S284 Astronomy

Are you ready for S284?

Contents

Introduction

This self-assessment aims to help you decide if you are ready to study S284 *Astronomy* and to identify areas of physics or maths that you need to be certain you understand before committing yourself to the module. You may wish to revise or study some maths and physics before undertaking the *Are you ready for?* quiz, or you may try the quiz, study and then come back and try it again. You should also read carefully the other comments on time commitments and study skills required for S284, and be very honest with yourself when deciding if this is the right course for you. Ultimately the choice to register for S284 is yours to make, but this *Are You Ready For?* quiz is designed to help inform your decision. We would encourage you to discuss your module choices with study advisers before registering.

Before starting this quiz, you should read the description of the module. It outlines the topics, the assessment strategy and the study materials that will be provided in S284.

Module S284 is a compulsory component of the Q64 Natural Sciences (Astronomy and Planetary Sciences) degree. It can also be taken as part of:

- a number of other science degrees, diplomas or certificates
- the Open Degree
- the S10 Certificate in Astronomy and Planetary Science or

as a stand-alone module.

Suggested prior learning

S284 is a Level 2 module designed primarily for students who are on the Q64 Natural Sciences (Astronomy and Planetary Sciences) degree, and who have completed (and passed) the Level 1 courses on that pathway, i.e. all three of S111, SM123 and MST124. However, it is also available to students with general scientific and mathematical skills acquired through other routes. No previous knowledge of astronomy is required, but we assume that you have a basic understanding of science and maths and know how to approach problems scientifically. As a guide, if you do not have passes at Level 1 in OU science and maths modules, you would need GCSE (or equivalent) level passes (grade C/5 or above) to be certain of having the level of maths and physics required to tackle the module.

Be honest with yourself about your prior knowledge in these areas because S284 is an astronomy course, and any further learning that is required to bring your maths and/or physics to the necessary level will have to be undertaken in your own time, and in addition to the study time required for S284.

You are unlikely to do well in S284 if short courses, MOOCS or BOCS in maths, physics, astronomy or planetary science are your only experience of studying science at university level. By themselves, these are not adequate preparation for S284; you will need the wider range of study skills gained from studying Level 1 university courses, or equivalent.

This previous experience will ensure that you have sufficient organisational and learning skills to study this Level 2 module, and that you are used to writing assignments, using mathematical notation, presenting calculations appropriately and then submitting assignments on time. You will need good motivation. We also assume that you have at least ten hours a week to devote to your S284 study. At least six of these hours will be ‘directed’ study, and the remainder ‘self-directed’ study and reflection.

Astronomy is a mathematical subject, so S284 includes equations and calculations, though many of the more complex astronomical ideas are explained qualitatively rather than quantitatively in S284. However, even though this course is not mathematically intensive, basic maths skills are required, so you should ensure that you can cope with the questions within this self-assessment guide before undertaking this module.

It is beyond the scope of this self-assessment to provide advice about choice of maths modules. However, if you are taking S284 with the intention of continuing to study physics and/or astronomy modules at Level 3, then at some stage prior to Level 3 you will need to study maths to a higher level than S284 demands. The Q64 Natural Sciences (Astronomy and Planetary Sciences) degree pathway currently includes MST224 *Mathematical methods*, which does provide suitable preparation for Level 3 astronomy and physics modules.

Self-assessment

The activities in this self-assessment take the form of simple questions based on concepts in physics and maths we assume you already know (and you may have met at Level 1 OU study, for example in S111, SM123 and MST124). The questions are all framed around the astronomy you'll meet in S284, to give you a flavour of the kinds of subjects you will study in S284. But don't worry, little knowledge of astronomy is needed for this quiz – it is mainly about the physics and maths skills required.

We suggest you work through all of the questions here before revealing the answers and checking your answers against those given. If you have difficulty in answering particular questions, you will find that that many of the answers provided give explanations of how to tackle the questions, as well as more general advice about the background knowledge and skills that we assume you would have before starting S284.

You will need a (basic scientific) calculator, and a pen/pencil and paper to complete this self-assessment.

Question 1 – Scientific notation

Astronomy involves some very large and very small numbers. It is very difficult to write these out in full every time (and hard to read), so throughout S284 you will find that very small and very large numbers are written in scientific notation, i.e. in the form $a \times 10^b$, where a is a number between 1 and 10 and b is a positive or negative integer (a whole number).

Note: Typically a number alone is insufficient to explain a scientific value – units are also required. Numbers in astronomy are very large or very small: astronomy can include some unusual, non-SI units, which may also include a 'power of ten', such as Giga, Mega or nano. As well as using scientific notation to express very large and very small numbers, this question also assumes a familiarity with SI physical units (such as W for power and kg m^{-3} for density).

(a) The luminosity of the Sun, i.e. the power radiated at all wavelengths, is 3.8×10^{26} W. If a typical power station generates 2500 MW, how many power stations would you need to keep the Sun shining?

(b) A dense interstellar gas cloud has about 10^{11} hydrogen atoms per cubic metre. If the mass of a hydrogen atom is roughly 10^{-27} kg, what is the density of the cloud in kilograms per cubic metre?

Question 2 – Wave equation and precision

A simple but important equation in S284 is $c = f\lambda$, which relates the speed of an electromagnetic wave (c, in metres per second) to its frequency (f, in hertz) and its wavelength (λ, in metres). The speed, c, is the speed of light which is 3.0×10^8 m s^{-1}.

Note: In S284 you will be expected to be comfortable rearranging equations such as the wave equation.

(a) Rearrange the above equation to make λ the subject. Use the rearranged equation to find the wavelength of a radio wave of frequency 100 MHz.

(b) Rearrange the above equation to make *f* the subject. What is the frequency of a light wave of wavelength 0.5 μm?

Comment: When doing calculations in S284 you will be expected to have a sense for the precision of your answers and to quote the results to an appropriate number of significant figures.

Look again at the answers we gave to Question 2(a) and (b).

(c) What difference do you notice in the precision of these answers?

(d) Why are they different?

(e) Suppose a student is asked to do similar calculations with different data but using a speed of 3×10^8 m s^{-1}. Which of the following results would you accept?

- A wavelength of 6 cm, 6.3 cm or 6.27 cm?
- A frequency of 7 MHz, 6.8 MHz or 6.79 MHz?

Question 3 – Law of gravitation

In S284 you will be studying stars and galaxies that move in response to gravitational forces described by Newton's law of gravitation. The law is often written as:

$$F = \frac{Gm_1m_2}{r^2}$$

Note: We expect you to have studied science/physics to the level where you would have seen Newton's law of gravitation and could easily answer part (a) of this question. If you struggle with parts (b) and (c) then you should at least be able to understand the answers given here, and feel confident that you could now answer similar questions. Regarding part (d), we expect you to be familiar with the SI system of physical units for commonly used quantities such as mass, length, speed, etc.

(a) Explain the meaning of each of the five quantities in the equation.

(b) Explain in words how F depends on r.

(c) If r increases by a factor of 10, how will F change?

(d) What SI units would you use for F, m_1, m_2 and r?

Question 4 – Distance of stars

One way to find the distance of a star is to measure a quantity, F, called the flux density (not to be confused with the different F in the previous question). It is a measure of the star's brightness in units of watts per square metre (W m^{-2}) and is given by

$$F = \frac{L}{4\pi d^2}$$

where L is the star's luminosity (in watts) and d is the distance (in metres).

Note: We don't necessarily expect you to be familiar with the equation given in this question. However, we do expect you to be confident in rearranging equations such as this one, and to be able to use them to carry out calculations correctly (including the correct use of units).

(a) Suppose you observe a star which you believe is identical to the Sun but much further away. If F is measured to be 5.0×10^{-9} W m^{-2}, how far away is the star?

(b) One light-year is 9.46×10^{15} m. How far away is the star in light-years?

Question 5 – Masses of stars

The lifetime of a star like the Sun is proportional to the inverse fourth power of the mass; i.e. $t \propto M^{-4}$, where t is the lifetime and M is the mass.

(a) If the lifetime of the Sun is 1.0×10^{10} yr, what is the lifetime of a star half the mass of the Sun?

(b) What is the lifetime of a star 10% more massive than the Sun?

Comment: The calculations required for this question are typical of the sorts of argument used in the module. Even if you struggled to answer this question, we expect you to understand the answers given here and, having seen this, to be able to apply this sort of reasoning to similar calculations.

Question 6 – The most complicated equation in the module

If you are concerned about maths, here is the most complicated equation you are going to see in S284:

$$M_{\mathrm{J}} = \frac{9}{4} \times \left(\frac{1}{2\pi n}\right)^{1/2} \times \frac{1}{m^2} \times \left(\frac{kT}{G}\right)^{3/2}$$

The equation is an expression for a quantity M_{J}, known as the Jeans mass. It is the minimum mass that a cloud of gas must have before it can collapse under its own weight to form a star. We will explain the meaning of the other quantities later. Will M_{J} get bigger or smaller if:

(a) n gets bigger?

(b) m gets bigger?

(c) T gets bigger?

Comment: This is quite a sophisticated question, so don't worry too much if you found it difficult. If so, you should spend some time developing your mathematical skills before and during S284. However, you will not have to memorise this equation, nor any other equations, in S284.

Question 7 – Composition of the Sun

Note: This question illustrates the importance of being able to interpret graphs. We expect you to be comfortable in interpreting and obtaining data from unfamiliar diagrams. You should be able to answer parts (a) to (d) of this question easily.

Much of the information in S284 is presented in the form of graphs and diagrams, which can convey a great deal of information very economically. An example is given in Figure 1, which shows the composition of the Sun for various distances,

R, from the centre. X is the amount of hydrogen, Y is the amount of helium and Z is the amount of everything else. X, Y and Z are expressed as a fraction by mass. The radius is shown as a fraction of the solar radius, $R_\odot$. (The symbol $\odot$ usually placed as a subscript, is used in astronomy to refer to the Sun.)

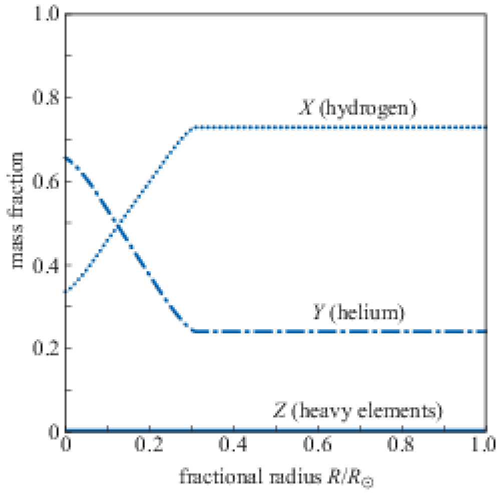

Figure 1 Variation of the mass fractions X, Y and Z with the fractional radius, R/R_0, for the Sun.

(a) Describe in words how X, Y and Z depend on radius.

(b) What is the *percentage* of hydrogen and helium at the centre of the Sun?

(c) What are the percentages in the outer layers of the Sun?

(d) What is the percentage of other elements in the Sun?

(e) Do X, Y and Z add up to 100%? Would you expect them to?

(f) At what radius do the amounts of hydrogen and helium stop changing?

(g) Why do you think the amount of hydrogen and helium is different at different radii?

Question 8 – Cepheids

Note: As in Question 7, this question highlights the importance of being able to interpret graphical information. It uses a graph with logarithmic scales: if you have not used such graphs previously, then before you start the module you will need to spend some time familiarising yourself with their properties.

A Cepheid is a type of star which varies in brightness with a regular period. The luminosity of any star is a measure of how much light the star emits. By measuring the period of variation of an unknown Cepheid, we can find how luminous it is from Figure 2.

Figure 2 has logarithmic scales on both axes, so you will have to read it carefully. Find the luminosity of Cepheids with the following periods:

(a) 30 days

(b) 3 days

(c) 10 days

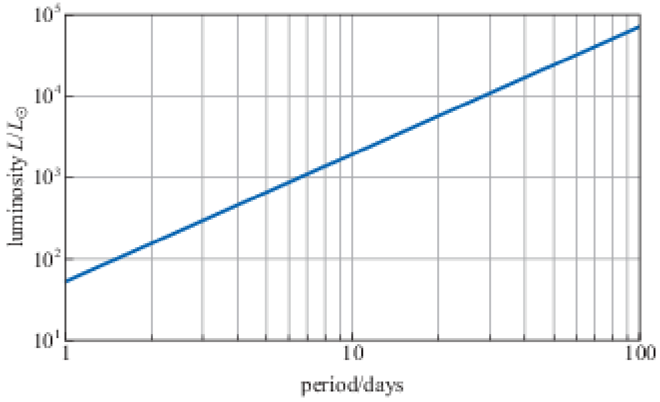

Figure 2 The period–luminosity relationship for Cepheid variable stars.

Question 9 – Energy in stars

Note: This question again relates to the use of graphs with logarithmic scales. If you find this question difficult, then before you start the module you will need to devote some study time to understanding how to use such graphs.

Nuclear reactions in most stars proceed by one of two processes known as the 'pp chain' and the 'CNO cycle'. Figure 3 shows the relative importance of these processes as a function of the core temperature of the star.

(a) At what temperature are the two processes of equal importance?

(b) At what temperature does the pp chain produce only 1% as much energy as the CNO cycle? [*Hint*: you need to find the temperature at which the two processes release energy at the same rate.]

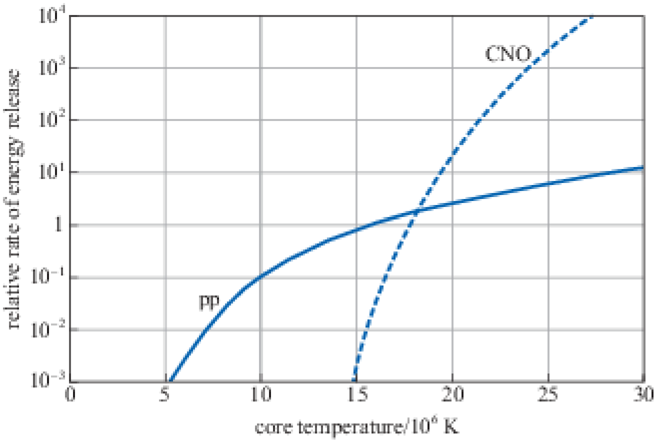

Figure 3 The rate of energy release for the three pp and CNO reaction chains as a function of temperature. A relative abundance of the elements as for the Sun has been assumed.

Question 10 – Hydrogen atom

Note: We expect you to have studied science/physics to a level where you are familiar with the components of the hydrogen atom (part (a)) and its basic properties (part (b)). You should be comfortable in using the diagram provided to answer the quantitative parts of the question.

Figure 4 represents the energy levels of a hydrogen atom with the energies given in units of electronvolts (eV).

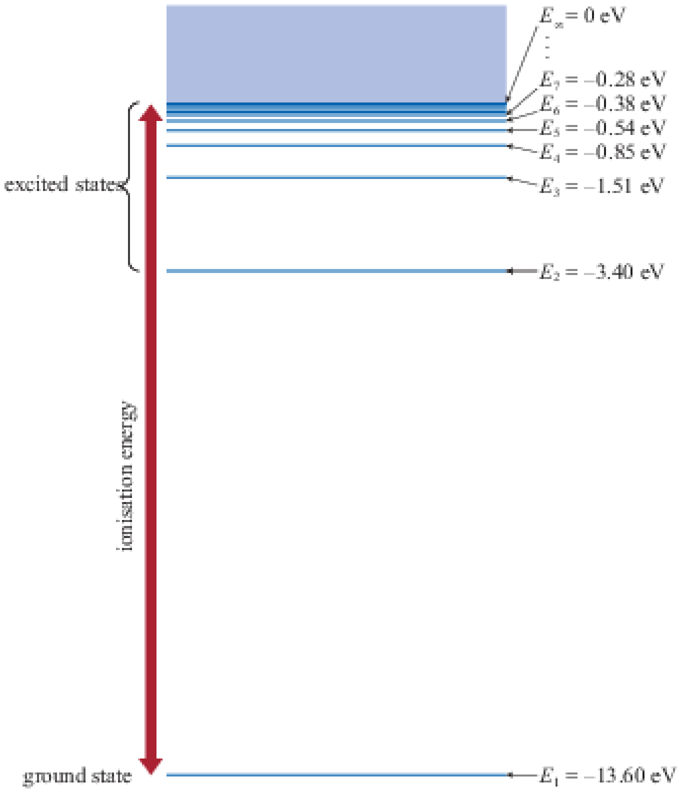

Figure 4 The energy-level diagram of a hydrogen atom.

(a) How many electrons does the atom have? How many protons?

(b) In which level would you normally expect to find the electron?

(c) If the electron is in level 3, what energy photons could the atom emit?

(d) The Sun's spectrum shows a hydrogen absorption line corresponding to a photon energy of 2.86 eV. Between which energy levels has the electron moved?

(e) Suppose the atom is in the ground state. What would happen if a photon of energy 11.0 eV were incident on the atom? What would happen if the photon energy were 22.0 eV?

Question 11 – Nuclear reactions

Note: We expect you to have studied science/physics to a level where you are familiar with the notation used in nuclear reaction equations.

The following equation represents a nuclear reaction that can occur in older stars.

$$^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{16}_{8}\mathrm{O} + \gamma$$

(a) Name the two nuclei that are reacting. What are the products?

(b) How many protons does the C nucleus have? How many neutrons does the O nucleus have?

(c) What is another name for the He nucleus?

(d) What would you expect the γ to do after it is formed?

Question 12 – Using the internet

Note: This question highlights the fact that you will have to use a computer and the internet in your studies of S284. You should be confident in using a computer to carry out a task such as described in this question, but note that the module is designed to help develop IT skills in areas that are vital for science, by giving you practice in skills such as the use of spreadsheets.

One feature of S284 is the multimedia activities that support the teaching. For this reason you need to have a personal computer and an internet connection. Spreadsheets are used for numerical analysis: we recommend using Office 365 (free to all OU students), but you may use another spreadsheet package if you are already comfortable using it. You will regularly use the internet to find information. If you have not used a computer in this way before, you may need to seek help outside the module materials, preferably before you start the module. You will occasionally need to download professional astronomy software: we will supply most of the software you need and help you learn how to use it.

To give you a flavour of this, we would like you to find out something about the Chandra X-ray Observatory. Use a web browser to go to http://www.chandra.harvard.edu/ and then answer the following questions.

(a) Where is the observatory?

(b) Who is the observatory named after? How were they honoured in 1983 and for what achievement?

(c) If you are really keen, try this *optional* and more challenging task: what instruments is the telescope equipped with and what range of photon energies can they detect?

Are you ready for S284?

What you have just read is a sample of the kinds of tasks you will be asked to do if you study S284. Did you enjoy the questions?

- If you did, and you were able to do all or most of them without too much trouble, then you are probably ready for S284 (see the detailed comments provided with the answers for more guidance about this).
- If you found all or most of them difficult – or did not enjoy doing them – then you should think carefully about whether S284 is the right module for you at the moment.

Where to get more help

The Sciences Good Study Guide (Northedge, A., Thomas, J., Lane, A. and Peasgood, A. (1997) Milton Keynes: Open University) is specially written for OU science students and contains a wealth of guidance on studying science courses. If you have found any of the questions here difficult, you would benefit from reading:

- Chapter 3 (‘Working with diagrams’)
- Chapter 4 (‘Learning and using mathematics’)

- Chapter 5 (‘Working with numbers and symbols’) and
- the Maths Help appendix, which contains almost 100 pages of worked examples of basic mathematical calculations.

If you would like to look at the S284 module materials before making up your mind you can look at the following free courses, which comprise sections of the predecessor module S282 study material:

- Comparing stars
- Introduction to active galaxies.

Additionally, you might be able to get hold of the S282 module texts through your local public library:

- Green, S.F. and Jones, M.H. (eds) (2015) *An Introduction to the Sun and Stars*. 2nd edn. Cambridge: Cambridge University Press.
- Jones, M.H. and Lambourne, R.J. (eds) (2004) *An Introduction to Galaxies and Cosmology*. 2nd edn. Cambridge: Cambridge University Press.

If you are already an OU student you can also ask for advice from your Student Support Team (SST) via StudentHome.

Answers to self-assessment questions

Question 1

(a) In scientific notation: 2500 MW = 2.5×10^9 W.

$$\text{number of power stations} = \frac{\text{luminosity of the Sun}}{\text{power of one power station}}$$

$$= \frac{3.8\times10^{26}\ \text{W}}{2.5\times10^{9}\ \text{W}} = 1.5\times10^{17}$$

(b) Density of gas cloud = mass of one atom × number of atoms per cubic metre

$$= 10^{-27}\ \text{kg} \times 10^{11}\ \text{m}^{-3} = 10^{-16}\ \text{kg m}^{-3}$$

By comparison, the density of air is 1.3 kg m^{-3}.

Question 2

(a) Rearranging the equation we get $\lambda = c/f$.

Next we give the frequency in SI units,

f = 100 MHz = 100×10^6 Hz = 1.0×10^8 Hz = $1.0 \times 10^8\ \text{s}^{-1}$.

Remember that 1 Hz = 1 cycle per second (s^{-1}).

So

$$\lambda = \frac{c}{f} = \frac{3.0\times10^{8}\ \text{m s}^{-1}}{1.0\times10^{8}\ \text{s}^{-1}} = 3.0\ \text{m}$$

100 MHz is near to the frequency of Classic FM, so Classic FM waves are about the size of a room!

(b) Rearranging the equation again we now get $f = c/\lambda$. The wavelength in SI units is λ = 0.5 μm = 5×10^{-7} m.

So

$$f = \frac{c}{\lambda} = \frac{3.0\times10^{8}\ \text{m s}^{-1}}{5\times10^{-7}\ \text{m}} = 6\times10^{14}\ \text{s}^{-1} = 6\times10^{14}\ \text{Hz}$$

(c) The wavelength is given to two significant figures (2 s.f.) and the frequency is given to only one significant figure (1 s.f.).

(d) In the calculation for wavelength, both the speed and the frequency are given to 2 s.f. So we quote the result to 2 s.f. as well. In the frequency calculation the wavelength is given to only 1 s.f., so the result is quoted to 1 s.f.

(e) As the speed has only 1 sf, the resulting wavelength or frequency must also have 1 s.f., no matter how precise the other data might be. So you should accept 6 cm and 7 MHz.

Question 3

(a) F is the gravitational force between two objects of mass m_1 and m_2 separated by a distance r. G is a constant known as the universal constant of gravitation.

(b) The force is proportional to the inverse square of the distance.

(c) If r increases by a factor of 10, F will change by a factor $1/10^2 = 0.01$ (i.e. the value of F decreases to one-hundredth of its initial value).

(d) You would measure F in newtons (N), m_1 and m_2 in kilograms (kg) and r in metres (m). The units of G are N m^2 kg^{-2}, but you are not expected to remember that.

Question 4

(a) First, rearrange the equation to make d the subject:

$$F = L/4\pi d^2$$

so

$$4\pi F\,d^2 = L \quad \text{and} \quad d^2 = L/4\pi F$$

hence

$$d = (L/4\pi F)^{1/2}$$

So

$$d = \left(\frac{3.8\times10^{26}\ \text{W}}{4\pi\times5.0\times10^{-9}\ \text{W m}^{-2}}\right)^{1/2} = 7.8\times10^{16}\ \text{m}$$

(b) In light-years:

$$d = \frac{7.8\times10^{16}\ \text{m}}{9.46\times10^{15}\ \text{m ly}^{-1}} = 8.2\ \text{ly}$$

Question 5

(a) The lifetime changes by a factor of $(0.5)^{-4} = 16$. So the star will last 16 times as long as the Sun, i.e. 1.6×10^{11} yr.

(b) The star's mass is 10% greater than the Sun, i.e. a factor of 1.1, so the lifetime changes by a factor of $(1.1)^{-4} = 0.68$. The lifetime will be 0.68×10^{10} yr = 6.8×10^9 yr.

Big stars have shorter lives than small stars!

Question 6

(a) If n gets bigger, the factor in the first pair of brackets will get *smaller*, so M_J will get smaller. (n is the number of molecules per cubic metre in the cloud, so the closer the molecules are packed together, the smaller the mass of the cloud needs to be for it to collapse.)

(b) If m gets bigger, $1/m^2$ gets *smaller*, so M_J gets smaller. (m is the mass of a molecule. If the molecules are heavier, the mass of the cloud, again, can be smaller and still collapse.)

(c) If T gets bigger, the factor in the second pair of brackets also gets bigger, so M_J gets bigger. (T is the temperature of the cloud. A hot cloud will need to be more massive to collapse under its own weight, since hot gas has a higher pressure which resists collapse.)

You came across G in Question 3, and k is another fundamental constant known as Boltzmann's constant.

Question 7

(a) X rises as you move further from the centre of the Sun (i.e. as R increases) then flattens off. Y falls from the centre then flattens off. Z remains constant, but low, from the centre to the Sun's surface.

(b) Reading from the vertical scale, the amount of hydrogen at the centre of the Sun is about 0.34 or 34% and the amount of helium is 0.65 or 65%.

(c) In the outer layers of the Sun (i.e. at higher values of $R/R_\odot$), the amount of hydrogen is approximately 73% by mass and the amount of helium is 25%.

(d) The amount of other elements (Z) is about 2% by mass throughout the Sun. Since the line for Z is invisible, you can only calculate this as a subtraction from your previous answers.

(e) Using the values we gave in part (b) above, at the centre of the Sun $X + Y + Z = 34\% + 65\% + 2\% = 101\%$! You might have slightly different values, depending how you measured them, and they may or may not add up to 100%. Every measurement has an uncertainty (perhaps about 1% either way here) and there may be slight errors in the diagram itself, so in general we would not expect the sum to be exactly 100%.

(f) The amounts of hydrogen and helium do not change beyond a fractional radius of 0.3 (i.e. 30% of the Sun's radius).

(g) If you know some astronomy you may be able to guess this one. The Sun is powered by thermonuclear fusion reactions in which hydrogen is converted into helium with the release of energy. The outer layers of the Sun, where X and Y are constant, still have their original composition, but the inner 30% of the radius is where the temperature is high enough for the reactions to occur. In this 'core' the hydrogen is being progressively replaced with helium.

(Note that the graph only illustrates a particular moment in time.)

Question 8

(a) 30 days on the horizontal axis (two tick marks to the right of the '10') corresponds to a luminosity of $10^4\,L_\odot$.

(b) 3 days corresponds to the second tick mark on the horizontal axis. Remember that the origin of the horizontal axis is not at zero but at 1 on logarithmic graph paper, and the subsequent ticks represent 2, 3, 4 and so on up to 10. It is not possible to show zero on a logarithmic scale!

If we draw a vertical line at 3 days it cuts the line about half-way between 10^2 and 10^3 and we might think the value we need is therefore 500. But this is not correct: on a logarithmic scale the 'half way' point between 100 and 1000 is more like 300 (since the log of 300 is about 2.5) so the luminosity of the star is about 300 $L_\odot$.

(c) For a period of 10 days we need a point about 0.3 of the distance between 10^3 and 10^4. This corresponds to about $2 \times 10^3\,L_\odot$. If you would rather not guess you can use the 10^x key on your calculator (i.e. to find $10^{3.3}$) to get a more accurate value.

Question 9

(a) The processes release energy at the same rate (and are therefore of equal importance) where the curves cross, at a temperature of 18×10^6 K.

(b) We need to find the point at which the CNO curve is 100 times higher than the pp curve. The intervals between the tick marks on the vertical scale each represent a factor of 10, so we mark two intervals on the edge of a sheet of paper and then move the paper until the marks match the gap between the curves. This occurs at $T = 23 \times 10^6$ K. A mathematical alternative is possible but is more complicated!

Question 10

(a) Hydrogen has one electron and one proton.

(b) The electron is normally in level 1. The atom is then said to be in its ‘ground state’.

(c) From level 3 the electron can drop either to level 2 or to level 1, emitting a photon in each case. The energies are:

$$(E_3 - E_2) = -1.51 \text{ eV} - (-3.40 \text{ eV}) = 1.89 \text{ eV}$$

$$(E_3 - E_1) = -1.51 \text{ eV} - (-13.60 \text{ eV}) = 12.09 \text{ eV}$$

From level 2 it could then drop to level 1. So we might also detect a photon of energy

$$(E_2 - E_1) = -3.40 \text{ eV} - (-13.60 \text{ eV}) = 10.2 \text{ eV}$$

(d) Because it’s an absorption line the electron must have moved to a higher level. Based on the data in Figure 4, the difference between levels 2 and 5 is 2.86 eV, so the electron has moved from 2 to 5.

(e) If the energy were 11.0 eV nothing would happen! The photon cannot be absorbed because there is no energy level 11.0 eV above level 1.

If the energy were 22.0 eV, the photon would be absorbed and the electron would escape from the atom with a kinetic energy of (22.0 – 13.6) eV = 8.4 eV. The atom would be ionised.

Question 11

(a) A nucleus of carbon reacts with a nucleus of helium (i.e. the ‘reactants’) to produce a nucleus of oxygen and a gamma-ray (the ‘products’).

(b) The C nucleus has 6 protons, as indicated by the bottom number to the left of the ‘C’. To calculate the number of neutrons in the O nucleus, you take the atomic number of 16 (the top number to the left of the ‘O’) and subtract the number of protons (8), which gives 8 neutrons. Note that the number of protons is not always the same as the number of neutrons.

(c) The helium (He) nucleus is also known as an alpha-particle.

(d) As the gamma-ray is a photon it will move away at the speed of light.

Question 12

(a) In space! It orbits between 16 000 km and 133 000 km above the Earth.

(b) It is named after Subrahmanyan Chandrasekhar, the eminent Indian-American astrophysicist who won the Nobel Prize for physics in 1983 for his ‘theoretical studies of the physical processes important to the structure and evolution of stars’ (Chandra X-ray Center, 2017). You will learn something about those processes in this module.

(c) According to the technical specification provided on the website (Chandra X-ray Center, 2008), unless otherwise stated, the instruments and their photon energies are:

- Advanced Charge-Coupled Imaging Spectrometer: 0.2 keV–10 keV
- High Resolution Camera: 0.1 keV–10 keV, but this is difficult to find. Alternatively, this website says 0.06 to 10 keV.
- High Energy Transmission Grating Spectrometer: 0.4 keV–10 keV
- Low Energy Transmission Grating Spectrometer: two values are given on different parts of the website – 0.08 keV to 2 keV (Chandra X-ray Center, 2019) and 0.09 keV to 3 keV.

Don't worry if this does not mean much to you at the moment. If you decide to study S284 you will return to this website to learn more about X-ray astronomy and the Chandra observatory.

References

Chandra X-ray Center (2008) *Chandra specifications*. Available at: https://www.chandra.harvard.edu/about/specs.html (Accessed: 23 October 2019).

Chandra X-ray Center (2017) *Subrahmanyan Chandrasekhar: the man behind the name*. Available at: https://www.chandra.harvard.edu/about/chandra.html (Accessed: 23 October 2019).

Chandra X-ray Center (2019) *Science instruments*. Available at: https://www.chandra.harvard.edu/about/science_instruments.html (Accessed: 23 October 2019).

Figure descriptions

Figure 1 Variation of the mass fractions X, Y and Z with the fractional radius, cap r solidus cap r sub circled dot operator, for the Sun.

Description

Figure 1 is a graph which shows the composition of the Sun at various distances, italic cap R, from the centre.

The y-axis gives the mass fraction, with no units, from 0 to 1 in steps of 0.2.

The x-axis gives the radius as a fraction of the solar radius, italic cap R divided by italic cap R subscript circled dot, from 0 to 1 in steps of 0.2.

Three lines are shown on the graph.

- The dotted blue line X is the amount of hydrogen. At the centre of the Sun the mass fraction of hydrogen is about 0.33. This rises to about 0.73 through the first third of the radial distance, and then remains constant to the outer edge of the Sun.
- The dashed blue line Y is the amount of helium. At the centre of the Sun, the mass fraction of helium is about 0.66. This drops to about 0.23 through the first third of the radial distance, and then remains constant to the edge.

- The solid blue line Z is the amount of everything else (the heavy elements). The mass fraction of these is close to zero across the graph, from core to edge of the Sun.

Figure 2 The period–luminosity relationship for Cepheid variable stars.

Description

This figure is a graph which shows the relationship between period and luminosity for Cepheid variable stars.

The y-axis gives the luminosity of the stars, measured relative to the solar luminosity, italic cap L divided by italic cap L circled dot, in equal divisions from 10 to the power 1 up to 10 to the power 5.

The x-axis gives the period of the stars in days, from 1 to 100, on a logarithmic scale.

The relationship is shown by a straight blue line from approximately 7 times 10 to the power 1 at a period of 1 day, to 9 times 10 to the power 4 at 100 days.

Figure 3 The rate of energy release for the pp and CNO reaction chains as a function of temperature. (The same relative abundance of elements as found in the Sun has been assumed.)

Description

This figure is a graph showing the rate of energy release for the pp and CNO reaction chains as a function of temperature.

The y-axis gives the relative rate of energy release of the nuclear reaction in equal divisions from 10 to the power minus 3 up to 10 to the power 4.

The x-axis gives the core temperature of the star in Kelvin, from 0 to 30 times 10 to the power 6.

The solid blue line illustrating the relationship for the pp chain goes through the following points:

- (5.5 times 10 to the power 6; 10 to the power minus 3)
- (10 times 10 to the power 6; 10 to the power minus 1)
- (c.15 times 10 to the power 6; 10 to the power 0)
- (28 times 10 to the power 6; 10 to the power 1)

The dashed blue line illustrating the relationship for the pp chain goes through the following points:

- (c.15 times 10 to the power 6; 10 to the power minus 3)
- (c.16 times 10 to the power 6; 10 to the power minus 1)
- (c.17 times 10 to the power 6; 10 to the power 0)
- (c. 23 times 10 to the power 6; 10 to the power 3)

The lines cross at the point (c.18 times 10 to the power 6; 10 to the power 0).

Figure 4 The energy-level diagram of a hydrogen atom.

Description

This energy level diagram of hydrogen consists of a set of many horizontal lines stacked above each other. The spacing between them becomes ever closer and closer moving up the diagram, until the uppermost levels are almost too close together to distinguish. The lowest level (the ground state) is labelled E subscript 1, the next highest is labelled E subscript 2, and the next highest E subscript 3, and so on. The energies of the excited states are also given, increasing upwards, as follows:

- E subscript 1 = minus 13.60 eV
- E subscript 2 = minus 3.40 eV
- E subscript 3 = minus 1.51 eV
- E subscript 4 = minus 0.85 eV
- E subscript 5 = minus 0.54 eV
- E subscript 6 = minus 0.38 eV
- E subscript 7 = minus 0.28 eV
- E subscript infinity = 0 eV

The difference between the ground state and the excited state is the ionisation energy.