Astro and Cosmology

1. Scientists believe that our universe began with a big bang, and is presently expanding. The ultimate fate of the universe depends upon the total amount of matter in the universe.One possibility is a big crunch where the universe eventually contracts back into a point of infinite density. A universe with such a future would be described as being

A closed.

B critical.

C flat.

D open.

(Total 1 mark)

2. On a Hertzsprung-Russell diagram our Sun is located on the main sequence. Which of the following statements is correct?

A All giant stars are larger and cooler than our Sun.

B All giant stars are larger and hotter than our Sun.

C All white dwarf stars are smaller and hotter than our Sun.

D All white dwarf stars are hotter and brighter than our Sun.

(Total 1 mark)

3. In which of the following situations would a blue shift be observed?

A Source and observer moving with the same velocity.

B Source moving along a circular path around an observer.

C Source moving away from a stationary observer.

D Source moving towards a stationary observer.

(Total 1 mark)

4. X and Y are identical stars. When viewed from Earth the flux from star X is 4 times the flux from star Y. Which of the following explanations is possible?

A X is twice as far away as Y.

B X is four times as far away as Y.

C Y is twice as far away as X.

D Y is four times as far away as X.

(Total 1 mark)

5. For a black-body radiator, the frequency at which maximum radiation of energy occurs is proportional to

A T^{-4}

B T^{-1}

C T

D T^{4}

(Total 1 mark)

6. Newton's law of gravitation can be applied to the Earth-Moon system. Which of the following statements is **not** correct?

A The value of *G* at the surface of the Moon is the same as that at the surface of the Earth.

B The gravitational force between the Earth and the Moon is proportional to the square of the separation of the Earth and the Moon.

C The gravitational force between the Earth and the Moon is proportional to the mass of the Moon.

D The orbital time of the Moon about the Earth is independent of the mass of the Moon.

(Total 1 mark)

7. When nearby stars are observed over a period of a year, their positions are seen to move in tiny ellipses relative to the background of more distant stars.

(a) Explain why relative movement of these nearby stars is observed.

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(3)

(b) By means of a labelled diagram, outline the steps necessary for this effect to be used to find the distance to nearby stars.

(3)

(c) The effect is too small for the distances to more distant stars to be determined. Outline a method which can be used for more distant stars.

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(1)

(Total 7 marks)

8. The Sun behaves as an approximate black-body radiator with peak energy radiation occurring at a wavelength of 5.2×10^{-7} m.

(a) (i) Show that the Sun has a surface temperature of about 6000 K.

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(2)

(ii) The radiation received from the Sun at the top of the atmosphere is 1.37 kW m^{-2}. Show the Sun's luminosity is about 4×10^{26} W.

Distance from the Sun to the Earth = 1.49×10^{11} m

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(2)

(iii) Hence calculate the radius of the Sun.

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Radius = ...

(2)

(b) The huge power output of the Sun is due to nuclear fusion reactions taking place within its core. State and explain the conditions necessary for fusion to occur.

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(3)
(Total 9 marks)

9. The Hubble Space Telescope (HST) was launched in 1990 into an orbit of radius 6940 km. The satellite makes 15 complete orbits of the Earth every 24 hours and its position high above the Earth's atmosphere has allowed high quality images of extremely distant objects to be produced.

(a) (i) Show that the HST has a centripetal acceleration of about 8 m s^{-2}.

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(4)

(ii) The HST is kept in orbit by the gravitational pull of the Earth. Use your answer to (a)(i) to calculate a value for the mass of the Earth.

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Mass = ...

(3)

(b) The telescope was named in honour of Edwin Hubble who measured the red shift of light from a number of galaxies and related it to their distance from the Earth.

Explain what is meant by the term *red shift* in this context and state the inference that Hubble made from his measurements.

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(2)

(c) The song “Nine Million Bicycles” by Katie Melua includes the lines, “We are 12 billion light years from the edge, that’s a guess, no one can ever say it’s true”.

(i) Explain how the line “12 billion light years from the edge” implies an age of 12 billion years for the universe.

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(2)

(ii) Calculate the value of the Hubble constant consistent with an age of 12 billion years for the universe.

1 billion years = 3.15×10^{16} s

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Hubble constant = ...

(2)

(iii) These lyrics were famously contested by Dr Simon Singh in the Guardian newspaper. He argued that the correct age was 13.7 billion years, and disputed that scientists had guessed the age of the universe. As a result Katie performed the song with revised lyrics.

Discuss the suggestion in the song that values for the age of the universe are only guesses.

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(3)
(Total 16 marks)

10. The gravitational field strength on the surface of the Earth is g. The gravitational field strength on the surface of a planet of twice the radius and the same density is

A $4g$

B $2g$

C g

D $g/4$

(Total 1 mark)

11. Cosmic background radiation is a remnant of the big bang and appears to pervade the universe. It has a maximum wavelength in the microwave region of the electromagnetic spectrum. This can be calculated to correspond to a temperature of about 3 K. This calculation is based on the assumption that

A the universe is spherical

B the universe is expanding

C space can be regarded as a black body

D space is a vacuum

(Total 1 mark)

12. The *x*-axis of a Hertzsprung-Russell diagram is log *T*. This is because

A the range of temperatures of the surfaces of stars is large

B the temperatures of the surfaces of stars are all very large numbers

C the scale has to start with the hottest stars

D the diagram would be impossible to interpret if log *T* was the *y*-axis

(Total 1 mark)

13. The spectrum of visible light from the Sun contains a number of dark lines known as Fraunhofer lines.

This is due to

A polarisation caused by the atmosphere

B absorption of light by atoms

C refraction of light by telescopic lenses

D the Doppler effect because atoms are moving very fast

(Total 1 mark)

14. All quasars show large red shifts in the light received from them. This shows that they

A have large diameters

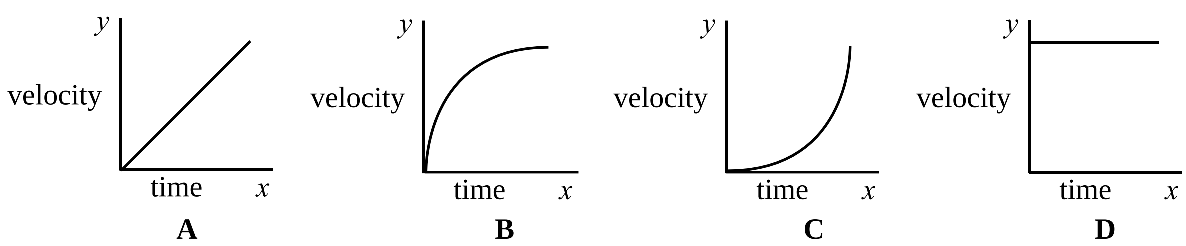
B are moving towards us at very high speeds

C have a low temperature

D are far away from earth

(Total 1 mark)

15. A space rocket takes off vertically from the surface of the Earth. Assuming the thrust remains constant which graph best represents the variation of velocity of the rocket with time f the universe expands forever it can be described as



(Total 1 mark)

16. Two stars in the night sky appear equally bright to an observer. The Ancient Greeks thought that all stars were the same distance from the Earth. State and explain **two** reasons why these two stars do not need to be the same distance from the observer.

Reason One

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(2)

Reason Two

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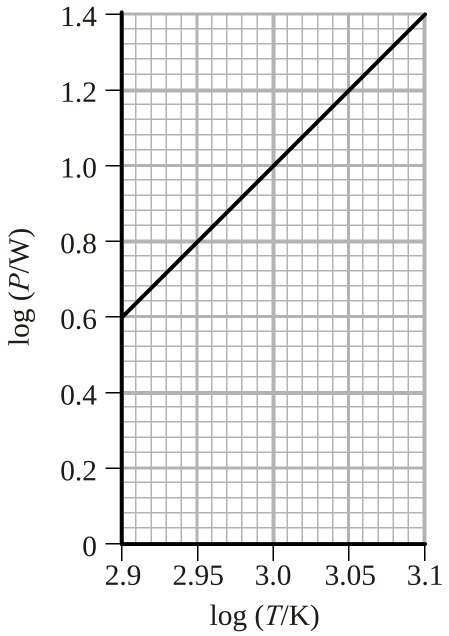
(2)
(Total 4 marks)

17. The graph shows how the logarithm of the electrical power P supplied to a filament lamp varies with the logarithm of the temperature T of the filament.



(a) *P* is related to *T* by a power law: $P = k\,T^n$

Use the graph to determine n.

n = ...

(2)

(b) A student suggests that this relationship is predicted by the Stefan-Boltzmann law.

Comment on this statement.

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(2)
(Total 4 marks)

18. The Hubble constant is thought to be about 70 000 m s^{-1} Mpc^{-1}.

(a) Give one reason why the value of this constant is uncertain.

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(1)

(b) State how an estimate of the age of the Universe can be calculated from the Hubble constant.

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(1)

(c) Explain how the ultimate fate of the Universe is associated with the Hubble constant.

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(3)

(Total 5 marks)

19. (a) A planet of mass *m* orbits a star of mass *M*. The radius of orbit is *r*. By considering the force required for circular motion in this situation, show that the period *T* of the orbit is given by $T^2 = \frac{4\pi^2 r^3}{GM}$.

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(3)

(b) Measurements have shown that star HD70642 has a planet which orbits the star with a period of about 6 years. The radius of the orbit is about 3× the radius of the Earth's orbit around the Sun.

(i) Use the formula in (a) to determine a value for the ratio $\frac{\text{mass of star HD70642}}{\text{mass of Sun}}$.

$\frac{\text{mass of star HD70642}}{\text{mass of Sun}}$ = ...

(3)

(ii) Because of the presence of the planet, the star HD70642 does not remain at rest. Instead, the planet and star both orbit around their common centre of mass. Explain why the orbiting speed of the star is very small in comparison to the speed of the planet.

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(2)

(c) Astronomers discovered the planet by observing the “Doppler Wobble” effect. As the planet orbits the star, light from the star undergoes a Doppler shift in its frequency. Explain why this method is likely to only detect **very large** planets.

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(3)
(Total 11 marks)

20. Read the following passage and answer the questions that follow.

A nova is a sudden brightening of a star. Novae are thought to occur on the surface of a white dwarf star which is paired with another star in a binary system. If these two stars are close enough to each other, hydrogen can be pulled from the surface of the star onto the white dwarf. Occasionally, the temperature of this new material on the surface of the white dwarf may become hot enough for the hydrogen to fuse to helium. This causes the white dwarf to suddenly become very bright. In a nova, this hydrogen fusion occurs by the “CNO” process, where helium-4 is produced by a series of steps in which protons react with various isotopes of Carbon, Nitrogen and Oxygen. Novae are used by astronomers as standard candles.

(a) Complete the equation which shows a typical part of the CNO process.

$$^{\cdots\cdots}_{8}O + ^{\cdots\cdots}_{\cdots\cdots}H \rightarrow ^{14}_{\cdots\cdots}N + ^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots$$

(3)

(b) What is a white dwarf ? Suggest why hydrogen fusion in the white dwarf is likely to be the CNO process.

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(3)

(c) The temperature required for these processes is 10^7 K.

(i) Calculate the mean kinetic energy, in keV, of the particles involved.

energy of particles = ... keV

(3)

(ii) Explain how this temperature arises.

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(2)

(d) Astronomers use novae as standard candles. Explain what a standard candle is, and suggest what this implies about the processes occurring in a nova.

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(3)

(Total 14 marks)

21. Classify each of the following stars by ticking **all** the appropriate boxes in the table.
$M_\odot$ = one solar mass.

Star	Core remnant	$<1.4\ M_\odot$	$>2.5\ M_\odot$	Main sequence
Neutron star				
Black hole				
White dwarf				

(Total 3 marks)

22. (i) For most of its life (11 billion years) the Sun will burn hydrogen in its core. A chemistry student might use the word **burn** to describe a chemical reaction involving oxygen.

Explain fully the meaning of the word **burn** when used in astrophysics to describe what happens in the core of a star. You may be awarded a mark for the clarity of your answer.

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(4)

(ii) When the Sun nears the end of its life it will burn helium in its core for a further 100 million years and become a red giant star. When it has depleted the helium in its core it is estimated that its surface temperature will fall from its present value of 5780 K to 3160 K and its radius will increase from 6.96×10^8 m to 1.26×10^{11} m.

Show that the luminosity of the Sun will increase by a factor of about 3000 due to these changes.

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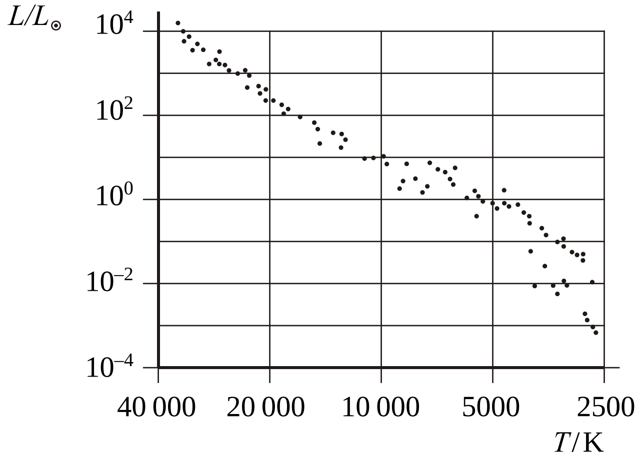
(4)

(iii) A Hertzsprung-Russell diagram is shown below.



Mark with an X the position of the Sun today.

Use the information given in (ii) to mark with a Y the position of the Sun when it has depleted its helium core.

(4)
(Total 12 marks)

23. (i) Near the end of its life the Sun will decrease in size and become a white dwarf.

State two other ways in which this type of star differs from the Sun as it is today.

1 ....

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2 ....

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(2)

(ii) Describe what will eventually become of a white dwarf star.

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(2)
(Total 4 marks)

24. (i) Sirius A is the brightest star in the night sky. It is 8.6 light years from Earth. Show that this distance is approximately 8×10^{16} m.

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(2)

(ii) Hence determine the intensity of Sirius A as seen from Earth.

The luminosity of Sirius A is 1.0×10^{28} W.

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(3)

(iii) Calculate the mass being converted into energy in the core of Sirius A every second.

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(3)

(iv) Sirius A has a surface temperature of 9900 K.

Calculate the peak wavelength of the radiation spectrum emitted by Sirius A.

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(2)
(Total 10 marks)

25. (i) Define the term binding energy.

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(1)

(ii) Use the following data to show that the binding energy of carbon-14 is approximately 100 MeV.

Masses: $^{14}_{6}C$ nucleus = 14.003 24 u

$^{1}_{1}p$ = 1.007 28 u

$^{1}_{0}n$ = 1.008 67 u

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(4)

(iii) The binding energy of carbon-12 is 89 MeV. Hence determine which of these two carbon isotopes is more stable.

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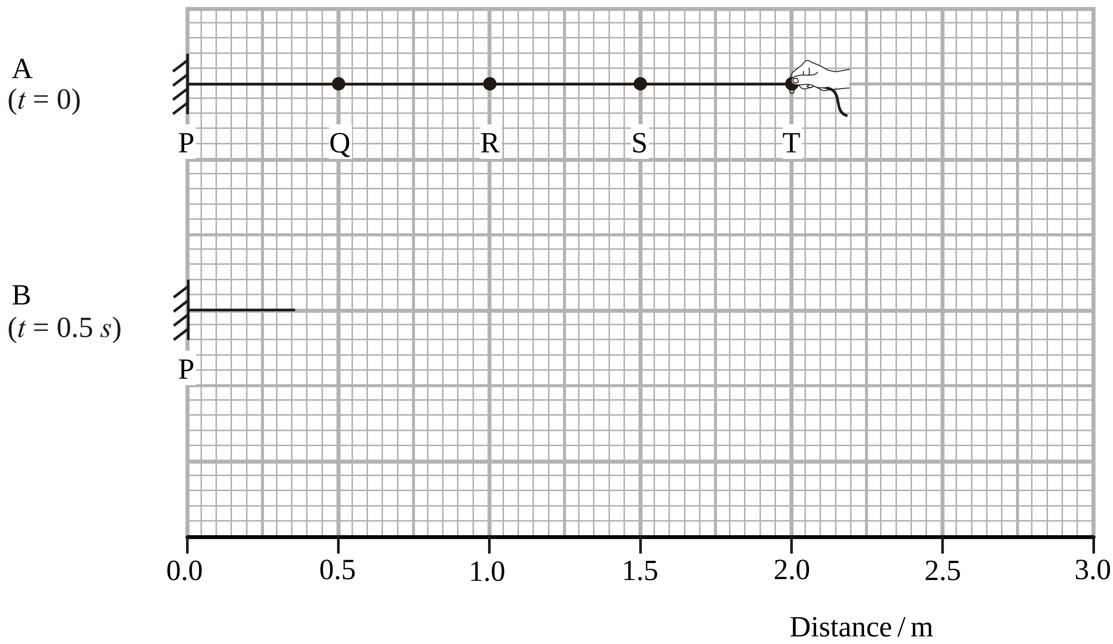
(3)

(Total 8 marks)

26. A physics teacher uses a simple model to illustrate the behaviour of the Universe. A long elastic cord, clamped at one end P, has knots Q, R, S and T tied in it at equal intervals.
Initially the cord is straight but unstretched with the knots 0.50 m apart, as shown in part A of the diagram.



The teacher grasps knot T and pulls it away from P at a steady speed of 0.80 m s^{-1}. The cord stretches uniformly.

(a) (i) On part B of the diagram, mark the position of knot T after 0.50 s.

(ii) Hence complete part B by marking the positions of knots Q, R and S after 0.50 s.

(2)

(b) Explain how this model represents the Universe and its behaviour.

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(2)

(c) Using values taken from the diagram, show how the model illustrates Hubble's law.

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(3)

(d) State **two** ways in which this demonstration is not a good model of the Universe.

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2 ....

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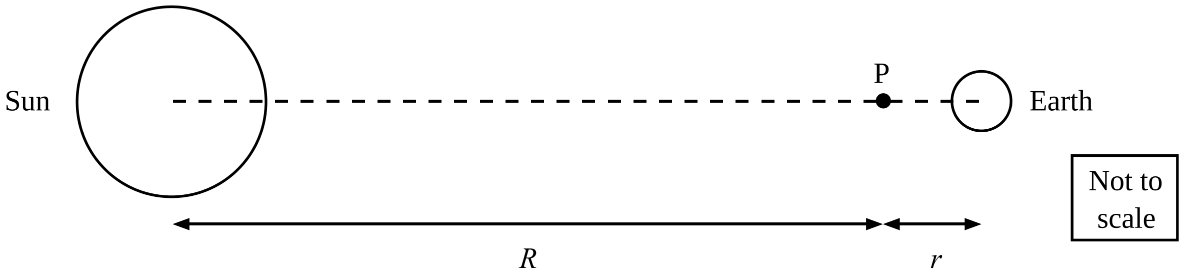
(2)
(Total 9 marks)

27. On a line between the Earth and the Sun is a point P where the gravitational field strength of the Sun is equal and opposite to that of the Earth. Point P is a distance R from the centre of the Sun and a distance r from the centre of the Earth.



The mass of the Sun is M_S. The mass of the Earth is M_E. The gravitational constant is G.

(a) Using the symbols given, write down an expression for

(i) the gravitational field strength of the Sun at point P

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(ii) the gravitational field strength of the Earth at point P.

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(1)

(b) The mass of the Sun is 2.0×10^{30} kg. The mass of the Earth is 6.0×10^{24} kg.

(i) Show that the ratio of R to r is about 600:1.

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(2)

(ii) Hence find the value of r, given that the distance from the centre of the Earth to the centre of the Sun is 1.5×10^8 km.

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r = ...

(2)

(c) SOHO, a satellite that monitors the Sun, is positioned at a point on the line between the Earth and the Sun. The gravitational forces acting on it keep it in the same relative position, orbiting the Sun at the same rate as the Earth.

On the diagram opposite, mark with a letter L a possible position for SOHO.

With reference to the circular motion of SOHO, explain how you decided on the position of L. You are **not** expected to perform any calculations.

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(3)
(Total 8 marks)

28. An accurate value of the Hubble constant has not been easy to calculate, owing to the difficulty of measuring the distances to distant galaxies. One method of determining astronomical distances is to observe supernovae, since we can predict the luminosity of these exploding stars.

(a) Name the type of reaction that produces energy in a star and allows it to radiate.

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(1)

(b) How can we determine:

(i) the distance of such a star using a measurement of the intensity of its light arriving at the Earth;

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(1)

(ii) the velocity of a distant star using the frequency of the detected light?

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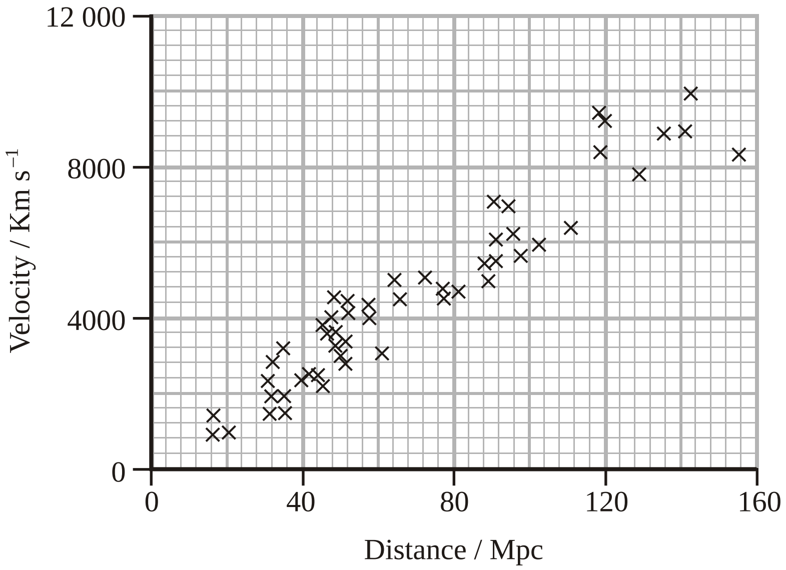
(2)

(c) Edwin Hubble discovered a relationship between velocity and distance of stars and galaxies. Some experimental results are shown below.



(i) Complete the graph with a line of best fit and state what this graph shows about the velocity of galaxies in the Universe.

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(2)

(ii) The Hubble time, $1/H_0$, gives an approximate age of the Universe. Use the gradient of the graph to determine this time.

$1 \text{ pc} = 3.09 \times 10^{16}$ m

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Hubble time = ... s

(2)

(Total 8 marks)

29. In a radio programme about space tourism, the presenter says that the Earth's atmosphere stops 100 km above the surface. A student decides to put this claim to the test, initially applying the following equation to gas molecules at this height:

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

where k is the Boltzmann constant.

(a) (i) State the meanings of the other symbols used in the equation.

m ....

$\langle c^2\rangle$ ....

T ....

(3)

(ii) What physical quantity does each side of the equation represent?

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(1)

(iii) Calculate a value for the velocity of an oxygen molecule at this height, where the temperature is −50 °C.

Mass of oxygen molecule = 5.4×10^{-26} kg

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Velocity = ...

(2)

(b) The student decides that if there really is no atmosphere above the height of 100 km this velocity must be equal to the escape velocity. The escape velocity is the minimum velocity needed for any particle to escape from the Earth's gravitational attraction. He obtains an expression for the escape velocity, starting with the total energy of a molecule at this height, i.e. its kinetic energy + its potential energy.

(i) He finds that the potential energy of a mass m at distance r from the centre of the Earth is given by $-GMm/r$, where M is the mass of the Earth. Hence show that the escape velocity is given by:

$$v_{\text{esc}} = \sqrt{\left(\frac{2GM}{r}\right)}$$

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(2)

(ii) Show that the escape velocity for an oxygen molecule from this height is more than 10 km s^{-1}.

Mass of Earth = 5.98×10^{24} kg
Radius of Earth = 6.37×10^{6} m

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(2)

(iii) The graph below shows the distribution of velocities for molecules in a sample of gas at −50 °C.

Use the graph below to explain whether oxygen molecules are likely to escape.

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(2)
(Total 12 marks)

30. (a) (i) When the Sun nears the end of its life it will become a red giant star. Give one similarity and one difference (apart from size, age and colour) between the Sun now and when it becomes a red giant.

Similarity. ....

....

Difference. ....

....

(2)

(ii) Complete the sentence below by circling the appropriate term within each pair of brackets.

A white dwarf star is a { cool, hot } star of { high, low } luminosity

and small { density, surface area } which has moved

{ higher up, lower down, off } the main sequence.

(2)
(Total 4 marks)

31. (i) A star of mass 30 $M_{\odot}$ has a lot more fuel available than our Sun. A student suggests that this star should therefore spend longer than the Sun on the main sequence. Criticise this statement. You may be awarded a mark for the clarity of your answer.

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(4)

(ii) Another high mass star becomes a supernova. If the mass of the core remnant left after the supernova stage is $2.2M_{\odot}$, circle the type of star that would be formed in the list below.

Red giant   Black hole   White dwarf   Neutron star   Black dwarf

(iii) The Sun will go through different evolutionary phases in the future. In the list below, circle all the types of star that the Sun will become at some stage in the future.

Red giant   Black hole   White dwarf   Neutron star   Black dwarf

(4)
(Total 8 marks)

32. A line in the hydrogen spectrum from a laboratory source has a wavelength of 656 nm.

(a) In the spectrum of light received from a distant galaxy X, this line appears at a wavelength of 684 nm. Calculate the speed of recession of galaxy X.

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Speed = ...

(3)

(b) A second galaxy Y is twice as far from the Earth as galaxy X. At what wavelength would you expect the same line to appear in the spectrum of light received from Y? Explain your reasoning.

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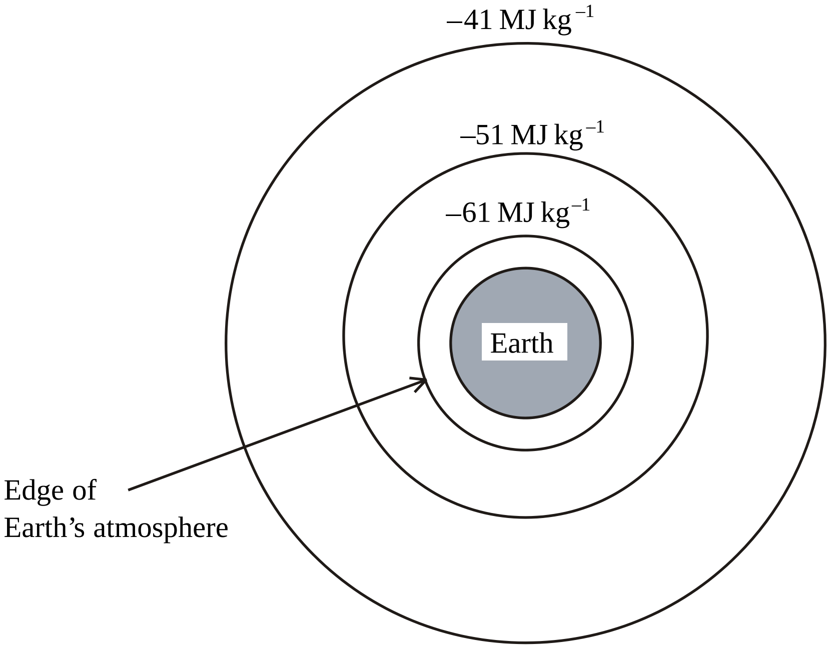
Wavelength = ...

(3)
(Total 6 marks)

33. The diagram shows three equipotential surfaces centred about the Earth with their values marked.



(a) State **two** deductions that can be made from the diagram.

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2 ....

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(2)

(b) The gravitational potential at the Moon's orbit due to the Earth alone is approximately –1.0 MJ kg^{-1}. Use this fact and information from the diagram above to show that a spacecraft, returning from the Moon's orbit using only the gravitational attraction of the Earth, would be travelling at approximately 11 km s^{-1} on arrival at the Earth's atmosphere.

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(4)

(c) There is a point between the Earth and the Moon where their gravitational attractions on a given mass are equal and opposite. Use the formula for the gravitational attraction between point masses to show that this distance is nearly 10 times further from the Earth than from the Moon.

Mass of the Earth $= 6.0 \times 10^{24}$ kg
Mass of the Moon $= 7.4 \times 10^{22}$ kg.

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(4)
(Total 10 marks)

34. (a) Explain the difference between the luminosity and the intensity of a star.

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(3)

(b) (i) The Sun has a surface temperature of 5800 K. Calculate the wavelength at which the intensity of its spectrum is a maximum.

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(2)

(ii) The radius of the Sun is 6.96×10^8 m. Show that its surface area is approximately equal to 6×10^{18} m^2.

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(2)

(iii) Hence calculate the luminosity of the Sun.

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(3)
(Total 10 marks)

35. (a) A brown dwarf is a star-like object that is composed of hydrogen but has insufficient mass to become a main sequence star. Explain, in terms of nuclear fusion, why stars need to exceed a certain minimum mass to join the main sequence. You may be awarded a mark for the clarity of your answer.

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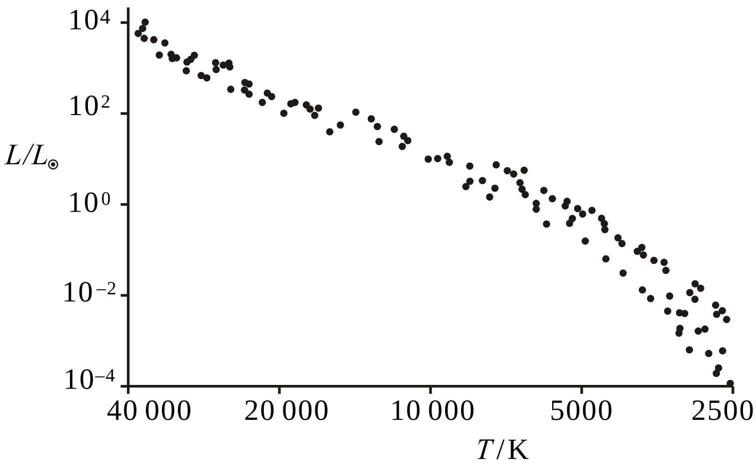
(4)

(b) The Hertzsprung-Russell diagram shows the luminosity of a star plotted against its temperature.



(i) Both scales of the diagram are logarithmic. State what is meant by logarithmic. Illustrate your answer by referring to the numerical values on the temperature axis.

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(2)

(ii) Add to the graph to indicate

1) a low mass star which is on the main sequence, marking this point L

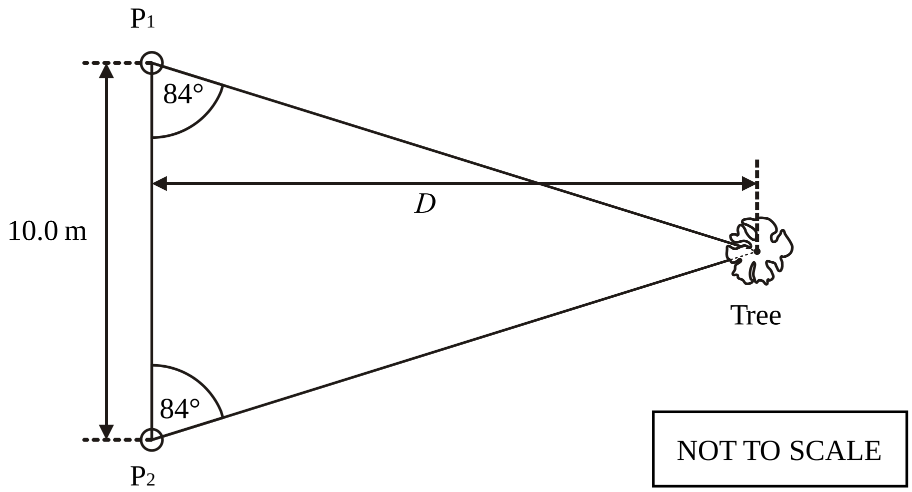
2) the area where white dwarf stars occur, marking this area W

3) the region where red giant stars occur, marking this area R

4) the position of the Sun, marking this point S.

(4)
(Total 10 marks)

36. Two pupils use a parallax method to calculate the distance to a nearby tree. They stand 10.0 m apart (the baseline, P_1P_2) and measure the angle between each other and the tree. The angle measured by each student is 84°. A plan view of this is shown.



(i) Calculate the distance *D*.

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(2)

(ii) State what astronomers use as their baseline in trigonometric parallax measurements of nearby stars.

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(1)

(iii) State why trigonometric parallax cannot be used to measure the distance to stars over 100 light years from Earth.

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(1)
(Total 4 marks)

37. Communication satellites are often placed in geostationary orbit. The speed v of a geostationary satellite is given by the expression

$$v = \omega r$$

where r is the radius of the orbit.

(a) A student calculates that ω has the numerical value of 7.27×10^{-5}. Show how he arrives at this figure.

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State the unit of ω.

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(3)

(b) Hence, or otherwise, calculate the height of such satellites above the Earth's surface, given that the Earth has a mass of 5.98×10^{24} kg and a radius of 6.38×10^{6} m.

....

....

....

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....

....

....

Height above Earth's surface = ...

(4)
(Total 7 marks)

38. Meteosat is a weather satellite which is in a geostationary orbit around the Earth, i.e. it stays above the same point on the Earth's surface all the time.

(a) Write down an expression for the gravitational force on this satellite, mass *m*, in an orbit of radius *r* around the Earth, mass *M*.

....

....

(1)

(b) Hence derive an expression for the gravitational field strength at a distance *r* from the centre of the Earth.

....

....

(1)

(c) Use this, together with an expression for the centripetal acceleration, to show that the radius r of the geostationary orbit is given by

$$r^3 = \frac{GMT^2}{4\pi^2}$$

where T is the time for one orbit of the satellite.

....

....

....

....

....

(3)

(d) Calculate this radius.

Mass M of the Earth = 6.0×10^{24} kg.

....

....

....

Radius = ...

(2)

(e) The mass and speed of the satellite do not appear in the above equation. Explain whether a satellite could remain in geostationary orbit with

(i) a greater mass.

....

....

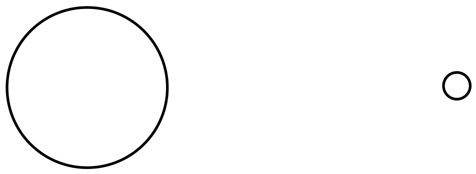
(ii) a greater speed.

....

....

(2)

(f) Explain why a satellite has to be over the equator to remain in a geostationary orbit. You may use the diagram to help your explanation.



....

....

....

....

(2)
(Total 11 marks)

39. The Joint European Torus (JET) was a nuclear fusion experiment near Oxford in England. JET was the first experiment to produce a controlled nuclear fusion reaction.

(a) Describe the process of nuclear fusion.

....

....

....

....

(2)

(b) Explain why it is difficult to maintain the conditions for nuclear fusion in a reactor.

....

....

....

....

(2)

(c) The nuclei which fused were two isotopes of hydrogen. Why should the fusing of hydrogen nuclei release energy?

....

....

....

....

(2)
(Total 6 marks)

40. (a) Wien's law can be written as

$$\lambda_{max} T = 2.90 \times 10^{-3} \text{ m K}$$

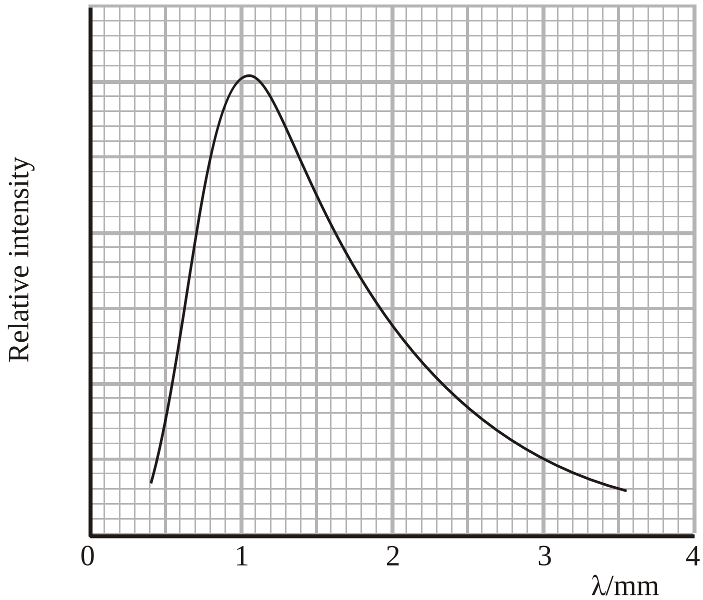
(i) Explain clearly what is meant by each symbol in Wien's law.

λ_{max} ....

T ....

(2)

(ii) The graph shows the wavelength distribution for radiation detected by the COBE satellite.



To what part of the electromagnetic spectrum does this radiation belong?

....

(1)

(iii) Use the graph to determine the temperature of the source of these emissions.

....

....

....

Temperature = ...

(3)

(b) A star that is considerably more massive than the Sun may end its life as a supernova. During a supernova explosion approximately 1×10^{46} J of energy can be released.

(i) State the minimum mass of a star that can become a supernova.

....

(1)

(ii) Use the data below to estimate how much energy is given off by the Sun during its approximate lifetime.

Luminosity = 3.9×10^{26} W

Approximate lifetime = 1×10^{10} y

....

....

....

Energy = ...

(3)

(iii) Estimate the ratio of the energy that is released when a supernova explodes to the total energy given off by the Sun during its lifetime.

....

....

Ratio = ...

(2)

(iv) When a supernova explodes, the mass of its core remnant determines its future. State the two possible outcomes and how each depends on the mass of the remnant.

....

....

....

....

....

....

(3)

(c) (i) If the Earth (mass = 6.0×10^{24} kg) had the same density as a neutron star it would be approximately 150 m in radius. Show that the average density of such an object would be approximately 4×10^{17} kg m^{-3}.

....

....

....

....

(2)

(ii) Explain how the neutrons in a neutron star were formed, both during and after the main sequence. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

(4)

(d) (i) Use the data below to calculate the intensity of the Sun as measured from Mars and from Earth.

Luminosity of the Sun = 3.90×10^{26} W

Sun – Mars distance = 2.28×10^{8} km

Sun – Earth distance = 1.50×10^{8} km

....

....

....

....

Intensity from Mars = ... Intensity from Earth = ...

(3)

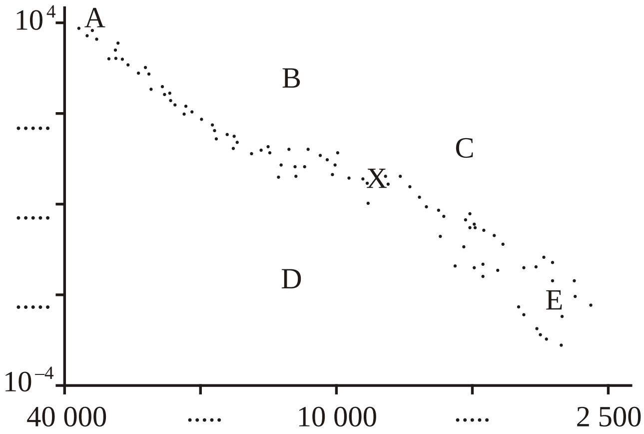
(ii) Hence show that the brightness of the Sun as seen from Mars is approximately 40% of its brightness from Earth.

....

....

(2)
(Total 26 marks)

41. On the Hertzsprung-Russell diagram shown below X indicates the position of the Sun.



(i) Add labels and units to each axis.

(2)

(ii) Complete the scale on the *y*-axis by adding three further values where indicated.

(2)

(iii) Complete the scale on the *x*-axis by adding two further values where indicated.

(1)

(iv) Letters A, B, C, D and E represent different stars. Identify all stars which could be:

a red giant	
a low mass star on the main sequence	

(2)

(v) Use the data below to show that the luminosity of the star ς Tau (Zeta Tauri) is approximately 4×10^{30} W.

Intensity = 1.9×10^{-8} W m^{-2}

Distance from Earth = 4.0×10^{18} m

....

....

....

....

(3)

(vi) One of the labelled stars on the Hertzsprung-Russell diagram is ξ Tau. Calculate the luminosity of ξ Tau in terms of solar luminosities and thus deduce which letter must represent this star. Luminosity of the Sun $L_{\odot} = 3.9 \times 10^{26}$ W.

....

....

....

Luminosity = ...

Star = ...

(3)

(Total 13 marks)

42. When stars undergo nuclear fusion, hydrogen is fused to form helium. As part of this process two ${}^{3}_{2}\text{He}$ nuclei react to form ${}^{4}_{2}\text{He}$.

$$ {}^{3}_{2}\text{He} + {}^{3}_{2}\text{He} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} $$

(i) Calculate the change in mass in one such fusion reaction.

Nucleus	Mass / 10^{-27} kg
${}^{3}_{2}\text{He}$	5.0055
${}^{4}_{2}\text{He}$	6.6447
${}^{1}_{1}\text{H}$	1.6726

....

....

....

....

....

....

Change in mass = ...

(2)

(ii) Hence calculate the energy released by this fusion reaction.

....

....

....

....

Energy = ...

(2)

(Total 4 marks)

43. (i) Write an equation for the density of a star in terms of its mass and radius.

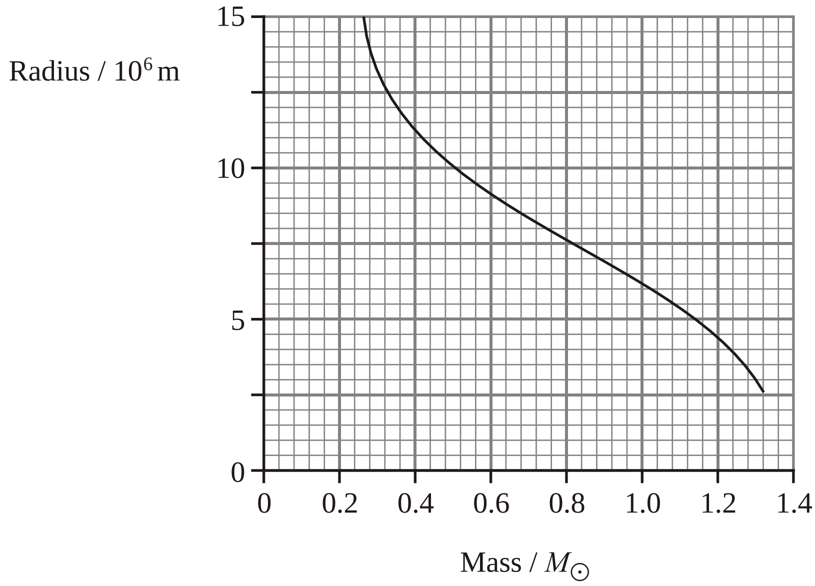
....

....

....

(1)

(ii) The graph shows the mass-radius relationship for white dwarf stars. The mass of the Sun $M_\odot = 2.0 \times 10^{30}$ kg.



Using the graph, calculate the density of two white dwarf stars and hence show that the density of a white dwarf increases as its mass increases.

....

....

....

....

....

(3)

(iii) Describe what eventually happens to a white dwarf star.

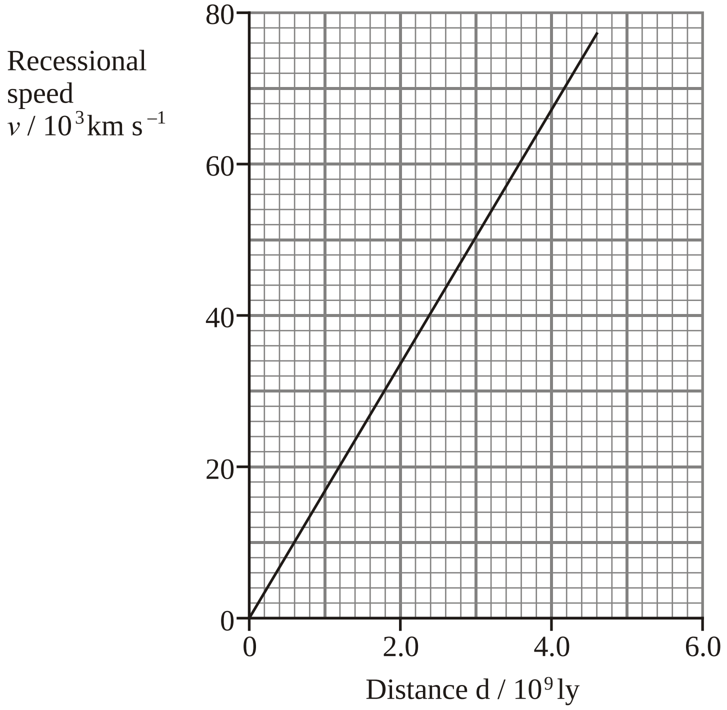
....

....

....

(2)
(Total 6 marks)

44. (a) Edwin Hubble examined the relationship between the recessional speed of galaxies, *v*, and their distance, *d*, from Earth. The graph shows the best-fit line for his results.



(i) Use the graph to determine a value for the Hubble constant, *H*, in s^{-1}. Show your working.

....

....

....

....

....

....

....

Hubble constant = ...s^{-1}

(4)

(ii) What is the main source of uncertainty in the value of *H*?

....

(1)

(b) Explain how the Hubble constant provides us with an estimate for the age of the Universe, *t*.

....

....

....

....

....

....

(2)

(c) Ionised calcium has a line spectrum which includes a spectral line of wavelength 393 nm. The observed wavelength of this calcium line in the radiation from a distant galaxy is 469 nm. Calculate the galaxy's recessional speed.

....

....

....

....

....

Recessional speed = ...

(3)

(d) Briefly explain how the value of the average mass-energy density of the Universe will determine whether the Universe is open or closed.

....

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....

(2)
(Total 12 marks)

45. (a) State Newton's law for the gravitational force between two point masses.

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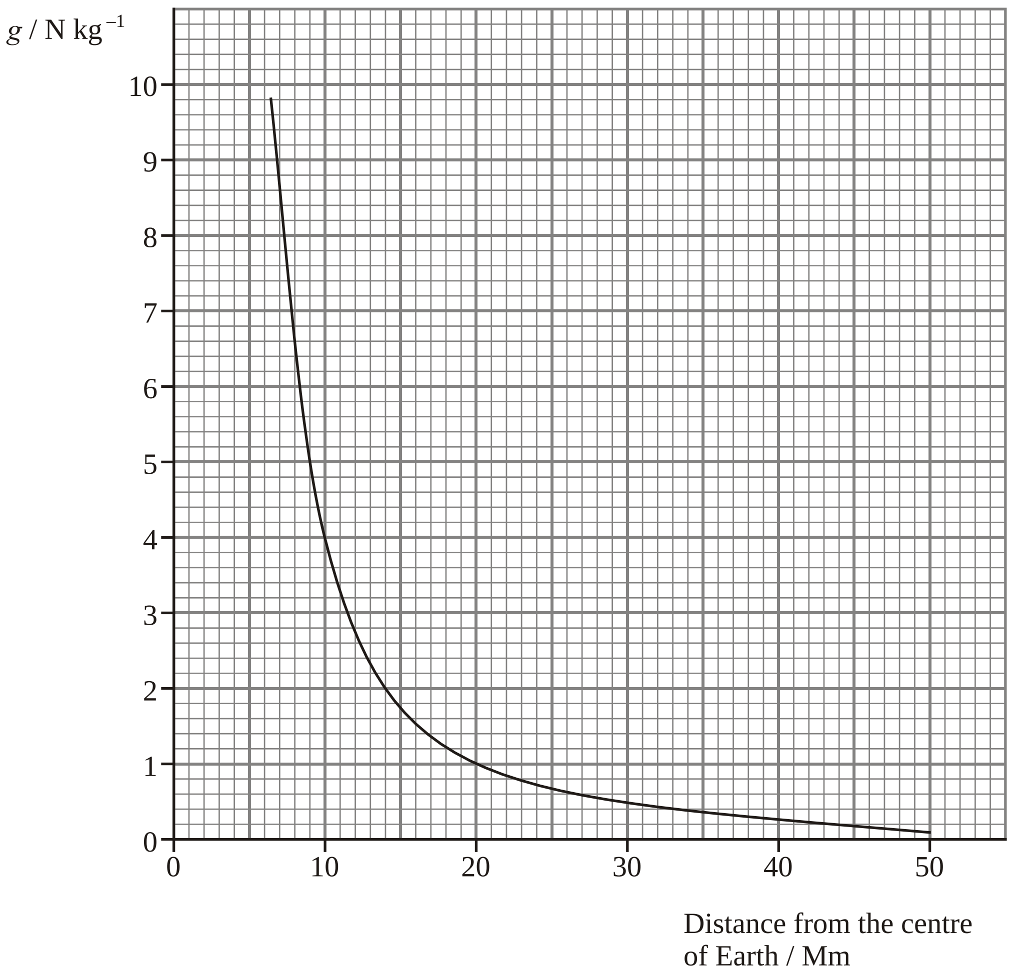
(2)

(b) The graph shows how the gravitational field strength g above the Earth's varies with the distance from its centre.



(i) Use the graph to demonstrate that the relationship between g and distance from the centre of the Earth obeys an inverse square law.

....

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....

(3)

(ii) The average distance between the centre of the Moon and the centre of the Earth is 380 Mm. Use information from the graph to determine the Earth's gravitational field strength at this distance.

....

....

....

....

Gravitational field strength = ...

(2)

(c) What effect, if any, does the Earth's gravitational field have on the Moon?

....

....

(1)

(Total 8 marks)

46. In July 2003 astronomers announced the discovery of a planet orbiting a star 90 light years from Earth. The astronomers used the Doppler effect to detect the planet.

You may have heard the Doppler effect when an ambulance using its siren passes you. Describe what would be heard as the ambulance approaches and then passes.

....

....

....

....

(2)

The method used by the astronomers is called the Doppler Wobble effect. When a planet orbits a star it pulls on the star, making it move slightly or 'wobble'. The larger the planet, the more the star wobbles.

Explain the use of the Doppler technique to discover the new planet. Include diagrams of the planet and star when the Doppler effect is most useful. Label your diagrams and show the direction of the Earth.

....

....

....

....

(4)

The astronomers discovered that the time for the planet to make one orbit around its star was six years. How did they determine this from their observations?

....

....

(1)

Use a gravitational force equation to explain why the method that astronomers used to discover this planet will not reveal any planets the size of Earth.

....

....

....

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....

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(4)

(Total 11 marks)

47. A student says that once you know about electric fields, you can apply the same laws to gravitational fields.

Write a set of revision notes defining each of these two types of field and stating the similarities and differences between them.

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(Total 6 marks)

48. The Cosmic Background Explorer satellite (COBE), launched in 1989, measured a cosmic background temperature of 2.725 K. Calculate the peak wavelength of the background spectrum that gives this temperature.

....

....

....

....

(3)

Which type of electromagnetic radiation forms this background spectrum?

....

(1)
(Total 4 marks)

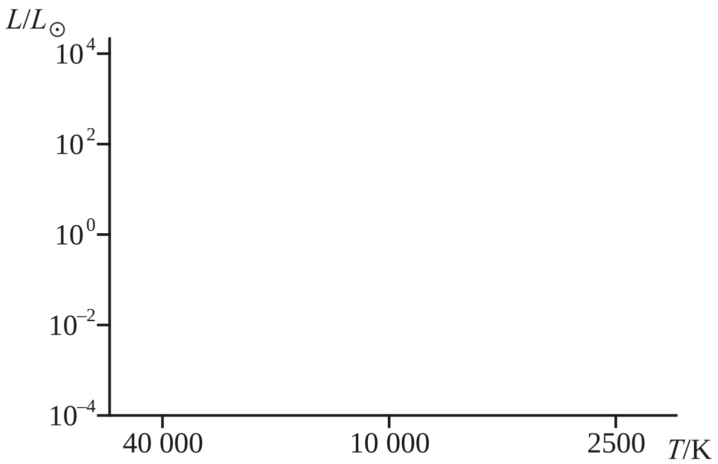
49. Define what is meant by a main sequence star.

....

....

(2)

A Hertzsprung-Russell diagram can be used to plot the luminosity of a star in terms of the luminosity of the Sun ($L_\odot$) against the star's surface temperature.



Add to the diagram a line to indicate where main sequence stars occur.

Mark clearly with a cross the location of the Sun.

(3)

Add to the diagram the regions where (i) white dwarf stars and (ii) red giant stars may typically be found. Label these clearly.

Use the diagram to estimate the average surface temperature of a red giant star.

....

(3)
(Total 8 marks)

50. The table shows the properties of three main sequence stars.

Star	Luminosity/$L_\odot$	Surface temperature/K
α Cen B	0.53	5250
Sirius A	26	9230
γ Cas	930 000	29 500

State which star would

(i) have the greatest mass ....

(ii) spend the greatest time on main sequence ....

(2)

The luminosity of the Sun is 3.9×10^{26}W. Calculate the luminosity of Sirius A.

....

....

(2)

Show that the area of Sirius A is approximately 2.5×10^{19} m^2.

....

....

....

....

....

(2)

Hence calculate the diameter of Sirius A.

....

....

....

....

(2)
(Total 8 marks)

51. (a) In a fast breeder reactor a nucleus of uranium $^{238}_{92}\text{U}$ absorbs a neutron to produce uranium, $^{239}_{92}\text{U}$. Write a balanced nuclear equation for this reaction.

....

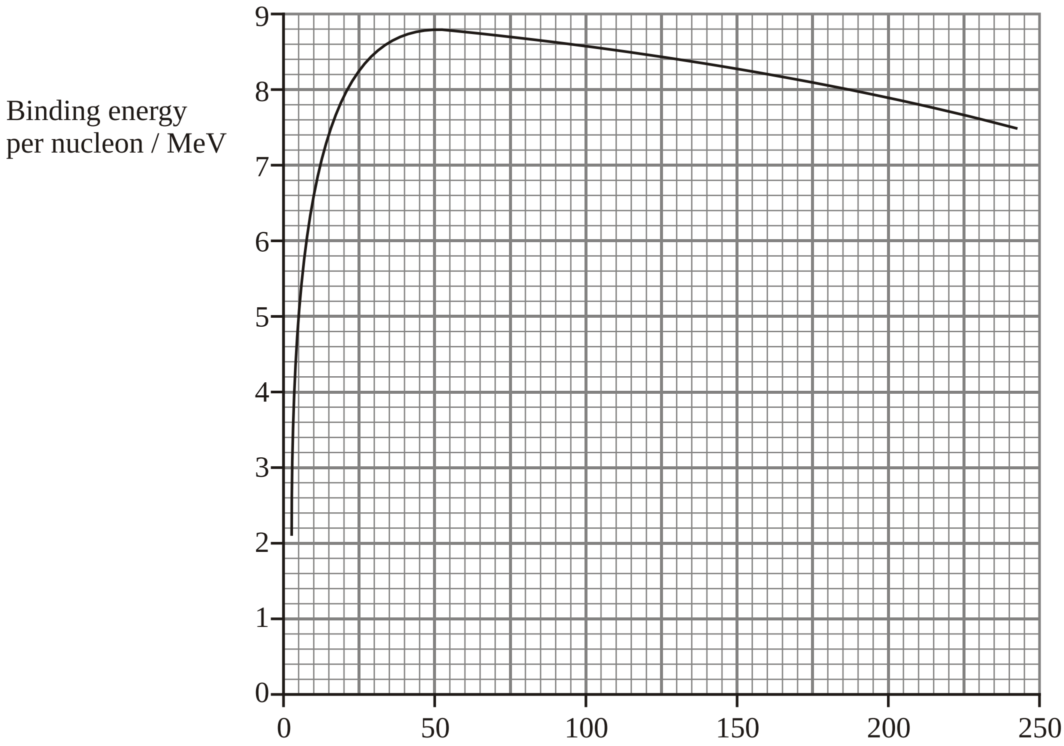
(1)

The $^{239}_{92}\text{U}$ subsequently undergoes a beta-minus decay to form neptunium Np. Write a balanced nuclear equation for this reaction.

....

(3)

(b) The graph shows how the binding energy per nucleon varies with another quantity.



(i) Add an appropriate label to the *x*-axis.

(1)

(ii) Mark clearly on the graph the approximate position of

- deuterium $^{2}_{1}H$, labelling this point H,
- iron $^{56}_{26}Fe$, labelling this point Fe,
- uranium $^{235}_{92}U$, labelling this point U.

(2)

(iii) Circle the most stable nucleus on the graph.

(1)

(iv) Use the graph to calculate the binding energy of a uranium-235 nucleus. Give your answer in GeV.

....

....

....

....

Binding energy = ... GeV

(3)
(Total 11 marks)

52. Hubble's law can be represented by the formula $v = Hd$.

(a) State the unit of the Hubble constant H.

....

(1)

(b) Show how the age of the Universe can be estimated by using the above formula. State an assumption that has to be made.

....

....

....

....

....

....

....

Assumption: ....

....

....

(4)
(Total 5 marks)

53. (i) The equation $I = L/\ 4\pi D^2$ can be used to determine the luminosity L of a star of known distance D and intensity I. Use this equation to show that the base units of intensity are kg s^{-3}.

....

....

....

(3)

(ii) Calculate the luminosity of a star which has a measured intensity of 1370 W m^{-2} and which is known to be 1.49×10^{11} m from Earth.

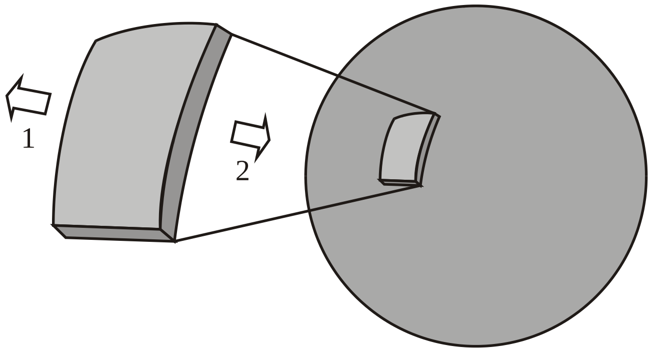
....

....

....

(3)
(Total 6 marks)

54. The diagram shows a main-sequence star. The arrows on the enlarged section of star material represent the forces acting on it.



(i) State the origin of these forces.

1. ....

....

2. ....

....

(2)

(ii) How do these forces compare in size?

....

(1)

(iii) State three differences between white dwarf stars and red giant stars. One of your answers should be numerical.

1 ....

....

2 ....

....

3 ....

....

(3)

(iv) What determines whether a neutron star will be formed from a supernova?

....

....

(2)
(Total 8 marks)

55. When the Sun was formed some 4.6×10^9 years ago, it was slightly smaller than it is today. Theoretical calculations show that it has become 40% more luminous and grown in radius by 6% (i.e. $L_\odot = 1.4\,L$ and $r_\odot = 1.06\,r$ where L and r represent the luminosity and radius of the Sun when it was formed).

Data for the Sun today:

Luminosity $L_\odot$ $= 3.9 \times 10^{26}$ W

Radius $r_\odot = 7.0 \times 10^5$ km

Temperature $T_\odot$ $= 5800$ K

(i) Calculate the luminosity of the Sun when it was formed.

....

....

....

(2)

(ii) Calculate the surface area of the Sun when it was formed.

....

....

....

(2)

(iii) Hence show that the surface temperature of the Sun has increased by approximately 300 K during its lifetime.

....

....

....

....

....

....

....

(4)

(iv) The Sun has become slightly more yellow during its lifetime. It used to be more orange in colour. This is because the wavelength at which the peak intensity of its emitted radiation occurs has decreased. Use Wien's law to calculate the decrease in the wavelength of the peak intensity.

....

....

....

....

....

....

(3)
(Total 11 marks)

56. (a) What is meant by the Doppler effect (electromagnetic Doppler effect) when applied to light?

....

....

....
(2)

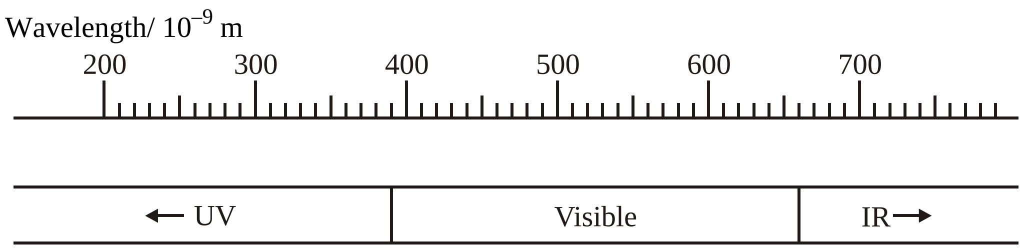
(b) Edwin Hubble reached a number of conclusions as a result of observations and measurements of red-shift. State two of these conclusions.

....

....

....
(2)

(c) The diagram gives values of wavelength for part of the electromagnetic spectrum.



A very hot distant galaxy emits violet light just at the edge of the visible spectrum. Estimate the maximum velocity the galaxy could have so that visible light could still be detected as it moves away from the Earth.

....

....

....

....
(4)

(d) The fate of the Universe is dependent on the average mass-energy density of the Universe. What is meant by the critical density of the Universe?

....

....

....

(2)
(Total 10 marks)

57. (a) (i) State Newton's law for the gravitational force between point masses.

....

....

....

(2)

(ii) Use this law to show that the gravitational field strength g at a distance r from the centre of the Earth, where r is greater than or equal to the radius R of the Earth, is given by

$$g = \frac{GM}{r^2}$$

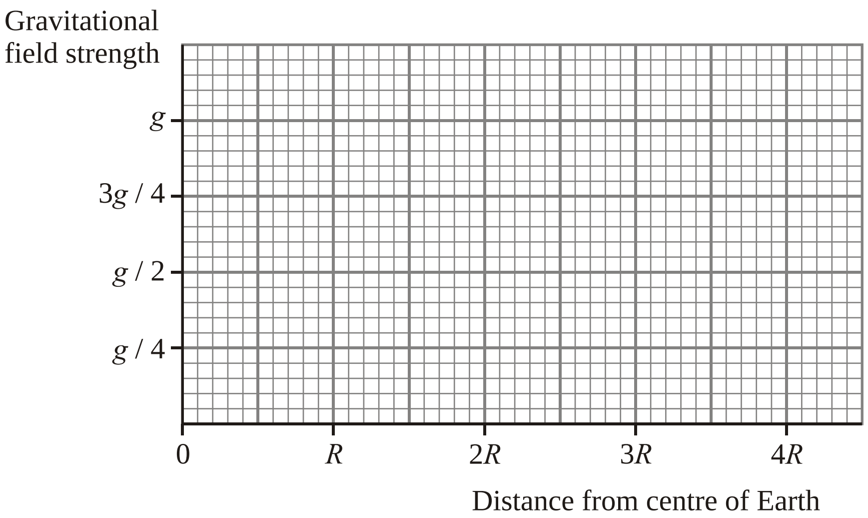
where M is the mass of the Earth.

....

....

(1)

(iii) Use the axes below to plot a graph to show how g varies as the distance r increases from its minimum value of R to a value of $4R$.



(3)

(b) (i) When a satellite, which travels in a circular orbit around the Earth, moves to a different orbit the change in its gravitational potential energy can be calculated using the idea of equipotential surfaces. What is an equipotential surface?

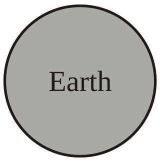
....

....

....

(1)

(ii) Add to the diagram below three equipotential surfaces which have equal changes of potential between them.



(2)

(c) The change in the gravitational potential energy of the satellite when it moves to a different orbit might be calculated using the expression

‘weight of satellite × change in height’.

(i) What condition must apply for this to be valid?

....

....

(ii) Explain your answer.

....

....

....

(2)
(Total 11 marks)

58. (i) What information about a star can be deduced from its spectrum?

....

....

(1)

(ii) In the spectrum of a nearby star, an absorption line is found at 420 nm, which is 20 nm nearer the blue end of the spectrum than its ‘laboratory’ position. What is the velocity of the star relative to Earth?

....

....

....

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....

....

....

....

(4)
(Total 5 marks)

59. Fission of ^{235}U (uranium-235) nuclei is used to provide the energy to heat the core of a nuclear reactor.

A typical fission reaction is given in the equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{111}_{44}Ru + ^{122}_{48}Cd + 3\,^{1}_{0}n + \text{energy}$$

Write down the number of protons and neutrons in the isotope of cadmium produced, ^{122}Cd.

Protons .... Neutrons ....

(2)

Describe briefly the process which occurs in a fission reaction.

....

....

....

....

....

....

(3)

The fission of one ^{235}U nucleus in the equation above releases 3.2×10^{-11} J of energy. Calculate the change in mass which occurs in this reaction.

....

....

....

(2)

A nuclear power station, which uses the fission of ^{235}U nuclei, generates 660 MW of electrical power and is 30% efficient. Calculate the number of fissions required each second to produce this power.

....

....

....

....

....

Number of fissions per second = ...

(2)

This number of atoms has a mass of less than a gram. Give **two** reasons why it is necessary to have a lot more fuel than this in a nuclear reactor.

....

....

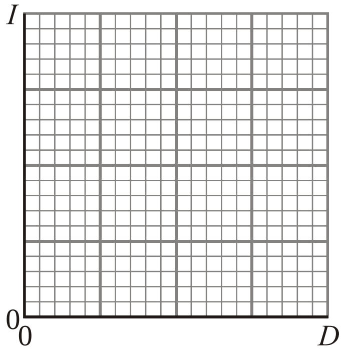
....

....

....

(2)
(Total 11 marks)

60. (a) On the axes below sketch a graph showing how the intensity I of a star varies with distance D from the star.



(2)

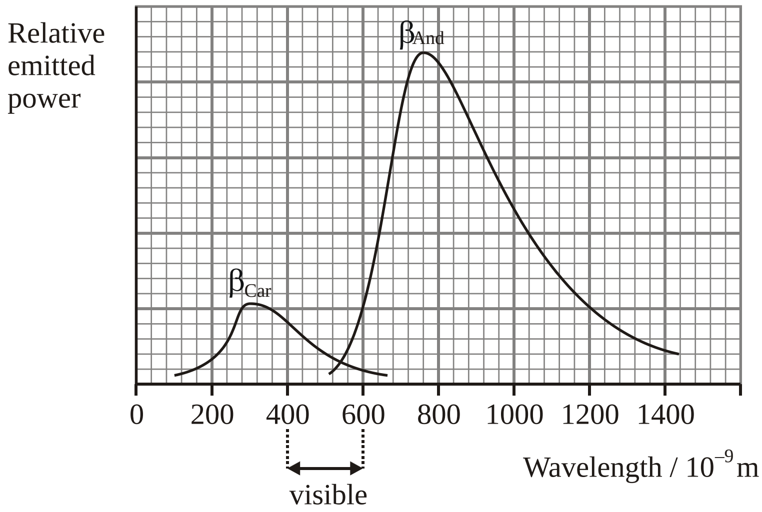
Give two reasons why measurements of a star's intensity are often made from above the Earth's atmosphere.

1. ....

2. ....

(2)

(b) The graph shows the energy distribution in the spectra of two stars β_{Car} and β_{And}.



What can be deduced about the colours of the two stars from the graph?

....

....

(1)

Estimate the surface temperature of β_{And}.

....

....

....

....

(3)

The luminosity of β_{Car} is 2.0×10^{28} W and it has a surface temperature of 9300 K. Calculate the surface area of β_{Car}.

....

....

....

....

(3)

By comparing the areas under the two graphs, estimate the luminosity of β_{And}.

....

....

....

....

(2)
(Total 13 marks)

61. Explain what is meant by a main sequence star.

....

....

(1)

Outline the life story of a white dwarf star starting from when it was a main sequence star. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

....

....

(4)

What determines whether or not a main sequence star eventually becomes a white dwarf? Quantify your answer.

....

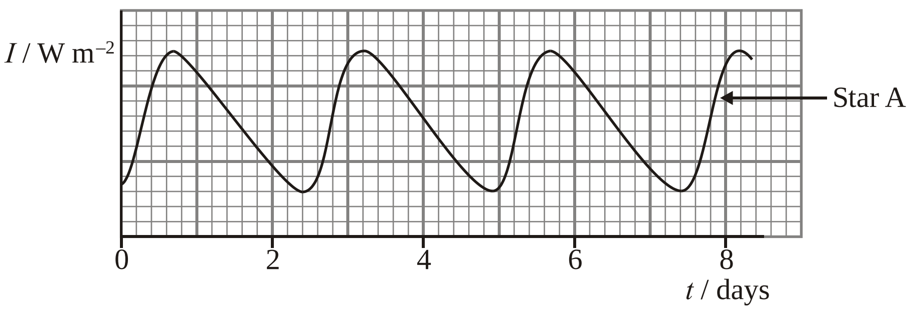
....

....

(2)
(Total 7 marks)

62. Cepheid variables are giant stars that have entered an unstable stage of their evolution. More luminous Cepheid variables pulsate at a slower rate than less luminous ones.

The graph, called a light curve, shows how the intensity of a Cepheid variable (star A) varies with time.



Determine the period of pulsation of star A. Show how you arrived at your answer.

....

....

....

(2)

Add to the graph another light curve showing how the intensity of a more luminous Cepheid variable (star B) might vary with time. Assume that star B has approximately the same average intensity as star A.

(3)

Describe how the pulsations of a Cepheid variable can be used to estimate the distance to the galaxy in which it is found.

....

....

....

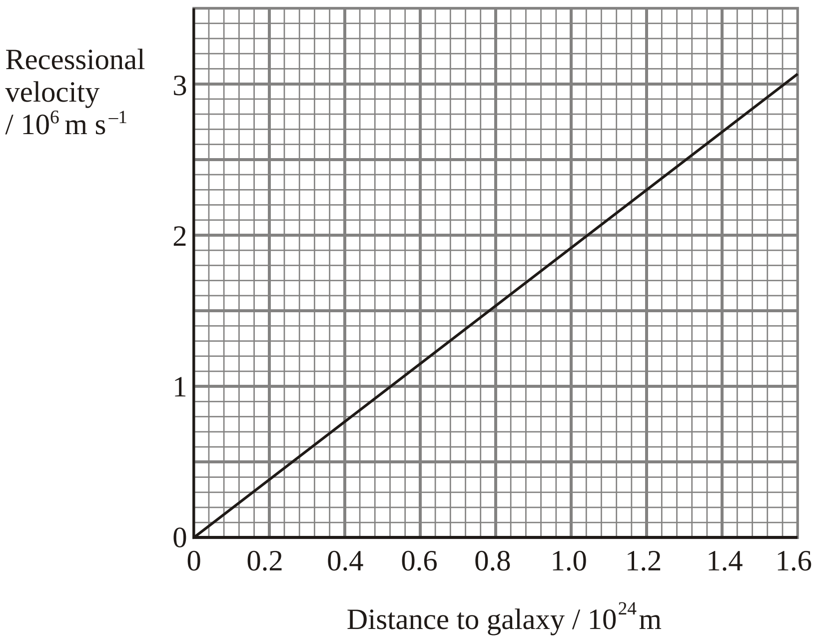
....

....

....

(3)
(Total 8 marks)

63. (a) The graph shows the best-fit line obtained when recessional velocity is plotted against distance from Earth for a large number of galaxies.



Use this graph to calculate a value for the Hubble constant.

....

....

....

Hubble constant = ...

(2)

A spectral line measured using a laboratory source has a wavelength of 372.7 nm. The same line, measured in light from a distant galaxy, has an apparent wavelength of 410.0 nm. Estimate the distance of this galaxy from Earth.

....

....

....

....

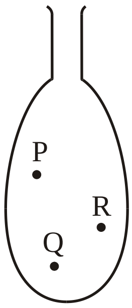
....

....

Distance = ...

(4)

(b) The diagram shows a deflated balloon. It has three dots on its surface, labelled P, Q and R. In the space next to the diagram, draw the balloon as it would appear when fully inflated. Mark the new positions of the three dots.



(2)

Explain how the inflation of the balloon can be used to model the expansion of the Universe. You may be awarded a mark for the clarity of your answer.

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(4)
(Total 12 marks)

64. State two ways in which a white dwarf star differs from a main sequence star.

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(2)

Describe what happens to a star after it has become a white dwarf.

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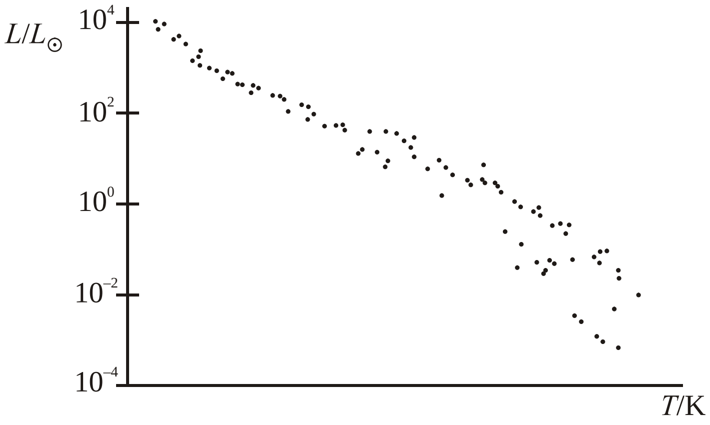
(2)

A Hertzsprung-Russell diagram showing the main sequence is drawn below. The luminosity of the Sun = $L_\odot$.



Add a scale to the temperature axis.

(2)

Identify **one** star on the diagram which has a luminosity very similar to that of the Sun. Label this star X.

(1)

Shade in a region on the diagram where white dwarf stars are located. Label this region W.

(1)

Label with an M the region on the diagram where the most massive main sequence stars are located.

(1)

Explain why the most massive main sequence stars have the shortest lifetimes. You may be awarded a mark for the clarity of your answer.

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(4)
(Total 13 marks)

65. Two stars, Deneb and Vega, are similar in colour. What can be deduced about the surface temperatures of the two stars? Explain your answer.

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(2)

The table gives some information about the two stars.

Star	Luminosity/W	Distance from Earth/m
Deneb	2.5×10^{31}	1.5×10^{19}
Vega	1.9×10^{28}	2.3×10^{17}

Which star has the greater surface area? Justify your answer.

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(3)

Which star will have the higher intensity and therefore appear brighter as seen from the Earth? Show all your working.

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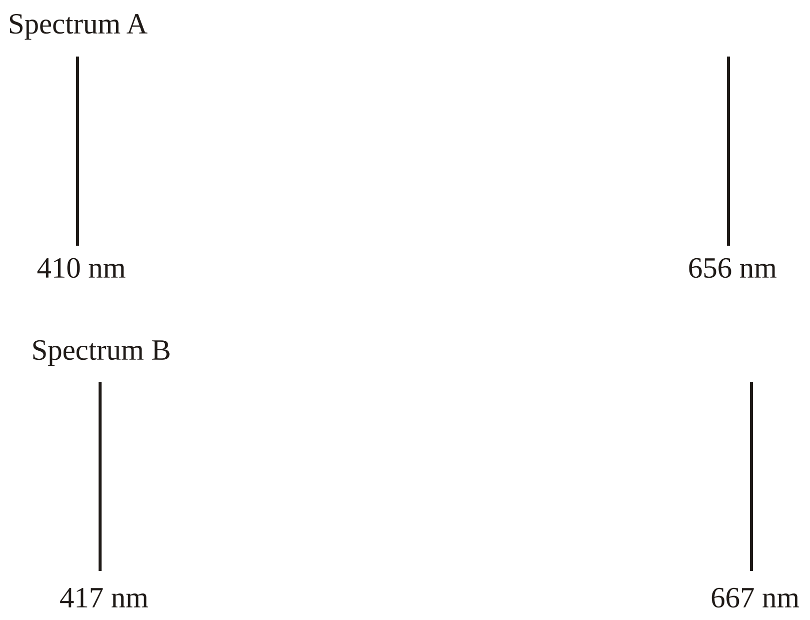
(4)
(Total 9 marks)

66. Spectrum A shows two emission lines of hydrogen obtained in a laboratory; spectrum B shows the same lines as obtained from light from a distant galaxy. Use these spectra to determine the **velocity** of this galaxy. (The diagrams are not to scale.)



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Velocity = ...

(4)

Using a value for the Hubble constant of 1.8×10^{-18} s^{-1}, estimate the distance of this galaxy from Earth.

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Distance = ...

(2)
(Total 6 marks)

67. Write down a formula which relates the force between two objects to their masses *M* and *m* and their distance *r* apart.

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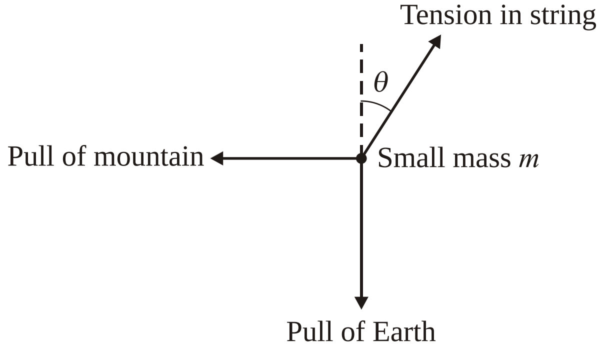
(1)

Nevil Maskelyne developed a suggestion of Newton to use a small mass *m* on the end of a string to detect the gravitational effect of a nearby large mass. Maskelyne used a mountain in Scotland as the nearby large mass. The diagram below illustrates the effect of the mountain on the small mass *m* on the end of the string.



By using a vector diagram or by considering the components of the tension in the string in the vertical and horizontal directions, show that

$$\tan\theta = \frac{MR^2}{M_e r^2}$$

where M is the mass of the mountain,
M_e is the mass of the Earth,
R is the radius of the Earth,
r is the distance between the small mass and the centre of mass of the mountain.

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(4)

From this experiment Maskelyne determined a value of 4.5×10^3 kg m^{-3} for the average density of the Earth. Use this result to calculate a value for the gravitational constant.

Radius of Earth = 6400 km
g = 9.8 m s^{-2}

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G = ...

(3)

This value differs from the accepted value by about 20%. Give one reason for this inaccuracy.

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(1)

Maskelyne calculated that the average density of the Earth was approximately twice that of the mountain. What does this suggest about the Earth's core?

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(1)
(Total 10 marks)

68. (a) State the meaning of *T* in the Stefan-Boltzmann law.

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State the unit of luminosity.

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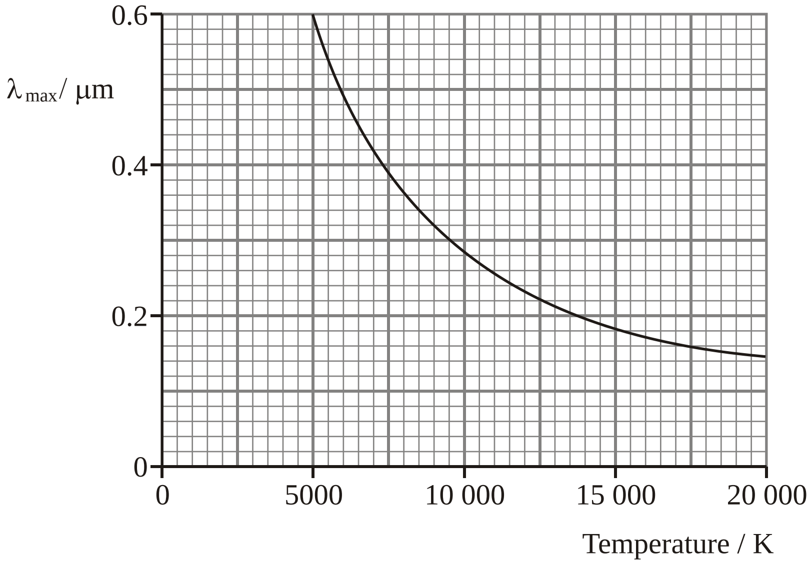
(3)

(b) The graph shows how λ_{max} (the wavelength of the peak of the radiation spectrum) for a range of stars varies with the surface temperatures of the stars.



Carry out appropriate calculations to show that this graph is consistent with Wien's law.

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(3)

Use the graph to estimate the surface temperature of a star whose intensity peaks at a wavelength of 0.4 µm.

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(1)

This star has a radius of 9.0×10^7 m. Calculate its luminosity.

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(4)

Calculate the rate in kg s^{-1} at which matter is being consumed in this star.

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(3)
(Total 14 marks)

69. (a) Complete the sentence below by circling the appropriate term within each pair of brackets.

A red giant is a { cool, hot } star of { high, low } luminosity and large { mass, surface area } which has moved { higher up the main sequence, lower down the main sequence, off the main sequence }.

(4)

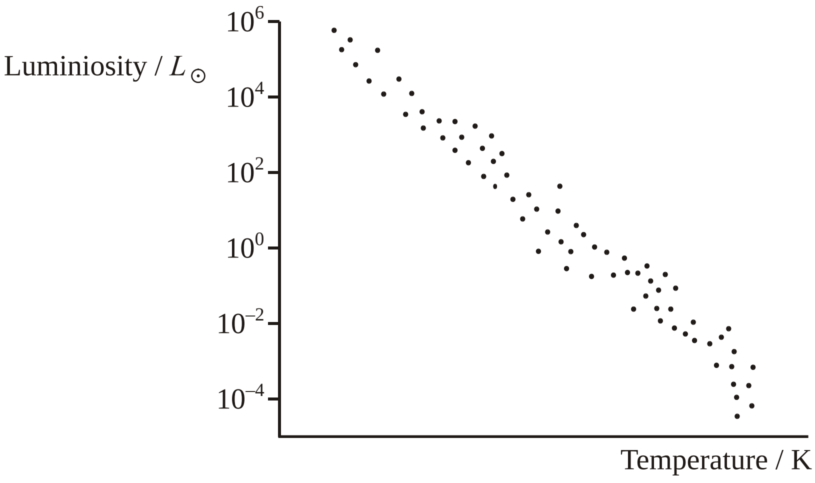
On the incomplete Hertzsprung-Russell diagram below

(i) add a scale to the temperature axis,

(ii) mark the approximate position X_s of the Sun (luminosity of the Sun = $L_\odot$),

(iii) shade in a region labelled W where a white dwarf star might be found,

(iv) shade in a region labelled R where the future red giant formed from the Sun will be found.



(5)

(b) Stars much more massive than the Sun may become supernovae. How do astronomers recognise a supernova?

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(2)

How is a supernova formed? You may be awarded a mark for the clarity of your answer.

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(3)
(Total 14 marks)

70. Eros, a stony asteroid, can be considered to be spherical and of radius 7800 m. Its gravitational field is so weak that a stone thrown vertically from its surface at more than 10 m s^{-1} (≈ 22 m.p.h.) will never return.

This speed is called the escape speed v_e from the asteroid.

(a) Sketch the gravitational field of Eros.

(2)

(b) Suggest why any gas molecules diffusing to the surface of Eros from its core do not form an atmosphere.

(2)

(c) The escape speed v_e from a spherical body such as this asteroid is related to the mass m_A and radius r_A of the asteroid by the equation

$$\upsilon_e \sqrt{\frac{2Gm_A}{r_A}}$$

where G is the gravitational constant.

(i) Show that this equation is homogeneous with respect to units.

(ii) Show that the mass of Eros is about 6×10^{15} kg and calculate its average density.

(5)

(d) Whether a stone thrown from the surface of Eros escapes or returns can be likened to the indefinite expansion or final contraction of our Universe.

(i) Sketch a graph to show how the size of our Universe varies with time since the Big Bang if it is to expand indefinitely. Label the axes of your graph.

(ii) State what governs whether our Universe will expand indefinitely or come together in a Big Crunch.

(4)

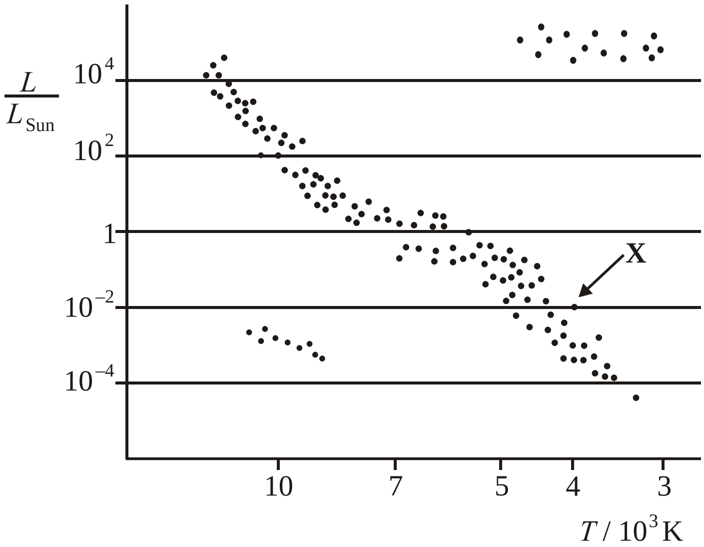
(e) At some future time, an asteroid of mass similar to that of Eros, i.e. of mass 6×10^{15} kg, may be found to be on a course which would result in it colliding with the Earth ten years later. In order to propel it off its course a rocket motor could be attached to the asteroid and fired to produce a force of 2×10^{6} N perpendicular to its path for 7000 s (≈ 2 hours).

(i) Calculate the change in the asteroid's velocity which this rocket firing would produce.

(ii) Suggest with a reason whether such an attempt to alter the asteroid's course would be worthwhile.

(4)
(Total 17 marks)

71. In the Hertzsprung-Russell (HR) diagram below, the dots represent stars.



What does T, on the horizontal axis, represent?

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(1)

Circle the dot on the diagram which represents our Sun.

(1)

Calculate the flux reaching the Earth from the star marked **X** on the HR diagram.

Distance from **X** to the Earth = 500 parsec
1 parsec = 3.09×10^{16} m
$L_{sun} = 3.9 \times 10^{26}$ W

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(3)

What force holds our Sun together?

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(1)

Explain how the nuclear processes within the Sun are able to release energy.

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(3)

At the end of the Sun's life, when energy can no longer be released in this manner, theory predicts that the Sun will become a larger star, of about the same mass, called a red giant.

(i) How will this change affect the Sun's gravitational pull on an outer planet? Explain your reasoning.

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(ii) On the HR diagram above, draw an arrow to represent the change in position of the Sun.

(3)
(Total 12 marks)

72. When a star moves off the main sequence It initially becomes a red giant. Describe the processes occurring which result in it becoming “giant-sized”. You may be awarded a mark for the clarity of your answer.

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(4)

Use Wien’s law to explain why these giant stars look red compared with their appearance when they were on the main sequence.

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(2)

Use Stefan’s law to explain why a red giant has greater luminosity than when it was a main sequence star.

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(3)
(Total 9 marks)

73. What is meant by the term binding energy? You may be awarded a mark for the clarity of your answer.

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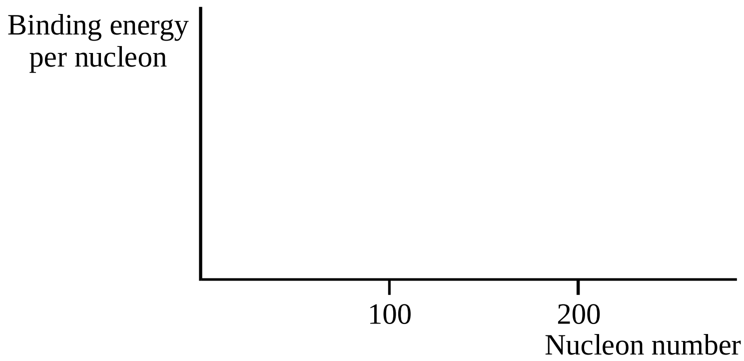
(3)

On the axes below sketch a graph of binding energy per nucleon against nucleon number.



(2)

The binding energy of $^{16}_{8}O$ is 123.45 MeV and the binding energy of 170 is 126.43 MeV.
Which of these two isotopes of oxygen would you expect to be more stable? Explain your answer.

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(3)
(Total 8 marks)

74. Calcium has a line spectrum, which includes the spectral line at a wavelength of 393 nm.

Calculate the frequency of this line.

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Frequency = ...

To which region of the electromagnetic spectrum does this line belong?

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(3)

What is a line spectrum?

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(1)

In cosmology, this calcium line may be used to determine the speed of recession of a distant galaxy.

A galactic cluster in Ursa Major has a recessional velocity of 1.43×10^7 m s^{-1}.
Calculate the wavelength of this calcium line as observed from Earth.

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Wavelength = ...

(3)

Given that this galactic cluster is 1.0×10^9 light years distant, calculate a value for the Hubble constant in s^{-1}.

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Hubble constant = ... s^{-1}

(4)

Another galactic cluster is 4.0×10^9 light years away from us. Suggest a value for the recessional velocity of this cluster.

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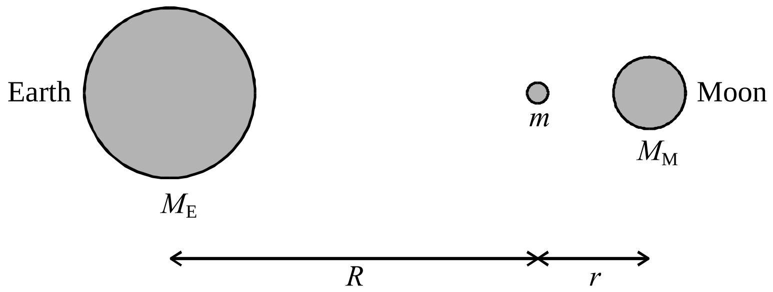
Velocity = ...

(1)
(Total 12 marks)

75. The diagram shows a body of mass *m* situated at a point which is a distance *R* from the centre of the Earth and *r* from the centre of the Moon.



The masses of the Earth and Moon are M_E and M_M respectively. The gravitational constant is G.

Using the symbols given, write down an expression for

(i) the gravitational force of attraction between the body and the Earth,

....

(ii) the gravitational force of attraction between the body and the Moon.

....

(2)

The resultant gravitational force exerted upon the body at this point is zero. Calculate the distance R of the body from the centre of the Earth given that

$$r = 3.9 \times 10^7 \text{ m} \quad \text{and} \quad M_E = 81\, M_M$$

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R = ...

(3)
(Total 5 marks)

76. In April 2002, the five nearest planets to the Earth lined up in the same part of our sky. As a result, all of them were pulling the Earth in the same general direction.

Some people worried that this would cause disastrous events on Earth, as the following extract from a newspaper article shows.

Doom at the start of the new millennium?
There will be a series of planetary alignments at the start of the new millennium. Will the earth tilt over? Will tidal forces trigger earthquakes? Will the polar ice caps melt?

Write down an expression for the gravitational force between two point masses *M* and *m* a distance *r* apart.

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(1)

Hence derive an expression for the gravitational field strength at a distance *r* from mass *M*.

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(2)

The distance between the Sun and the Earth = 1.50×10^{11} m.

Show that the Sun's gravitational field strength at this distance is about 6×10^{-3} N kg^{-1}.

Mass of Sun = 1.99×10^{30} kg.

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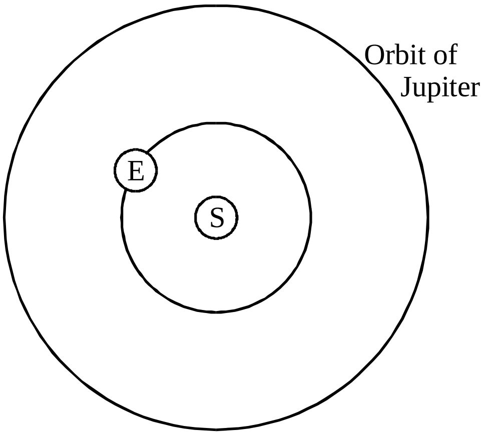
(2)

Jupiter is the most massive planet in our Solar System. Its maximum gravitational field strength at the Earth is 3.2×10^{-7} N kg^{-1}.

The diagram shows the orbits of the Earth and Jupiter around the Sun.



E = Earth
S = Sun

Not to scale

On the diagram

(i) mark the position of Jupiter at which it has maximum gravitational effect on the Earth,

(ii) draw labelled arrows on E to show the directions of the gravitational fields of Jupiter and the Sun.

(2)

Assume that the main gravitational field acting, on the Earth is that of the Sun.

Calculate the maximum percentage change in this gravitational field strength which Jupiter could make.

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(1)

Venus (our nearest neighbour in space) Is about 400 times less massive than Jupiter, but, at its nearest, is 15 times closer. Calculate the maximum value of the ratio

$$\frac{\text{gravitational field strength at the Earth due to Venus}}{\text{gravitational field strength at the Earth due to Jupiter}}$$

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(2)

With reference to your calculations, comment on whether an alignment of the five planets is likely to cause disastrous events on Earth.

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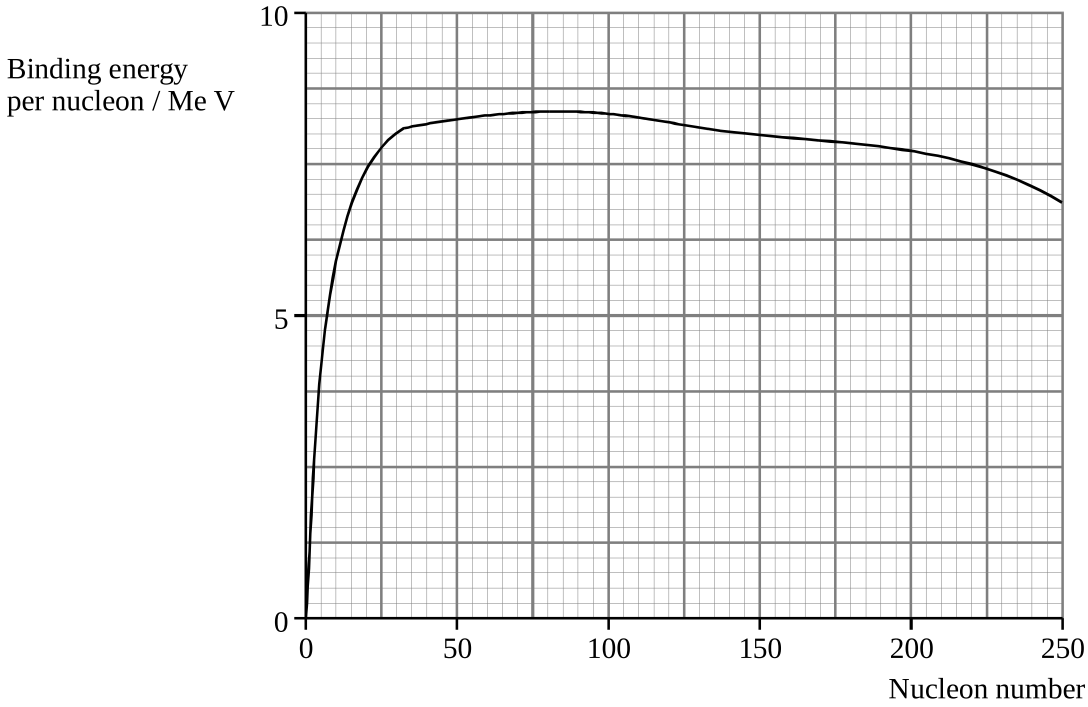
(1)
(Total 11 marks)

77. Nuclear power stations use the fission of uranium-235 to produce thermal energy. The simplified graph below can be used to explain energy transformation by nuclear fission



What is meant by binding energy?

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(1)

Use the graph to estimate the binding energy (in eV) of a nucleus of uranium-235.

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Binding energy = ... eV

(2)

When a uranium-235 nucleus undergoes fission, two smaller nuclei are formed, each with about half the number of nucleons.

Show that the energy released in the fission of one nucleus of uranium-235 is about 4×10^{-11} J.

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(3)

1.0 kg of uranium-235 contains 2.6×10^{24} nuclei.

Calculate the energy released by the fission of 1.0 kg of uranium-235.

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Energy = ...

(1)
(Total 7 marks)

78. An asteroid is observed heading towards the Earth. To find the speed of the asteroid a radio signal is directed at it from a station on Earth and the reflected signal is collected.

Explain why the reflected signal will have a much lower intensity than the transmitted signal.

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(2)

Explain how the reflected signal can be used to calculate the speed of the asteroid.

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(3)

The time interval between transmitting the signal and receiving its reflection is 120 s. Currently, the asteroid is approaching the Earth with a speed of 4 km s^{-1}.

Calculate

(i) the distance to the asteroid,

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(ii) the time the asteroid will take to travel this distance, stating any assumptions you make.

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(3)

Explain why this asteroid is very unlikely to collide with the Earth.

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(1)
(Total 9 marks)

79. Cosmologists have found evidence for a planet orbiting a distant star called Tau Boötes. This star is about the same mass as our Sun. The spectrum of light from this star varies with time. Initial results suggested that the spectrum included a small amount of reflected light coming from the surface of the orbiting planet.

The light reflected from the planet surface is

- blue-green
- periodically getting brighter, then dimmer
- of varying wavelength, due to the planet's orbital speed.

The final observation led to the deduction that the orbital speed is about 70 km s^{-1}.

Deduce whether this planet is closer to or further from its star than the Earth is from the Sun and discuss these three observations.
(The Earth has an orbital speed of about 30 km s^{-1}.)

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(Total 6 marks)

80. The intensity of solar radiation at the top of the Earth's atmosphere is 1.4 kW m^{-2}. The Sun's average distance from the Earth is 1.5×10^{11} m.

Show that the luminosity of the Sun is approximately 4×10^{26} W.

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(3)

Why is the intensity at the top of the Earth's atmosphere used in this calculation?

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(1)

The Sun's energy is produced when hydrogen 'burns' to form helium. Four protons are required to make each helium nucleus. Use the data below to estimate the energy released for each helium nucleus created. (Your answer will be only approximate as it ignores the positrons which are also released in the process.)

Data: mass of proton = 1.67×10^{-27} kg
mass of helium nucleus = 6.64×10^{-27} kg

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Energy released = ...

(4)

Show that the number of helium nuclei created per second in the Sun is approximately 1×10^{38}.

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(1)

Hence estimate the mass of hydrogen burned per second in the Sun.

....

....

....

Mass of hydrogen = ...

(2)
(Total 11 marks)

81. Use the data below to calculate the binding energy in MeV of a nucleus of oxygen, $^{16}_{8}O$.

Data:	mass of proton	=	1.007 276 u
	mass of neutron	=	1.008 665 u
	mass of oxygen nucleus	=	15.990 527 u

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Binding energy = ... MeV

(3)

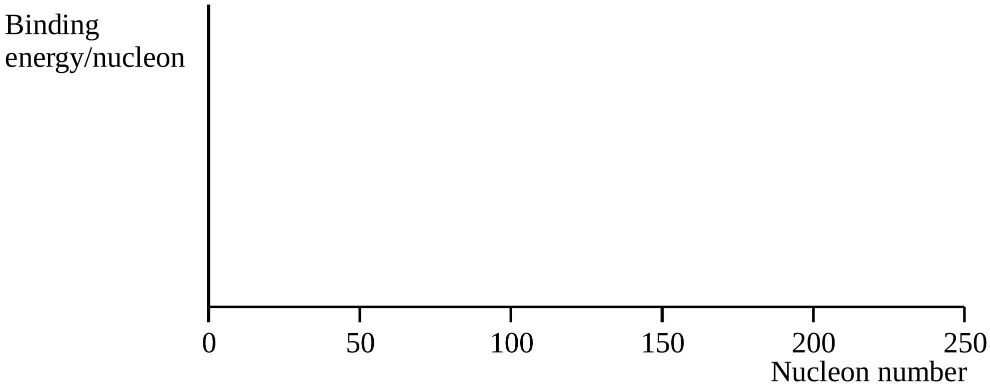
Calculate the binding energy per nucleon of $^{16}_{8}O$.

....

Binding energy per nucleon = ...

(1)

On the axes below sketch a graph of binding energy per nucleon against nucleon number.



(2)

Show on the graph the approximate position of

(i) oxygen, labelling this point O,

(ii) iron, the most stable element, labelling this point Fe,

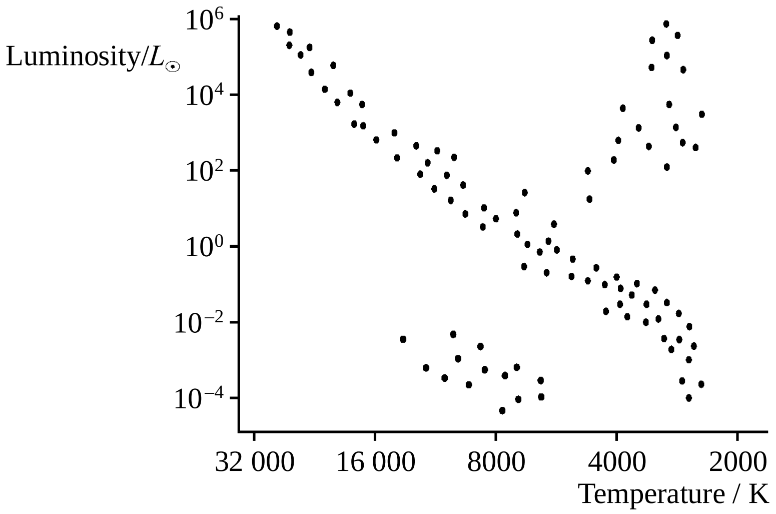
(iii) uranium, $^{238}_{92}U$,labelling this point U.

(3)
(Total 9 marks)

82. The table shows the properties of three stars.

	Star	Luminosity/$L_\odot$	Temperature/K
A	α Ori	6×10^4	3500
B	Procy B	3×10^{-4}	7000
C	β Per	2×10^2	12 000

On the Hertzsprung-Russell diagram below, mark with an x_A, x_B and x_C the approximate position of each of the three stars.



(1)

State whether each star is a main sequence star, a red giant or a white dwarf.

α Ori ....

Procy B ....

β Per ....

(3)

Use the Stefan-Boltzmann law to calculate the surface area and hence the radius of α Ori.
(Luminosity of the Sun = 3.8×10^{26} W.)

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Surface area = ...

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Radius = ...

(5)
(Total 9 marks)

83. Explain why the term **light year** is a measure of distance and not of time.

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(1)

Show that the light year is equivalent to a distance of approximately 9×10^{15} m.

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(2)

Explain why the annual parallax method is only suitable for measuring the distance to nearby stars.

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(3)
(Total 6 marks)

84. What is a supernova?

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Describe briefly what happens during the formation of a supernova. You may be awarded a mark for the clarity of your answer.

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(5)

What are the two possible fates for the central core remnant from a supernova explosion?

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(2)
(Total 7 marks)

85. The value of G, the gravitational constant, is 6.67×10^{-11} N m^2 kg^{-2}. What are the base units of G?

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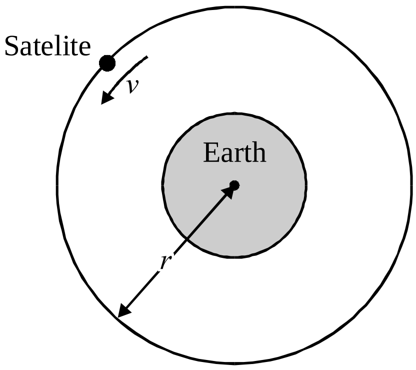
(1)

A satellite orbits the Earth, mass M, in a circular path of radius r, with speed v, as shown in the diagram.



It can be shown that the period of orbit T of the satellite is given by

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

Show that this equation is homogeneous with respect to units.

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(2)

Personal navigation devices use the Global Positioning System (GPS). GPS satellites are in a non-equatorial orbit at a height of 20 000 km above the Earth. The time to complete one orbit is 12 hours. Given that the radius of the Earth is 6400 km, use the above relationship to find the mass *M* of the Earth.

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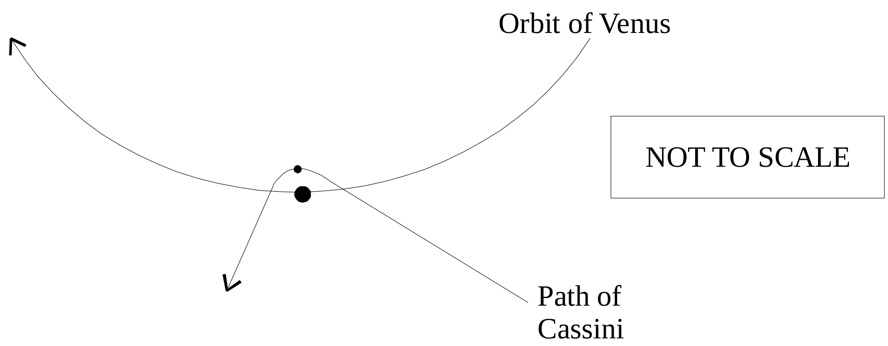
Mass of the Earth = ...
(3)
(Total 6 marks)

86. The Cassini spacecraft was launched from Earth in 1997 and is expected to reach Titan, one of Saturn's moons, in 2004. Cassini's energy at launch was insufficient for it to reach Titan without assistance from the gravitational pull of planets like Venus and Jupiter. The diagram shows the path of Cassini past Venus. Cassini is at its **closest** approach, just 284 km from the surface of Venus.



Write an expression for the magnitude of the gravitational force on Cassini at a distance *r* from the centre of Venus.

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(1)

Hence derive an expression for the gravitational field strength at a distance *r* from the centre of Venus.

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(2)

Calculate the maximum acceleration of Cassini caused by Venus.

Mass of Venus = 4.87×10^{24} kg

Radius of Venus = 6100 km

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Maximum acceleration = ...

(3)

State and explain the effect of this acceleration on the velocity of Cassini at its closest distance to Venus.

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(2)

Communications between Earth and Cassini are by microwaves using a frequency of 7.2 GHz. As the spacecraft approached Jupiter its speed away from the Earth was 12 m s^{-1}. Calculate the percentage change in frequency of the microwaves received by Cassini from Earth.

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Percentage change = ...

(2)
(Total 10 marks)

87. The equations below represent a typical fission and a typical fusion reaction.

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{138}_{55}Cs + ^{96}_{37}Rb + X^{1}_{0}n$ $\qquad$ $^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + Z\,p$

State the values of X and Z for the two nuclear equations above.

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X = ... $\qquad$ Z = ...

(2)

Write a short account of the physics of nuclear fission and fusion explaining the similarities and differences between them. You may include diagrams in the space below.

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(5)
(Total 7 marks)

88. Stars β Ori and α Cet have temperatures of approximately 11 000 K and 3600 K respectively. Calculate the wavelength at which the intensity of radiation from each star is a maximum. Give your answers in nanometres.

β Ori ....

....

α Cet ....

....

(3)

Use the Stefan-Boltzmann law to calculate the power emitted per square metre of surface, measured in W m^{-2} , for β Ori.

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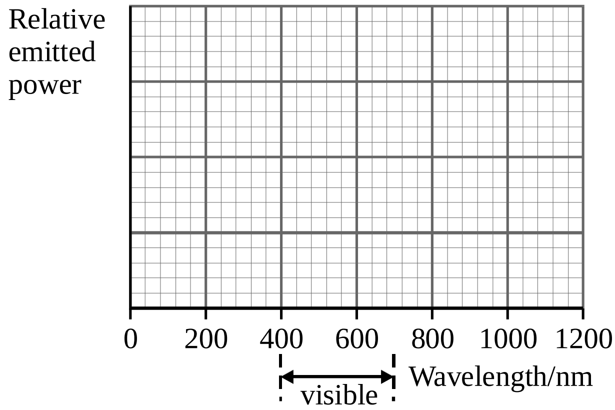
(2)

The power emitted per square metre of surface for α Cet = 1.0 × 10^{7} W m^{-2}.

Sketch two graphs on the axes below, showing how this emitted power is distributed over different wavelengths for each star. Label your graphs Ori and Cet.



(3)

The visible spectrum extends from approximately 400 nm to 700 nm. Use your graphs to explain why β Ori is a bluish star, while α Cet is reddish.

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(2)
(Total 10 marks)

89. (a) Draw a labelled diagram to illustrate the principle of how the distance to a nearby star can be measured using the annual parallax method.

(4)

Why is this method only suitable for nearby stars?

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(1)

(b) Stars of more than eight solar masses may undergo a spectacular supernova explosion. Outline the processes that take place in the star that result in such an event. You may be awarded a mark for the clarity of your answer.

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(4)

What may happen to the core remnant from such an event?

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(1)
(Total 10 marks)

90. The Doppler shift may be used in the study of distant galaxies. Explain what is meant by a Doppler shift and how it is used to deduce the motion of distant galaxies. You may be awarded a mark for the clarity of your answer.

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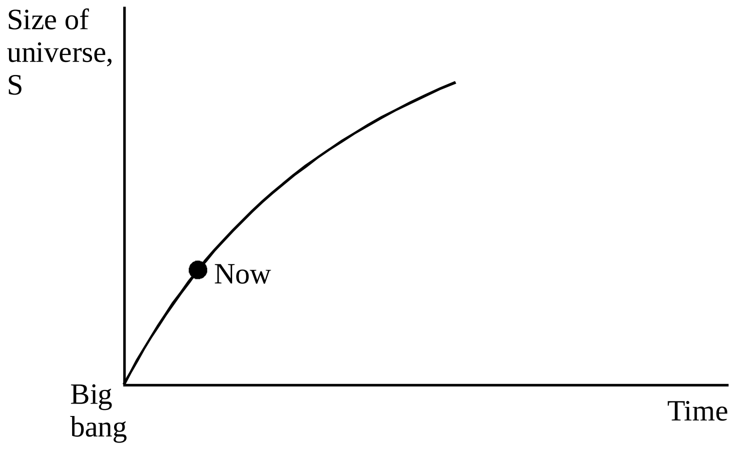
(5)

The graph shows the variation of the size S of an open universe against time t.



On the same axes, sketch a second graph showing how S varies with t for a closed universe.

(1)

It can be shown that the Universe is closed if its density exceeds a critical value ρ.
This is determined from the Hubble constant H using

$$\rho = kH^2$$

where k is a known constant.

Outline the experimental difficulties in determining ρ accurately.

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(3)
(Total 9 marks)

91. An example of a nuclear fission reaction is given by the equation below.

$$^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{144}_{56}\text{Ba} + {}^{92}_{36}\text{Kr}$$

Data:

Nuclear masses

Uranium –235	= 235.04394u
Barium –144	= 143.92285u
Krypton –92	= 91.92627u
Mass of neutron	= 1.00870u

Use this data to calculate the energy released in joules for each fission.

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Energy per fission = ...

(4)

Calculate the power output if 1 mole of uranium–235 undergoes fission by the above reaction and releases its energy in 5.0 s.

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Power = ...

(3)
(Total 7 marks)

92. Write a word equation which states Newton's law of gravitation.

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(2)

Mars may be assumed to be a spherical planet with the following properties:

Mass m_M of Mars	=	6.42×10^{23} kg
Radius r_M of Mars	=	3.40×10^{6} m

Calculate the force exerted on a body of mass 1.00 kg on the surface of Mars.

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Force =..

(3)

For any planet the relationship between g (the free fall acceleration at the surface) the planet's density ρ and its radius R is

$$g = \frac{4}{3}\pi\rho GR$$

Has Mars a larger, smaller or similar radius to the Earth?

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Explain your reasoning.

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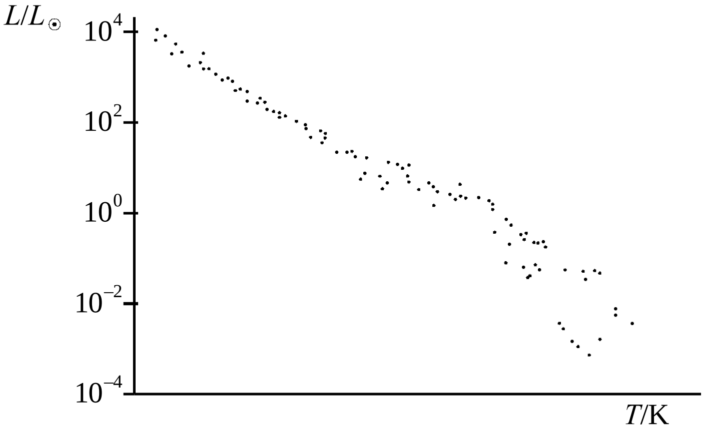
(2)
(Total 7 marks)

93. A Hertzsprung-Russell diagram showing the main sequence is drawn below. Luminosity of the Sun = $\boldsymbol{L_\odot}$.



Draw a circle on the diagram showing the region where the Sun is located. Label this circle S. Draw another circle showing the region where the most massive main sequence stars are located. Label this circle M.

(2)

Indicate on the temperature axis the approximate temperatures of the coolest and of the hottest stars.

(2)

Explain why large mass stars spend less time than the Sun on the main sequence.

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(2)

The luminosity of the Sun is 3.9×10^{26} W. Calculate the rate at which mass is being converted to energy in the Sun.

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Rate = ...

(3)
(Total 9 marks)

94. Astronomers who are interested in finding life elsewhere in the Universe, are searching for planets orbiting other stars. A planet will be too small to see, but still can cause a star to appear to wobble as the planet orbits it.

One such wobbling star is 47 Ursae Majoris, which has a mass of 2.2×10^{30} kg. The period of its wobble is 9.2×10^{7} s.

From the wobble, the astronomers deduced that there is a planet of mass 4.5×10^{27} kg orbiting 47 Ursae Majoris at a distance of 3.1×10^{11} m.

Show that the force on the star due to this planet is about 7×10^{24} N.

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(2)

Hence calculate the acceleration of the star towards the planet.

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Acceleration = ...

(1)

Explain with the aid of a diagram why the star wobbles.

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(3)

The star is orbiting about the centre of mass of the star/planet system.

Show that the speed of the star in its circular orbit is about 50 m s^{-1}.

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(3)

The astronomers found out about this planet by measuring changes in the light emitted by 47 Ursae Majoris. Calculate the maximum change in wavelength which they can observe for light from the hydrogen spectrum of wavelength 656 nm.

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(2)
(Total 11 marks)

95. Discuss the ultimate fate of the Universe. Your answer should include reference to dark matter and the reason why the fate of the Universe is uncertain.

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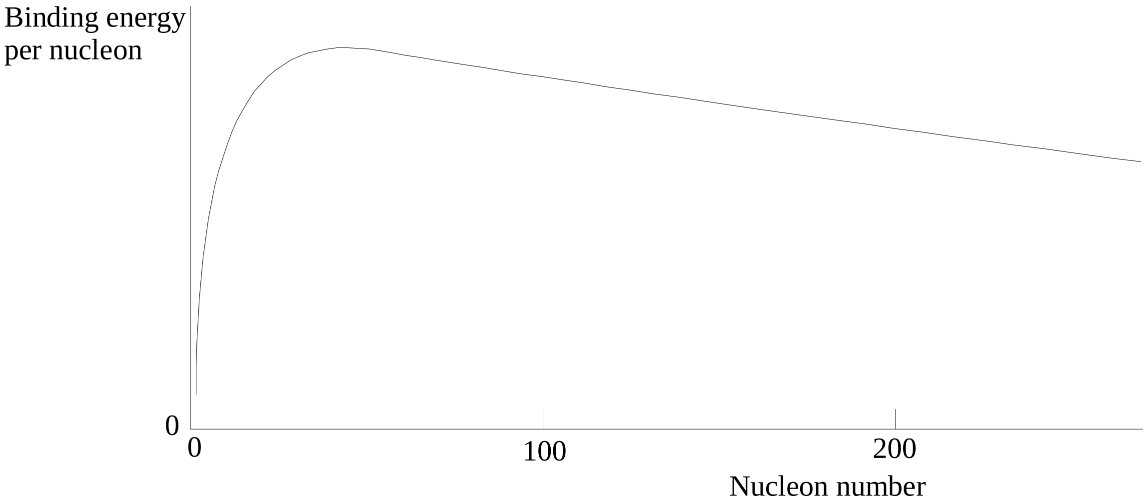
(Allow one lined page)

(Total 6 marks)

96. A graph of binding energy per nucleon against nucleon (mass) number is shown.

Label the approximate positions of the elements, deuterium D (an isotope of hydrogen), uranium U and iron Fe.



(2)

What is meant by the term *binding energy?*

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With reference to the graph, state and explain which of the elements mentioned above would be likely to undergo nuclear fission.

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(5)
(Total 7 marks)

97. Draw diagrams to represent

(i) the gravitational field near the surface of the Earth,

(ii) the electric field in the region of an isolated negative. point charge.

(4)

How does the electric field strength *E* vary with distance *r* from the point charge?

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(1)

Give an example of a region in which you would expect to find a uniform electric field.

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(1)
(Total 6 marks)