S282 Astronomy

Are you ready for S282?

The Open University

Contents

Introduction

The aim of this booklet is to help you decide whether you are ready to study S282 *Astronomy* and to identify topics that you may wish to study or revise before committing yourself to the module.

You first should make sure that you have read the description of the module available on the Open University website at: http://www.open.ac.uk/courses/modules/s282. This module is a compulsory component of the Q64 Natural sciences (Astronomy and Planetary Sciences) degree but can also be taken as part of a number of other degrees, diplomas or certificates (see http://www.open.ac.uk/courses/find/astronomy-and-planetary-science) or as a stand-alone module.

Suggested prior learning

S282 is a Level 2 module designed primarily for students who have completed Level 1 of the Natural science degree but is accessible to students with general scientific skills (such as those provided by S111 Questions in Science). No previous knowledge of astronomy is necessary, but we assume that you have a basic grounding in science and maths and know how to approach problems scientifically. We also assume that you have sufficient experience and organisational skills to study a university course at Level 2, and that you are used to writing assignments and submitting them on time. You will also need good motivation and around 7 or 8 hours a week of time you can devote to study.

Please note you are unlikely to do well in S282 if Level 1 short courses in astronomy and planetary science are your only experience of studying science at university level. By themselves, these are not adequate preparation for S282; although no prior astronomy knowledge is required for S282, you will need the appropriate study skills from wider level 1 or equivalent experience.

Although astronomy is a mathematical subject, S282 has been designed to be accessible to those who have not taken mathematics modules at level 1. However, basic maths skills are required so you should ensure that you can cope with the questions below before undertaking this module.

If you have a good pass in GCSE Mathematics or have taken an introductory module in mathematics such as S151 Maths for Science then you should have the necessary skills.

If you are taking S282 with the intention of studying physics or astrophysics at Level 3, then at some stage you will need to study maths more systematically and to a higher level than S282 requires. While it is beyond the scope of this booklet to provide advice about choice of maths modules, we note that the Q64 pathway currently includes MST124 Essential Mathematics I and MST224 Mathematical Methods that provide preparation for level 3 astrophysics modules.

Self-assessment

The activities in this booklet take the form of simple questions based on examples taken from the S282 module materials. These will give you a taste of what it will be like to study S282, as well as identifying areas of background science and maths which you may need to study or revise.

We suggest you work through all of the questions here before checking your answers against those given at the end of this booklet. If you have difficulty in answering particular questions, you will find that the given answers give full explanations of how to tackle the questions and more general advice about the background knowledge and skills that we would assume you to have before starting S282.

Question 1 – Big and small numbers

Throughout S282 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).

(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

A simple but important equation in S282 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}.

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

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

Question 3 – Precision

Look again at the answers we gave to Question 2.

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

(b) Why are they different?

(c) 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 4 – Law of gravitation

In S282 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:

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

(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 5 – 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).

(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 6 – 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?

Question 7 – The most complicated equation in the course

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

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

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?

Question 8 – Composition of the Sun

Much of the information in S282 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.
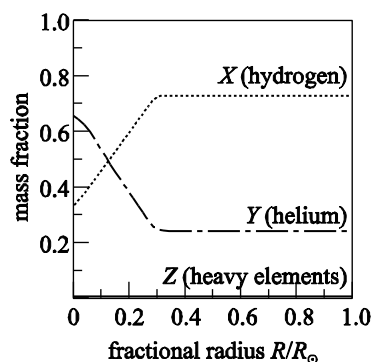

Figure 1 Variation of the mass fractions X, Y and Z with the fractional radius, R/R_0, for the Sun.

Figure 1 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_0. (The symbol 0, usually placed as a subscript, is used in astronomy to refer to 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 9 – Cepheids

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:

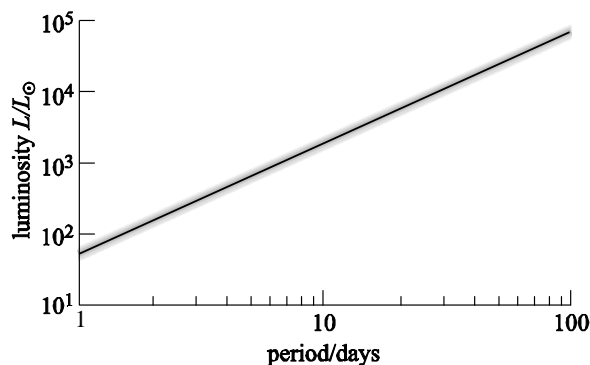(a) 30 days

(b) 3 days

(c) 10 days

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

Question 10 – Energy in stars

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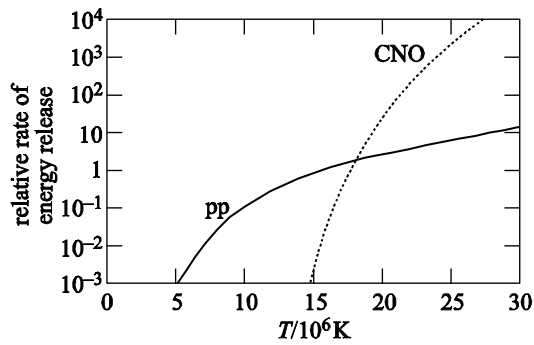
Figure 3 The rate of energy release for the three pp and CNO reaction chains as a function of temperature. A relative abundance of the elements as for the Sun has been assumed.

Question 11 – Hydrogen atom

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

(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?
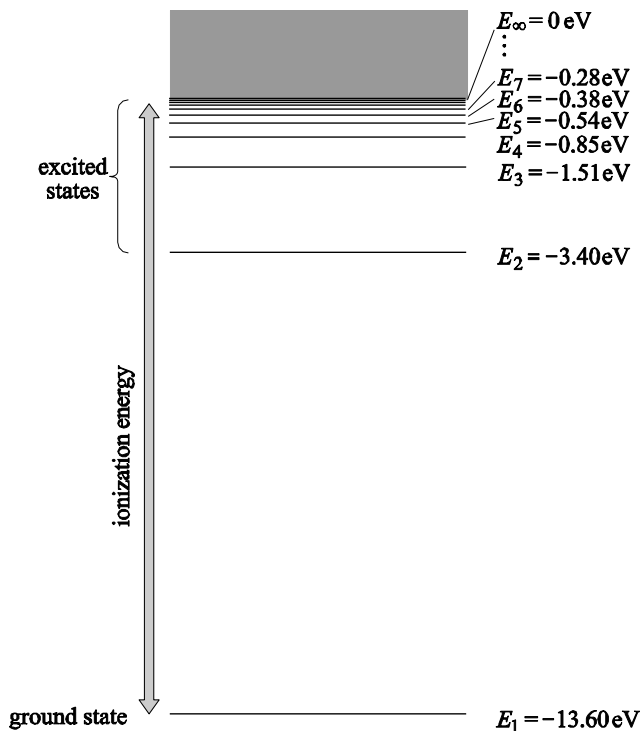

Figure 4 The energy-level diagram of a hydrogen atom.

(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 12 – Nuclear reactions

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

$$^{12}_{6}\text{C} + {}^{4}_{2}\text{He} \rightarrow {}^{16}_{8}\text{O} + \gamma$$
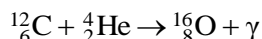
(a) Name the two nuclei that are reacting. What are the products?

(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 13 – Using the Web

One feature of S282 is the multimedia activities that support the teaching in the module books. For this reason you need to have a personal computer and an internet connection. Spreadsheets are used for numerical analysis and you will occasionally use the Web to find information. Don't worry if you have not used a computer in this way before; 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 was he 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 S282?

What you have just read is a sample of the kinds of tasks you will be asked to do if you study S282. 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 S282 (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 S282 is the right module for you at the moment.

Where to get more help

The Sciences Good Study Guide (A. Northedge, J. Thomas, A. Lane and A. Peasgood, Open University, 1997, ISBN 07492 3411 3) 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) and Chapter 5 (Working with numbers and symbols). The Maths Help appendix contains almost 100 pages of worked examples of basic mathematical calculations.

If you would like to look at the S282 module materials before making up your mind you can consult the OpenLearn unit which forms part of S282, from:

http://www.open.edu/openlearn/science-maths-technology/science/physics-and-astronomy/comparing-stars/content-section-0

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

An Introduction to the Sun and Stars, Second Edition, by Simon F. Green and Mark H. Jones (editors), (2015) Cambridge University Press, ISBN-978 1 107 49263 9.

An Introduction to Galaxies and Cosmology, Second Edition, by Mark H. Jones and Robert J. Lambourne (editors), (2004) Cambridge University Press, ISBN-978 1 107 49261 5.

If you are already an OU student you can also ask for advice from your Student Support Team (SST) via StudentHome or by emailing *ug-science-support@open.ac.uk.*

Answers to self-assessment questions

Question 1

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

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

$$= \frac{3.8 \times 10^{26} \text{ W}}{2.5 \times 10^9 \text{ W}} = 1.5 \times 10^{17}$$

(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}.

Comment: As well as using scientific notation to express very large and very small numbers, this question also assumes a familiarity with physical units (such as W for power and kg m^{-3} for density). It is expected that your previous study would have covered these topics.

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 = 1.0×10^8 s^{-1}.

So

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{ m s}^{-1}}{1.0 \times 10^8 \text{ s}^{-1}} = 3.0 \text{ m}$$

(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 $\lambda = 0.5$ μm $= 5 \times 10^{-7}$ m.

So

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \text{ m s}^{-1}}{5 \times 10^{-7} \text{ m}} = 6 \times 10^{14} \text{ s}^{-1} = 6 \times 10^{14} \text{ Hz}$$

Comment: In S282 you will be expected to be comfortable rearranging equations such as the wave equation.

Question 3

(a) The wavelength is given to two significant figures (2 sf) and the frequency is given to only one significant figure (1 sf).

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

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

Comment: When doing calculations in S282 you will be expected to develop a sense for the precision of your answers and quote the results to an appropriate number of significant figures.

Question 4

(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-hundreth of its initial value).

(d) We 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.)

Comment: It is expected that you would 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 struggled with parts (b) and (c) of this question, 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 would expect you to be familiar with the SI system of physical units for commonly used quantities such as mass, length, speed, etc.

Question 5

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

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

so

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

So

$$d = \left(\frac{3.8 \times 10^{26} \text{ W}}{4\pi \times 5.0 \times 10^{-9} \text{ W m}^{-2}} \right)^{1/2} = 7.8 \times 10^{16} \text{ m}$$

(b) In light-years:

$$d = \frac{7.8 \times 10^{16} \text{ m}}{9.46 \times 10^{15} \text{ m ly}^{-1}} = 8.2 \text{ ly}$$

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

Question 6

(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!

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 would expect that you understand the answers given here and, having seen this, you could now apply this sort of reasoning to similar calculations.

Question 7

(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 have come across G in Question 4 and k is another fundamental constant known as Boltzmann's constant.

Comment: This is quite a sophisticated question, so don't worry too much if you found it difficult. If you find this sort of question difficult you should spend some time developing your mathematical skills during S282. However, be assured that you will not have to memorise this equation, nor any equations in S282!

Question 8

(a) X rises from the centre then flattens off. Y falls from the centre then flattens off. Z remains constant, but low, from the centre to the 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_0, the amount of hydrogen is 73% and the amount of helium is 25%.

(d) The amount of other elements (Z) is about 2% throughout the Sun.

(e) Using the values at the centre of 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.

Comment: This question illustrates the importance of being able to interpret graphs. S282 expects students to be comfortable in interpreting and obtaining data from unfamiliar diagrams. You should have been able to answer parts (a) to (d) of this question easily.

Question 9

(a) 30 days on the horizontal axis (two tick marks to the right of the '10') corresponds to a luminosity of $10^4 L_0$.

(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 $300 L_0$.

(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 $2 \times 10^3 L_0$. If you would rather not guess you can use the 10^x key on your calculator to get a more accurate value.

Comment: As in Question 8, this question highlights the importance of being able to interpret graphical information. This question uses a graph with logarithmic scales: if you have not used such graphs before, then you will need to spend some time during the course familiarising yourself with their properties.

Question 10

(a) The processes produce the same amount of energy (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.

Comment: This question again relates to the use of graphs with logarithmic scales. If you found this question difficult, then you will need to devote some study time during the course to understanding how to use such graphs.

Question 11

(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:

$(E_3 - E_2) = -1.51$ eV $- (-3.40$ eV$) = 1.89$ eV

$(E_3 - E_1) = -1.51$ eV $- (-13.60$ eV$) = 12.09$ eV

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

$(E_2 - E_1) = -3.40$ eV $- (-13.60$ eV$) = 10.2$ eV

(d) Because it's an absorption line the electron must have moved to a higher level. 2.86 eV is the difference between levels 2 and 5 so it 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.

Comment: We would expect you to have studied science/physics to a level where you would be 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.

Question 12

(a) A nucleus of carbon reacts with a nucleus of helium to produce a nucleus of oxygen and a gamma-ray.

(b) The C nucleus has six protons, the O nucleus has an atomic number of 16 and therefore $16 - 8 = 8$ 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.

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

Question 13

(a) In space! It orbits between 16 000 km and 139 000 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.' You will learn something about those processes in this module.

(c) 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)

- High Energy Transmission Grating Spectrometer (0.4 keV–10 keV)

- Low Energy Transmission Grating Spectrometer (0.08 keV–2 keV or 0.09 keV–3 keV)

Don't worry if this does not mean much to you at the moment. If you decide to study S282 you will return to this website to learn more about X-ray astronomy.

Comment: This question highlights the fact that you will have to use a computer and the internet in your studies of S282. 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 topics which are vital for science such as spreadsheets.