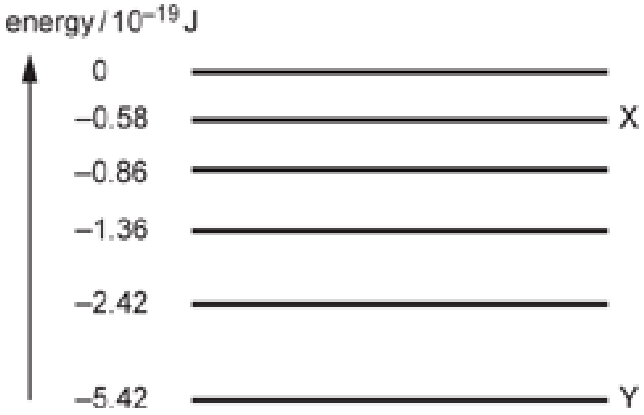
1(a). The diagram shows some of the energy levels of the electron in a hydrogen atom.



An electron moves from energy level X to energy level Y.

Show that the wavelength of the photon produced is about 410 nm.

[2]

(b). The light from the stars in a distant galaxy is analysed on the Earth using a diffraction grating. Dark lines are observed in the spectrum.

An astronomer concludes that the dark line at a wavelength 432 nm corresponds to the electron transition between X and Y.

i. Explain the origin of the dark lines.

[2]

ii. Calculate the recession velocity *v* of the galaxy.

v = ... m s^{-1} **[2]**

iii. State the name of the theory that is supported by evidence from the measurement of the recession velocities of galaxies in the universe.

[1]

2. Describe how to determine the wavelength λ of a monochromatic laser pointer using a diffraction grating.

As part of your answer, explain how to

- analyse the measurements collected using a graphical method.
- improve the accuracy of the measurements taken.

You are given the number of lines per mm for the diffraction grating.

[6]

3(a). This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy.

Fig. 21.1 shows the relative intensities of different wavelengths of electromagnetic radiation from Nu Persei.

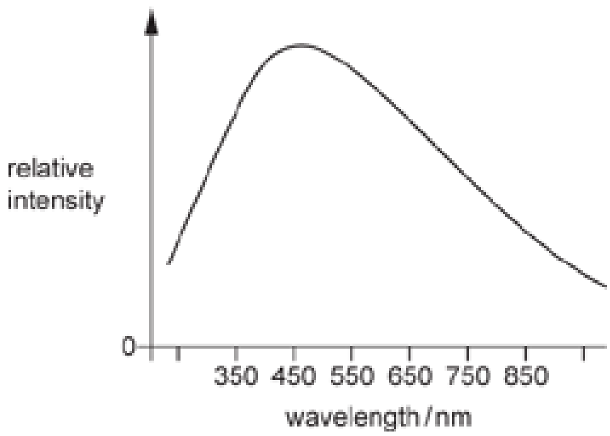


Fig. 21.1

The surface temperature of the Sun is 5800 K and its wavelength at which maximum intensity is emitted is 500 nm.

The luminosity of Nu Persei is 2.3×10^{29} W.

i. Use **Fig. 21.1** to show that the surface temperature of Nu Persei is about 6300 K.

[2]

ii. Estimate the radius of Nu Persei.

radius = ... m **[3]**

(b). This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy. Electromagnetic radiation is collected from Nu Persei by a sensor with an efficiency of 11% and cross-sectional area 1.0×10^{-4} m^2.

The radiant power collected by the sensor is 7.0×10^{-15} W.

i. Show that the radiant power per unit area arriving at the sensor is about 6×10^{-10} W m^{-2}.

[2]

ii. By the time the electromagnetic radiation from Nu Persei reaches Earth, the radiation from Nu Persei is evenly distributed over a spherical area with radius equal to the distance between Nu Persei and Earth.

Calculate the distance of Nu Persei from Earth in light years.

distance = ... light years **[4]**

(c). This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy. The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. *L* is the luminosity of a star and *L* is the luminosity of the Sun.

The temperature data from earlier in this question is repeated in the table below.

Star	**Surface temperature / K**
Sun	5800
Nu Persei	6300

Comment on the uncertainty in your value, calculated in **part (ii) above**, of the distance of Nu Persei from Earth. You may write on the diagram as part of your answer.

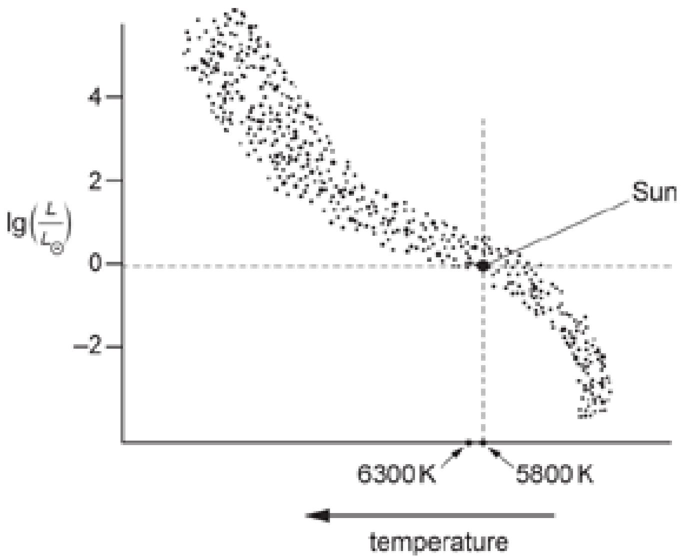


Fig. 21.2

[3]

4. Stars rotate around the centre of their galaxy.

Observations suggest that the stars at the edges of galaxies are moving at much higher velocities than expected.
What is the name given to the current explanation for these observations?

A Chandrasekhar limit
B Dark matter
C The Cosmological principle
D Wien's displacement law

Your answer **[1]**

5(a). A pulsar is a rapidly rotating neutron star that emits radio waves.

i. Describe the formation of a neutron star.

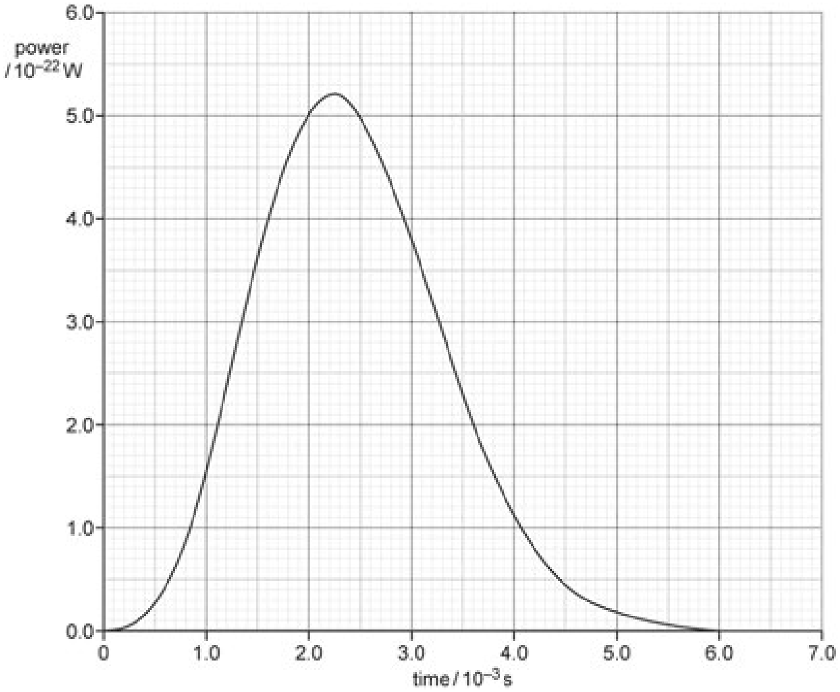
____ **[2]**

ii. State **one** characteristic of a neutron star.

____ **[1]**

(b). An astronomer uses a radio telescope to observe a pulsar.

The graph below shows the power that the telescope receives due to the radio waves from one full rotation of a pulsar.



i. By calculating the area between the curve and the horizontal axis, estimate the total energy received by the telescope in one full rotation of the pulsar.

total energy received = ... J **[2]**

ii. The surface area of the telescope is about 3000 m^2.

The distance to the pulsar is about 300 pc.

By assuming that the radiation from the pulsar is emitted equally in all directions, estimate the total energy emitted in one full rotation.

energy emitted = ...J **[3]**

6. A star has a mass similar to that of the Sun.

Describe how the position of this star on a Hertzsprung-Russell (H-R) diagram changes as it evolves.

Fig, A is a blank H-R diagram.

You may add information to Fig, A as part of your response.

Fig, B shows the relative intensities of different wavelengths of light in the spectrum of a star.

Explain how information from Fig. B could be used to suggest the stage of evolution of the star. Describe the limitations of the analysis.

Fig. A

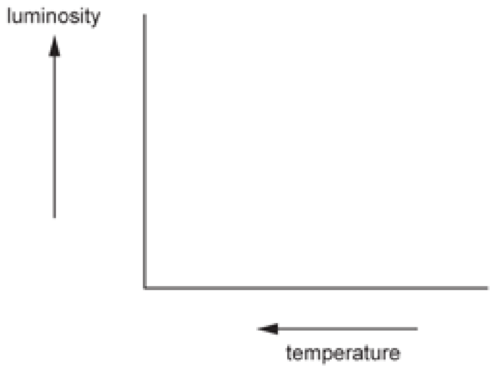
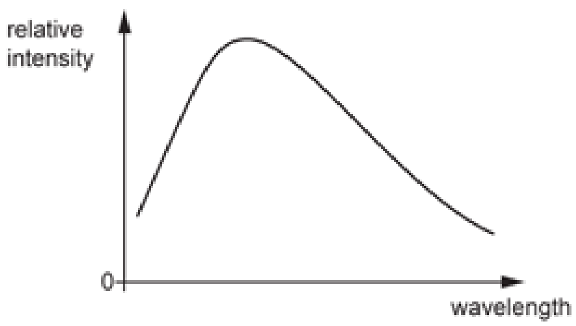


Fig. B



[6]

7. The Hipparcos space telescope used stellar parallax with a precision of 9.7×10^{-4} arcseconds to determine the distance to stars.

One of the stars studied was Polaris A. Data about this star is in the table below.

Parallax angle	7.5×10^{-3} arcseconds
Radius	2.1×10^{10} m
Mass	1.1×10^{31} kg
Surface temperature	6000 K
Temperature of the atmosphere of the star	4.0×10^{6} K

i. Estimate the maximum stellar distance in parsecs that could be measured using Hipparcos.

maximum stellar distance = ...pc **[1]**

ii. Calculate the percentage uncertainty in the calculated value of the distance to Polaris A.

percentage uncertainty = ... % **[2]**

8. An early estimate for the Hubble constant was 500 km s^{-1} Mpc^{-1}.

What is the value of this estimate in units of s^{-1}?

1 parsec = 3.1×10^{16} m

A 2.3×10^{-18}
B 1.6×10^{-17}
C 1.6×10^{-5}
D 0.5

Your answer ☐ **[1]**

9. During the evolution of the universe there was a period of inflation.

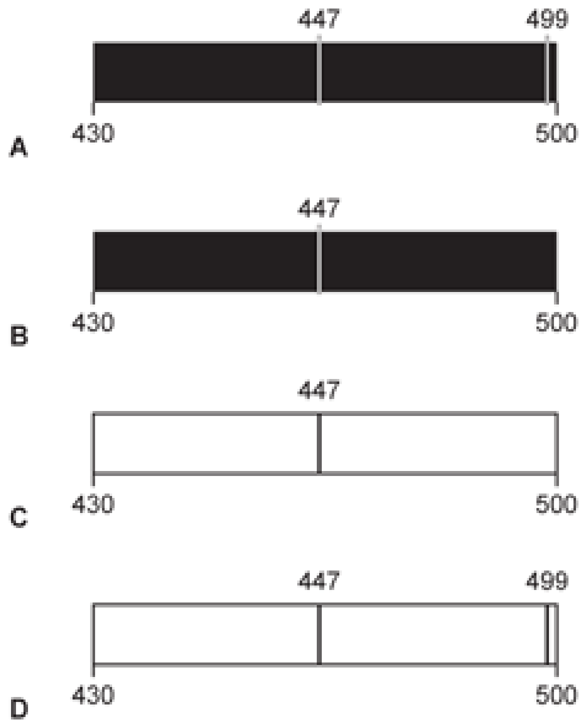
Which forms of matter, if any, existed 10^{-10} s after the big bang?

A Atoms
B Leptons
C None
D Quarks

Your answer ☐ **[1]**

10. Part of the emission spectrum for hydrogen in a laboratory is shown. All wavelengths are given in nm.

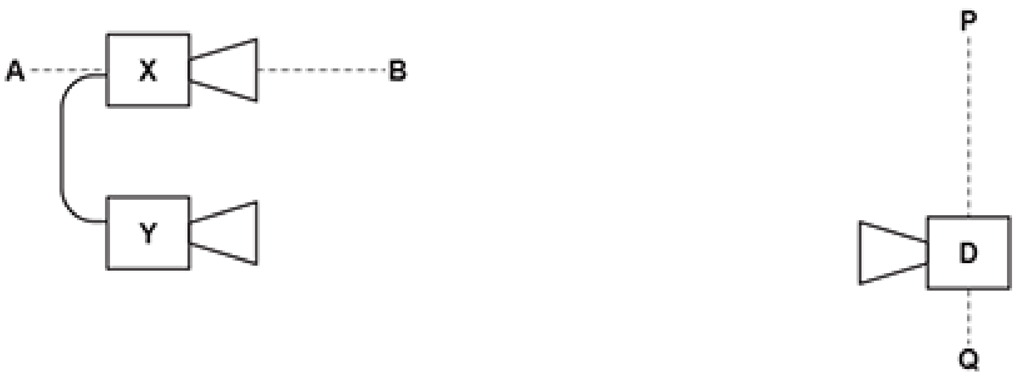
Which diagram shows the corresponding part of the absorption spectrum observed from Earth emitted from a galaxy moving away with a velocity of 0.031 c?



Your answer [1]

11. A student experiments with microwaves emitted from a transmitter. The frequency *f* of the microwaves from the transmitter can be adjusted.

The student connects two microwave transmitters **X** and **Y**, and places them in front of a microwave detector **D**, as shown in the diagram below.



The transmitters **X** and **Y** produce **coherent** vertically polarised microwaves with the same frequency *f*.

The detector **D** is sensitive to vertically polarised microwaves only.

When the detector **D** is moved along the line **PQ**, a pattern of maximum and minimum intensity is observed. Adjacent maxima are separated by a distance *x*.

i. *Explain:

- why this pattern of intensity occurs
- the expected relationship between the frequency *f* and the distance *x*
- how to verify this relationship experimentally.

[6]

ii. Transmitter **X** is rotated about the line **AB** and the experiment is repeated at different orientations until it has been rotated by 180°.

Describe and explain the observed patterns of maximum and minimum intensity.

[3]

12(a). Astronomers can detect microwave background radiation coming from space in every direction.

The temperature of this microwave radiation is 2.7 K and its **total** intensity is about 3×10^{-6} W m^{-2}.

Describe the origin of the microwave background radiation.

____

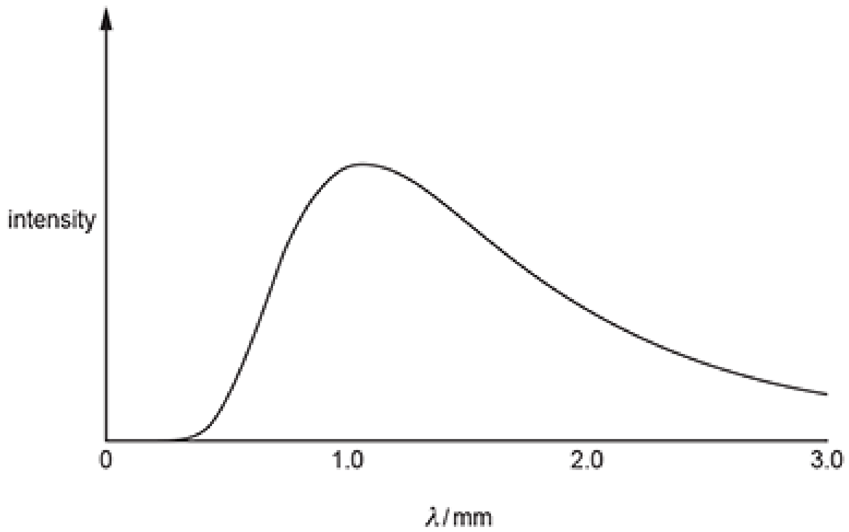
____

____

____ **[2]**

(b). The figure below shows how the intensity of the microwave background radiation varies with its wavelength λ.

The **peak** intensity is at a wavelength of 1.1 mm.



This spectrum of microwave background radiation changes with temperature according to Wien's displacement law.

i. Suggest and explain how the spectrum might have looked in the distant past. You may draw on the figure to support your answer.

____

____

____

____ **[2]**

ii. Calculate the energy of a photon which has a wavelength of 1.1 mm.

energy = ... J **[2]**

iii. Estimate the number of photons of microwave background radiation incident per second on the back of your hand.

Assume that all emitted photons have the energy calculated in **(ii)**, and that the back of your hand has a surface area of 150 cm^2.

number of photons per second = ...s^{-1} **[2]**

iv. A scientist suggests that the microwave background radiation could be used as an energy source.

The scientist proposes using large tanks of water to absorb the microwave radiation.

Estimate the maximum rise in temperature that could be produced per second for a large cylindrical tank of depth 5.0 m. Assume that all microwave radiation incident on the top of the tank is absorbed.

density of water = 1000 kg m^{-3}
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

maximum rise in temperature per second = ...°C s^{-1} **[3]**

13(a).

A nebula is a giant cloud of gas and dust in space. A nebula **X** is modelled as a sphere of gas and dust particles of diameter 6.4 pc.
The nebula has 1.0×10^{12} gas and dust particles per m^3 and a temperature of 250 K. The nebula behaves like an ideal gas.

i. Show that the volume of the nebula is 4.1×10^{51} m^3.

1 pc = 3.1×10^{16} m

[2]

ii. Calculate the **total** kinetic energy E_k of the gas and dust particles in the nebula.

E_k= .... J **[3]**

(b). The nebula that formed the Sun is estimated to have a diameter of 3.0 pc and had a similar composition to nebula **X** in **(b)**.

The mass of the nebula **X** is **much greater** than the mass of the Sun.

i. Calculate the ratio $\frac{\text{mass of nebula } \mathbf{X}}{\text{mass of the Sun}}$

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

ii. After a long time, nebula **X** will form a stable star.

Describe the eventual evolution of this star.

____ **[4]**

14(a).

A team of astronomers have measurements to determine the peak surface temperature *T* and luminosity *L* of a distant star. They plan to use Stefan's law to estimate the radius *r* of this star.

Explain whether the astronomers should attempt to measure *T* or *L* more precisely to reduce the uncertainty in *r*.

____ **[2]**

(b). *It is suggested that the luminosity *L* and the mass *M* of a star can be compared to the Sun by the equation

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^b$$

where $L_\odot$ is the luminosity of the Sun and $M_\odot$ is the mass of the Sun.
The value of *b* is between 3 and 4.

Table 22 shows some data of five stars.

Main sequence star	$\frac{M}{M_{\odot}}$	$\frac{L}{L_{\odot}}$
Pi Andromedae A	6.5	800
Alpha Coronae Borealis A	3.2	80
Gamma Virginis	1.7	6.0
Eta Arietis	1.3	2.5
70 Ophiuchi A	0.78	0.4

Table 22

Fig. 2 2 shows the $\lg\left(\frac{L}{L_{\odot}}\right)$ against $\lg\left(\frac{M}{M_{\odot}}\right)$ plot for these stars.

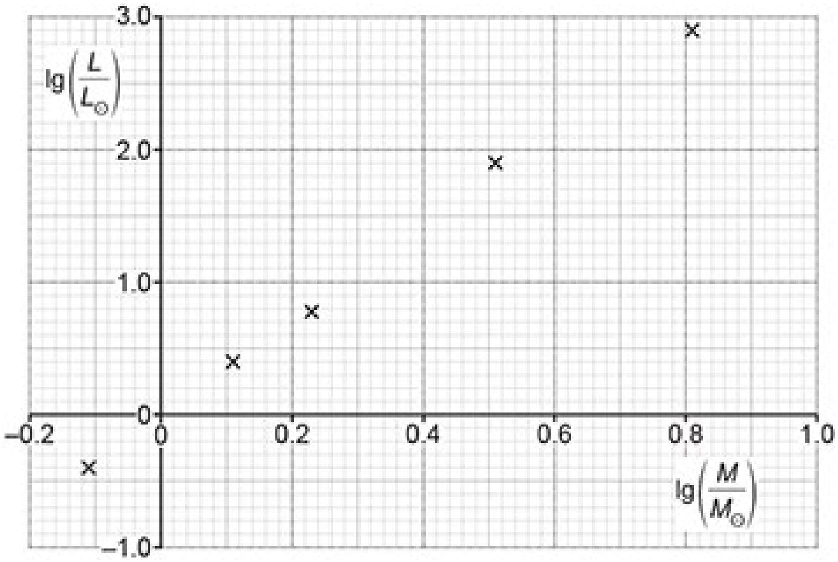


Fig. 22

The luminosity of a star is directly proportional to the rate of fusion of hydrogen nuclei.

Use **Fig. 22** to determine *b* and use your knowledge of Hertzsprung–Russell (HR) diagrams to deduce how the lifespan of hotter stars compares with lifespans of cooler stars.

[6]

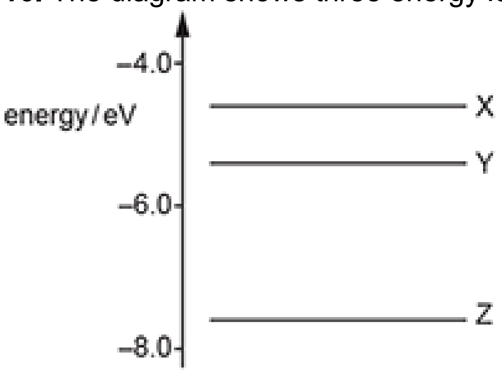
15.

A nebula is a giant cloud of gas and dust in space. The nebula can produce a star over a long period of time.

State what causes the initial collapse of the nebula.

[1]

16. The diagram shows three energy levels X, Y and Z of an electron within a gas atom.



Which transition is correct when the electron absorbs a photon with the shortest wavelength?

A Z → X
B X → Z
C Y → X
D X → Y

Your answer **[1]**

17. Light from a hydrogen source is incident normally at a diffraction grating. The first order maximum of the H-alpha spectral line of wavelength 486 nm is observed at angle of 30.0°.

Light from a distant receding star is observed using the same diffraction grating. The light is incident normally at the grating as before. The speed of this star is 0.16*c*, where *c* is the speed of light in a vacuum.

What is the observed angle of the first order maximum of the H-alpha spectral line from the light of this receding star?

A 24.8°
B 30.0°
C 34.8°
D 35.5°

Your answer ☐ **[1]**

18. A galaxy, 1.0×10^9 light-years away from the Earth, has a recession speed of 23 000 kms^{-1}.

Which expression, based on the information above, is correct for the age of the universe in seconds?

A $\text{age} = \frac{1.0 \times 10^9}{23000 \times 10^3}$

B $\text{age} = \frac{1.0 \times 10^9 \times 1.5 \times 10^{11}}{23000}$

C $\text{age} = \frac{1.0 \times 10^9 \times 9.5 \times 10^{15}}{23000 \times 10^3}$

D $\text{age} = \frac{1.0 \times 10^9 \times 3.1 \times 10^{16}}{23000 \times 10^3}$

Your answer ☐ **[1]**

19. Astronomers observe approximately the same number of distant galaxies per unit volume of space in all directions.
Which idea does this observation support?

A Big bang model of the universe
B Cosmological principle
C Existence of dark matter
D Hubble's law

Your answer ☐ **[1]**

END OF QUESTION PAPER