3.

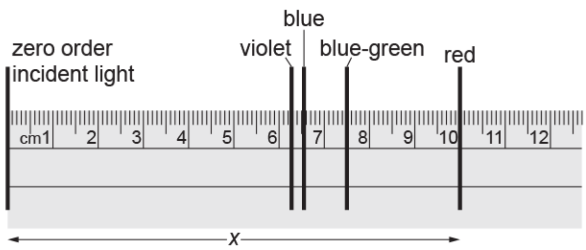


Fig. 5.3

The student decides to determine the wavelength of the photons which form the red line observed at x = 10 cm on the ruler.

- Describe how the information that has been given can be used to determine the wavelength of the red photons.
- Estimate the percentage uncertainty in the measured value of the wavelength.

---

[6]

56. Hubble's law can be used to estimate the age of the universe. Fig. 23 shows some of Hubble's early measurements of nearby galaxies plotted on a v against d graph, where v is the recessional speed of a galaxy and d is its distance from us.

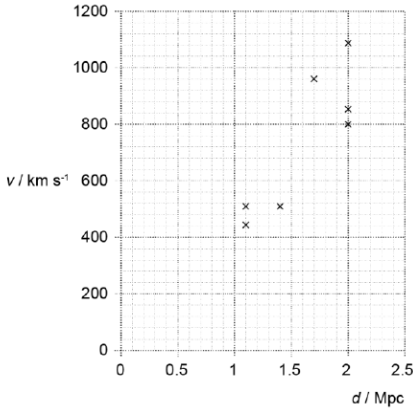


Fig. 23

i. State how v was determined.

[1]

ii. Use Fig. 23 to estimate a value for the Hubble constant H_0 in km s^{-1} Mpc^{-1}.

H_0 = ...km s^{-1} Mpc^{-1} **[3]**

iii. Use your answer to part **(ii)** to estimate Hubble's initial value for the age of the universe in years.

age = ...years **[3]**

57. Algol is a triple-star system, with stars Aa1, Aa2 and Aa3 orbiting each other.
This triple-star is 90 light-years from the Earth.

The table shows some data about the three stars of Algol.

Star	**Luminosity of star / L⊙**	**Surface temperature of star / K**
Aa1	**182**	**13 000**
Aa2	**6.92**	**4500**
Aa3	**10.0**	**7500**

The luminosity of each star is in terms of the solar luminosity L⊙.

i. Define the **luminosity** of a star.

---

[1]

ii. Use Stefan's law to determine the ratio $\frac{\text{radius of star Aa2}}{\text{radius of star Aa3}}$.

ratio = ... **[2]**

iii. Use Wien's displacement law to explain which star would have the **longest** wavelength at the peak intensity of the emitted electromagnetic radiation.

---

[2]

iv. Suggest how an astronomer using just an optical telescope can deduce that the three stars of Algol have different surface temperatures.

---

[1]

v. The light from each star passing through a diffraction grating shows an absorption line spectrum. Explain how a specific absorption line is produced in this type of spectrum in terms of **photons** and **electrons**.

----

[3]

END OF QUESTION PAPER