S283 Planetary science and the search for life

Are you ready for S283, Planetary science and the search for life?

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1 Introduction

If you are intending to study S283, you should make sure that you have the necessary background knowledge and skills to be able to enjoy the module fully and to give yourself the best possible chance of completing it successfully. Please read through these notes carefully and work through all the self-assessment questions. This is a useful exercise even if you have already studied other Open University Science modules and have completed one of the recommended prior modules for S283 (see Section 2 below). Working through these diagnostic notes will serve as a reminder of some of the knowledge and skills which it is assumed that you will have, either from the Level 1 Science module S111 (or one of its predecessors), or from other prior study.

S283 *Planetary science and the search for life* requires a basic level of competence in mathematics and understanding of some physical processes and some chemistry, and it is also beneficial if you have some prior grounding in the geosciences (e.g. geology). If you are not confident in answering most of the questions, you should consider doing some additional preparatory work before starting S283. If you are coming to S283 without having studied S111 or one of its predecessors it is essential that you establish whether your background and experience give you a sound basis on which to tackle the module. If you find that you can answer most of the questions in these notes, then it is likely that you are well prepared to take on S283. However, if you find that you have substantial difficulties with more than about two questions in Section 3 (maths skills) or five questions in Section 4 (science concepts), then you should consider taking a module that will prepare you for S283.

More to remind you of things you have forgotten than to teach you new things, S283 provides a lengthy document called *Background Science,* which is available online for S283 students via the module website. You can refer to that during your studies of S283, whereas the notes here are to help you decide whether or not you are adequately prepared to begin the module.

If, after working through these notes, you are still unsure about whether or not S283 is the right module for you, we advise you to seek further help and guidance from your StudentHome page or from your Student Support Team.

2 Suggested prior study

You are not assumed to have any knowledge of planetary science or astronomy; however, we recommend that you have completed a Level 1 Science module (preferably the discontinued S104 *Exploring Science* or S111 *Questions in Science*), as for S283 you need an understanding of basic scientific and mathematical skills equivalent to this level.

Whatever your route into S283, as an absolute minimum we recommend that you should have reached a standard equivalent to either an O-Level pass or a GCSE grade B or above in mathematics, physics and chemistry.

3 Mathematical skills

Being comfortable with *basic* mathematical and graphical skills is the single most important way you can be prepared for S283. Please be certain that you can (with a little reminding, if necessary):

- **Add, subtract, divide** and **multiply**
- Use a **scientific calculator**
- Understand **scientific notation** using **powers of ten** (e.g. 10^3, 10^{-5}, 6.2×10^{-1}) and perform calculations using scientific notation
- Perform simple **unit conversions** (e.g. μm to mm, mm to m, m to km)
- Manipulate **equations**, involving addition, subtraction, division or multiplication, to find an unknown
- Plot data on **graphs** choosing appropriate scales and axes, and interpret graphical data correctly
- Express quantities as **ratios, fractions** or **percentages**
- Calculate **areas** or **volumes** using given formulae
- Quote to an appropriate number of **significant figures.**

Self-assessed test for numeracy

Try the following questions to test your mathematical skills. Some of these questions have multiple-choice answers, and some do not. It is essential that you are comfortable with the skills tested in these questions before you start S283. You should take no more than 2 hours on this part.

Question 1

Work out the answers to the following sums, using your calculator as appropriate:

(a) 6998 – 15 774

(b) (–5) + (–9)

(c) (8 + 6) × (5 – 2)

(d) Find x and express its value to three significant figures (a = 15.0 and b = 81.0).

$$x = \frac{a}{b} \times 100\%$$

Question 2

Calculate to two significant figures the volumes of boxes with the following dimensions:

(a) 2.0 m × 8.0 cm × 9.0 mm (express the answer in cm^3);

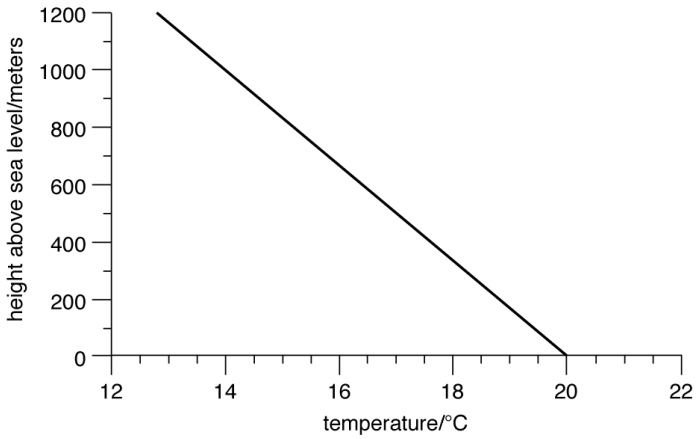
(b) 87 cm × 9.0 cm × 8.0 m (express the answer in m^3).

Question 3

The following figure shows a general plot of temperature change with altitude where the temperature at sea-level is 20.0 °C.

(a) What is the temperature at a height of 300 m above sea level?

(b) How much would you expect the temperature to rise when descending from a height of 1 km to sea level?



Question 4

Rearrange the following equation in terms of *y*:

$2x + 3y = 4(x + y)$

$y =$

Question 5

Rearrange the following equation in terms of v:

$$f = \frac{8gRs}{v^2}$$

$v =$

Question 6

The volume V of a sphere of radius r is given by the formula:

$$V = \frac{4}{3}\pi r^3$$

Which of these answers is the volume of a sphere of radius 5.00 m?

(a) 105 m^3

(b) 167 m^3

(c) 500 m^3

(d) 524 m^3

Question 7

The age of the Earth is calculated as 4.6 billion years. Express this number in scientific notation (a billion is 1 000 000 000 years).

Question 8

In science, the kelvin temperature scale (abbreviated to K) is often used in preference to the more well-known Celsius temperature scale. 0 kelvin is equivalent to –273 °C, and a change in temperature of 1 K is equal to a change of 1 °C. Which one of the following is equivalent to 10 °C?

(a) –283 K

(b) –263 K

(c) 263 K

(d) 283 K

Question 9

A substance contains 3.5×10^{-2} particles per cubic metre. How many particles will there be in a volume of 10^4 m^3?

(a) 3.5×10^{-2}

(b) 350

(c) 35

(d) 3.5

4 Key concepts developed in recommended prior modules and further developed in S283

This section outlines concepts that are developed in S283 and in which prior knowledge is either essential or helpful.

4.1 Basic physical concepts

Units

All measured quantities must have units associated with them. The units used in S283 conform to the SI (Système International d'Unités) system.

When carrying out the multiplication or division of quantities, the operation must apply to the units as well as to the numbers involved. For instance, a room measures 3 m × 4 m, so its area is 3 × 4 (m × m) = 12 m^2. Similarly, the speed of a car is calculated by dividing the distance it has travelled by the time it has taken to travel that distance. The unit of speed is therefore:

$$\frac{\text{distance}}{\text{time}} = \frac{\text{m}}{\text{s}} = \text{m s}^{-1}$$

where s^{-1} is the same as saying 'per second'.

The unit of acceleration is 'metres per second squared' = m s^{-2}.

Forces (S111 Topic 3 or S104 Books 3 and 7)

Newton's second law states that the magnitude of an unbalanced force on an object is equal to the mass of the object multiplied by the magnitude of its acceleration. The direction of the acceleration is the same as the direction of the unbalanced force. In symbols, $F = ma$.

The SI unit of force is the newton (N): 1 N = 1 kg m s^{-2}.

Energy (S111 Topics 2 and 8 or S104 Books 3 and 7)

Energy exists in a number of different forms. It can be converted from one form into another and transferred from one object to another or from one location to another. The SI unit of energy is the joule (J): 1 J = 1 kg m^2 s^{-2}. The law of conservation of energy states that the total amount of energy in an isolated system is constant since energy is neither created nor destroyed. If an object of mass m is moving with speed v then its energy of motion, known as the kinetic energy E_k, is proportional to v^2. The equation for kinetic energy is given by:

$$E_k = \frac{1}{2}mv^2$$

If the height above the Earth's surface of an object of mass m changes by Δh (the Greek letter Δ (delta) is often used to denote a change in some quantity) the change in gravitational potential energy is proportional to the mass of the object and the height above the ground. The equation is given by $\Delta E_g = mg\Delta h$, where g, the acceleration due to gravity, is equal to 9.8 m s^{-2}.

Power, P, is the rate at which energy, E, is transferred in time t, and is given by

$$P = \frac{E}{t}$$

The SI unit of power is the watt (W): 1 W = 1 J s^{-1}.

Self-assessed test for physics

Question 10

What are the basic SI units of

(a) mass,

(b) length and

(c) time?

What are the SI units of

(d) speed and

(e) density?

Question 11

A passenger accidentally drops a 480g camera from a hot-air balloon at a height of 90m

(a) Using the gravitational potential energy equation above what is the change in gravitational potential energy as the camera falls to the ground

(b) If this energy is converted to kinetic energy what is the speed v of the camera as it hits the ground?

Question 12

The luminosity (power output) of the Sun is 3.84×10^{26} J s^{-1} Calculate the amount of energy that the Sun radiates in one day.

4.2 Basic chemical concepts

An understanding of chemical concepts underpins many of the processes discussed in S283. The following list highlights some of the concepts you should be familiar with. You should also recognize chemical symbols and be able to balance chemical equations.

Atoms, molecules and compounds (S111 Topics 1 and 4 or S104 Book 4)

You should be familiar with the idea that all 'matter' is composed of atoms. Every atom contains a nucleus at its centre, which contains protons and neutrons. The nucleus is surrounded by a cloud of electrons. Protons are positively charged, neutrons have no charge and electrons are negatively charged. Protons and neutrons each have approximately the same mass,

whereas the mass of an electron is negligible. The number of protons in its nucleus, called the atomic number, Z, characterizes the atom of any element. Carbon for example has 6 protons, whereas nitrogen has 7 and oxygen has 8.

Different atoms of the same element, which differ only in the number of neutrons they contain, are known as isotopes of that element, and have different atomic masses. The mass of any atom is expressed by the relative atomic mass, which compares the mass of that atom to the atomic mass of the isotope of carbon with six neutrons. On this scale, the relative atomic mass of ^{12}C is defined as 12.000. A particular isotope of an element can be specified by the mass number, *A*, which is the relative atomic mass rounded to the nearest whole number; it gives the total number of protons and neutrons in an atom. Radiogenic isotopes decay to form daughter products either of the same element (no change in atomic number) or a different element (atomic number changes).

Atoms may combine with other atoms. Some common elements exist as diatomic molecules rather than simple atoms, e.g. the gases oxygen (O_2), hydrogen (H_2), nitrogen (N_2) and chlorine (Cl_2). Atoms may also combine with atoms of different elements to form compounds, e.g. carbon dioxide (CO_2). In each case, the chemical formula indicates the numbers of the different atoms combining together.

Solids, liquids and gases

The three phases (or states) of matter are solid, liquid and gas. A substance can exist in any of these phases, depending on its temperature, and the pressure to which it is exposed.

Bonding, valency and masses (S111 Topic 5 or S104 Book 4)

Atoms can bond together to form molecules or compounds. This is done by forming ionic, covalent or metallic bonds. The valency of an atom refers to the number of bonds it can form in a molecule or compound, and relates to the number of electrons in the outer shell. The mass of a compound or molecule is equal to the sum of the relative atomic masses (*A*) of all the atoms bonded together.

Chemical symbols, formulae and equations (S111 Topic 5 or S104 Book 4)

All elements are represented by a one- or two-letter symbol, e.g. magnesium is Mg. When necessary, the atomic number is written at the lower left-hand corner, the mass number at the upper left-hand corner. If the element is ionized the charge is shown at the upper right-hand corner of this symbol. In chemical formulae, the relative number of different atoms that form the compound or molecule is shown at the lower right-hand corner of the chemical symbol.

Reactions between various elements and compounds are written as chemical equations showing the reactants on the left-hand side and the products on the right-hand side. The reactants and products are linked by an arrow (e.g. $\rightarrow$) indicating the direction of the reaction, or by two arrows indicating that the reaction is reversible (e.g. $\rightleftarrows$ but this is sometimes simplified to an equality sign =). As atoms are neither created nor destroyed during chemical reactions, the number of atoms of each type present on one side of the equation must be the same as the number of each type on the other side, i.e. the equation must be balanced.

Question 13

Which chemical elements are represented by the following symbols?

(a) H; (b) He; (c) C; (d) N; (e) O; (f) Al; (g) Fe; (h) Au; (i) Pb.

Question 14

Fill in the missing numbers or chemical symbols in the following list of nuclei. Which of the nuclei are isotopes of each other? (You may find it useful to be reminded that the first eight elements, in order of increasing atomic number, are hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen and oxygen.)

(a) ${}^{1}_{?}\mathrm{H}$; (b) ${}^{18}_{?}\mathrm{O}$; (c) ${}^{14}_{6}?$; (d) ${}^{4}_{?}\mathrm{He}$; (e) ${}^{17}_{8}?$; (f) ${}^{2}_{1}?$; (g) ${}^{12}_{?}\mathrm{C}$; (h) ${}^{16}_{?}\mathrm{O}$.

Question 15

When Sodium reacts with water, hydrogen gas and sodium hydroxide (NaOH), are produced. Balance the following chemical equation that shows this reaction:

$Na(s) + H_2O(l) \rightarrow NaOH(aq) + H_2(g)$

Question 16

The thorium isotope ${}^{230}_{90}\mathrm{Th}$ undergoes *four* successive alpha decay reactions. In each decay it loses a helium nucleus (i.e. ${}^{4}_{2}\mathrm{He}$). Which of the following lead isotopes is the final daughter product?

(a) ${}^{238}_{82}\mathrm{Pb}$; (b) ${}^{214}_{82}\mathrm{Pb}$; (c) ${}^{222}_{82}\mathrm{Pb}$; (d) ${}^{246}_{82}\mathrm{Pb}$.

Question 17

The relative atomic masses of some common elements are as follows:
hydrogen (H) = 1.01, carbon (C) = 12.0, oxygen (O) = 16.0,
calcium (Ca) = 40.1.

What are the relative masses of:

(a) water (H_2O);

(b) carbon dioxide (CO_2);

(c) calcium carbonate ($CaCO_3$)?

4.3 Geological concepts

There are two key geological concepts most useful for studying S283:

- **Igneous, metamorphic and sedimentary rocks** (S111 Topic 7 or S104 Book 2)
- **The rock cycle** (S104 Book 2)

Rocks are continually being formed and destroyed by geological processes, including internal processes such as magma generation and metamorphism, and surface processes such as weathering, transport and erosion.

In addition to the above, it would be helpful if you were also familiar with the following concepts, all of which are covered in S104.

Plate tectonics (S111 Topic 7 or S104 Book 6)

The outer layer of the Earth is divided into a series of rigid plates, which can move apart to form new crust or collide to deform or destroy it. Plate tectonics is the name given to the processes involved in the movement and deformation of lithospheric plates, and is controlled by internal processes in the mantle.

Geological time (S111 Topic 7 or S104 Book 6)

The age of the Earth is calculated to be 4.6 billion years (4600 Ma), with geological processes taking place over hundreds to millions of years. Geological time can be discussed in two ways:

Relative measurements: where one rock sequence or geological event is considered as being older or younger than another, according to the law of superposition.

Absolute measurements: this is done by radiometrically dating rocks using isotopes, and is used to assign an age in millions of years (Ma).

Partial melting (S111 Topic 7 Section 5.2 or S104 Book 6)

Self-assessed test for geology

Question 18

Which *two* of the following statements are *incorrect*?

(a) A rock is a solid assemblage of mineral grains.

(b) A mineral is a solid material with a chemical composition that falls within certain narrow limits.

(c) Rocks are always composed of more than one mineral.

(d) Erosion is the gradual wearing away of a rock by physical breakdown, chemical solution and transportation of material.

(e) Silicates are composed primarily of silicon and hydrogen.

(f) Weathering involves the breaking up of a rock into small rock fragments and mineral grains.

Question 19

How are igneous rocks formed?

Question 20

How are sedimentary rocks formed?

Question 21

How are metamorphic rocks formed?

5 Other skills

You will find it useful to have acquired the following skills:

Basic study skills: organize time for study, learn to pace study, read effectively to identify relevant information and data from scientific texts and accounts.

Writing skills: the ability to write coherently, present arguments in a logical sequence, and write a scientific account with appropriate diagrams.

5.1 Computer-based activities

Many of the activities in S283 are based on software packages, spreadsheets or information from the internet. The main information technology skill that you need prior to studying S283 is to be able to use a personal computer under the Microsoft Windows operating system. If you are unsure as to whether you have sufficient experience of using a personal computer, please see the Computing Questionnaire that is given in the Appendix.

The handling of numerical data is an important skill in planetary science, and it is for this purpose that the module will give you practice in the use of spreadsheets. The module will also develop your skills in using the internet as an information resource.

6 Further reading/revision

S111 Questions in Science, Open University Level 1 Science module.

S112 Science: concepts and practice, Open University Level 1 Science module.

The basic chemical and physical concepts are also covered in any good GCSE-level chemistry and physics textbooks respectively.

If you lack a background in geology a suitable book to read would be *Teach Yourself Geology* by D.A. Rothery, Hodder and Stoughton, 2008 (ISBN 978-0-340-95879-7) or the 2003 edition (ISBN 0-340-86753-1).

7 Answers to self-assessment questions

Answer 1

(a) –8776

(b) –14

(c) 42 (8 + 6 = 14, 5 – 2 = 3, 14 × 3 = 42)

(d) $x = 18.5\%$

$$\left(x = \frac{15.0}{8.0} \times 100\% = 0.1852 \times 100\% = 18.52\% \right)$$

Answer 2

(a) 1400 cm^3; (b) 0.63 m^3.

The answer to (a) is:

200 cm × 8 cm × 0.90 cm = 1440 cm^3. To two significant figures, this is: 1400 cm^3.

Similarly in (b), (0.87 m × 0.09 m × 8.0 m) gives 0.6264 m^3, which is 0.63 m^3 when expressed as two significant figures.

Answer 3

(a) Reading off the plot, the temperature at 300 m is between 18.0 °C and 18.5 °C.

(b) Reading off the plot, the temperature at the surface is 20 °C and the temperature at 1 km (1000 m) is 14 °C. You would therefore expect the temperature to rise 20 – 14 = 6 °C.

Answer 4

$y = -2x$

Starting with: $2x + 3y = 4(x + y)$

First, multiply the 4 through the right-hand side of the equation:

$2x + 3y = 4x + 4y$

Then, add $-4y$ to each side. By doing this all the y variables end up on the left-hand side:

$2x + (3y - 4y) = 4x + (4y - 4y)$, which simplifies to: $2x - y = 4x$

Then, add $-2x$ to each side so all the x variables end up on the right-hand side:

$(2x - 2x) - y = (4x - 2x)$, which simplifies to:

$-y = 2x$

multiplying through by (–1) gives us:

$y = -2x$

Answer 5

$$v = \sqrt{\frac{8gRs}{f}}$$

Starting with:

$$f = \frac{8gRs}{v^2}$$

First, multiply both sides by v^2

$$fv^2 = 8gRs$$

Then, divide both sides by *f*:

$$v^2 = \frac{8gRs}{f}$$

Then, take the square root of each side to achieve the final answer in terms of v:

$$v = \left(\frac{8gRs}{f}\right)^{\frac{1}{2}} \text{ or } v = \sqrt{\frac{8gRs}{f}}$$

Answer 6

(d) 524 m^3

$$V = \frac{4}{3}\pi 5^3$$

$$= \frac{4}{3}\pi(125)$$

= 523.60, which is the same as 524 to three significant figures.

Answer 7

4.6×10^9 years

The superscript '9' shows how many times 4.6 has been *multiplied* by 10.

Answer 8

(d) 283 K

The relationship is that temperature in kelvin (T_k) is equal to temperature in Celsius (T_c) plus 273. That is:

$T_k = T_c + 273$

Therefore, for a temperature in Celsius (T_c) of 10 °C:

$T_k = 10 + 273$

$T_k = 283$.

Answer 9

(b) 350

3.5×10^{-2} particles $m^{-3} \times 10^4$ $m^3 = 3.5 \times 10^{-2} \times 10^4$ particles

$= 3.5 \times 10^2$ particles = 350 particles.

Answer 10

(a) kilogram, kg;

(b) metre, m;

(c) second, s;

(d) metres per second, m s^{-1};

(e) kilograms per cubic metre, kg m^{-3}.

Answer 11

(a) The gravitational potential energy lost by the camera as it falls to the ground is given by:

$\Delta E_g = mg\Delta h$

Where m is the mass of the camera, Δh is the height of the balloon above the ground, and g is the acceleration due to gravity, is equal to 9.8 m s^{-2}.

ΔE_g =0.48 kg × 9.8 m s^{-2} × 90m = 423.36 J = 420 J (to 2 s.f.)

(b) The kinetic energy possessed by the camera as it hits the ground is equal to the gravitational potential energy it loses as it falls from the balloon to the ground. So we can write:

$$Ek = \tfrac{1}{2} m v^2 = 423.36 \text{ J}$$

$$\tfrac{1}{2} \times 0.48 \text{ kg} \times v^2 = 423.36 \text{ J}$$

$$0.24 \text{ kg} \times v^2 = 423.36 \text{ J}$$

$$v^2 = 423.36 \text{ J}/0.24 \text{ kg}$$

Looking at units: J = kg m^2 s^{-2}

So: $v^2 = 1764$ m^2 s^{-2}

$v = \sqrt{1764}$ m^2 s^{-2} = 42 m s^{-1} (to 2 s.f.)

Answer 12

The energy radiated is given by $E = Pt$ where P is the Sun's luminosity and t is one day. So:

$E = 3.84 \times 10^{26}$ J $s^{-1} \times 1$ day

$= 3.84 \times 10^{26}$ J $s^{-1} \times (24 \times 60 \times 60)$ s

$= 3.32 \times 10^{31}$ J

Answer 13

(a) Hydrogen,

(b) Helium,

(c) Carbon,

(d) Nitrogen,

(e) Oxygen,

(f) Aluminium,

(g) Iron,

(h) Gold,

(i) Lead.

Answer 14

(a) ${}^{1}_{1}\mathrm{H}$; (b) ${}^{18}_{8}\mathrm{O}$; (c) ${}^{14}_{6}\mathrm{C}$; (d) ${}^{4}_{2}\mathrm{He}$; (e) ${}^{17}_{8}\mathrm{O}$; (f) ${}^{2}_{1}\mathrm{H}$; (g) ${}^{12}_{6}\mathrm{C}$; (h) ${}^{16}_{8}\mathrm{O}$

(b) ${}^{18}_{8}\mathrm{O}$; (e) ${}^{17}_{8}\mathrm{O}$ and (h) ${}^{16}_{8}\mathrm{O}$ are isotopes of each other, as are (a) ${}^{1}_{1}\mathrm{H}$ and (f) ${}^{2}_{1}\mathrm{H}$; and (c) ${}^{14}_{6}\mathrm{C}$ and (g) ${}^{12}_{6}\mathrm{C}$.

Answer 15

The balanced equation is:

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

On the left is: 2 × Na, 2 × O and 4 × H, atoms

On the right is: 2 × Na , 2 × O and 4 × H (2 from the NaOH and 2 from the H_2) atoms

Hence there are the same numbers for each atom on each side.

Answer 16

The correct answer is (b).

Because there are four decays in which a helium nucleus is emitted, the total decrease in mass number is (4 × 4) = 16, and the total decrease in atomic number is (4 × 2) = 8. So the resultant nucleus has $A = 230 - 16 = 214$ and $Z = 90 - 8 = 82$. The element with atomic number 82 is lead, as noted in the question, so the resulting nucleus is the lead isotope

${}^{214}_{82}\mathrm{Pb}$.

Answer 17

Relative masses of molecules and compounds are calculated by summing the relative atomic masses of the elements according to the weighting indicated by the chemical formula.

(a) A molecule of water contains two hydrogen atoms and one oxygen atom, so its relative mass is $(2 \times 1.01) + 16.0 = 18.02$ (or 18.0 to 3 significant figures).

(b) A molecule of carbon dioxide contains one atom of carbon and two atoms of oxygen so its relative mass is $12.0 + (2 \times 16.0) = 44.0$.

(c) The compound calcium carbonate contains calcium, carbon, oxygen in the ratio 1 : 1 : 3 so its relative mass is $40.1 + 12.0 + (3 \times 16.0) = 100.1$ (or 100 to 3 significant figures).

Answer 18

(c) and (e) are incorrect. A rock can be composed of just one mineral, for example sandstone is composed almost entirely of quartz, although it is more common for a rock to contain more than one mineral. Silicates are predominately composed of silicon and oxygen atoms (plus one or more metallic elements), rather than hydrogen.

Answer 19

Igneous rocks are formed by the cooling and crystallization of magma (*ignis* is Latin for fire).

Answer 20

Sedimentary rocks are formed from sediments that have been laid down on the surface of a planet, and have subsequently undergone processes such as compaction and cementation.

Answer 21

Metamorphic rocks can be derived from sedimentary or igneous rocks (or pre-existing metamorphic rocks). They are rocks that have had their texture and/or mineralogy changed by the action of heat and/or pressure though without being melted.