

# ANSWERS

## 2022 JSOE

### Theme: sustainability

Each question is worth 1 mark unless otherwise specified.

Total number of questions = 50.

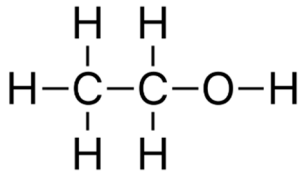
Total marks = 63.

Questions with a green background were optional. They ask for written explanations of previous questions. These did not contribute to the students' overall marks, but were used to discriminate between the top students for the purposes of selection for the Junior Science Olympiad Spring School.

	<p>The theme of this year's exam is sustainability. The idea of living sustainably is both an ancient and a recent idea in human history. Sustainability presumes that resources are finite, and should be used wisely with a view to long-term priorities and consequences.</p> <p>In 2015, the United Nations published 17 Sustainable Development Goals for the world.</p>																																																
1.	<p>Goal 7 of the UN's 17 goals is to "ensure access to affordable, reliable, sustainable and modern energy for all." This means moving away from fossil fuels, which cause three key problems for a sustainable future: they will eventually run out, they cause significant damage to the environment, and they cause adverse health effects.</p> <table border="1"><caption>Estimated data from the electricity generation fuel mix chart</caption><thead><tr><th>Year</th><th>Black coal (%)</th><th>Brown coal (%)</th><th>Natural gas (%)</th><th>Renewables (%)</th><th>Other (%)</th></tr></thead><tbody><tr><td>1994-95</td><td>58</td><td>21</td><td>10</td><td>10</td><td>1</td></tr><tr><td>1999-00</td><td>58</td><td>24</td><td>8</td><td>10</td><td>1</td></tr><tr><td>2004-05</td><td>55</td><td>23</td><td>11</td><td>10</td><td>1</td></tr><tr><td>2009-10</td><td>48</td><td>22</td><td>18</td><td>12</td><td>1</td></tr><tr><td>2014-15</td><td>42</td><td>20</td><td>22</td><td>18</td><td>1</td></tr><tr><td>2019-20</td><td>41</td><td>13</td><td>21</td><td>25</td><td>1</td></tr><tr><td>2020</td><td>40</td><td>13</td><td>20</td><td>27</td><td>1</td></tr></tbody></table> <p><a href="https://www.energy.gov.au/data/electricity-generation">https://www.energy.gov.au/data/electricity-generation</a></p> <p>The graph above shows the mix of fuels used in Australia to generate electricity over the last few decades.</p> <p>Which fuel source has increased by the <i>greatest proportion</i> since 2004-05?</p> <ul style="list-style-type: none"><li>A. Black coal</li><li>B. Brown coal</li><li>C. Natural gas</li><li><b>D. Renewables</b></li><li>E. Other</li></ul>	Year	Black coal (%)	Brown coal (%)	Natural gas (%)	Renewables (%)	Other (%)	1994-95	58	21	10	10	1	1999-00	58	24	8	10	1	2004-05	55	23	11	10	1	2009-10	48	22	18	12	1	2014-15	42	20	22	18	1	2019-20	41	13	21	25	1	2020	40	13	20	27	1
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2020	40	13	20	27	1																																												

2. Biofuels are classed as renewable fuels. Ethanol – a kind of alcohol – can be used as a replacement for petrol and diesel.

Ethanol is made up of molecules, which can be represented as:



Ethanol can be represented by the formula:

- A. COH
- B. C<sub>2</sub>OH
- C. CH<sub>6</sub>O
- D. C<sub>2</sub>H<sub>6</sub>O
- E. C<sub>3</sub>H<sub>6</sub>

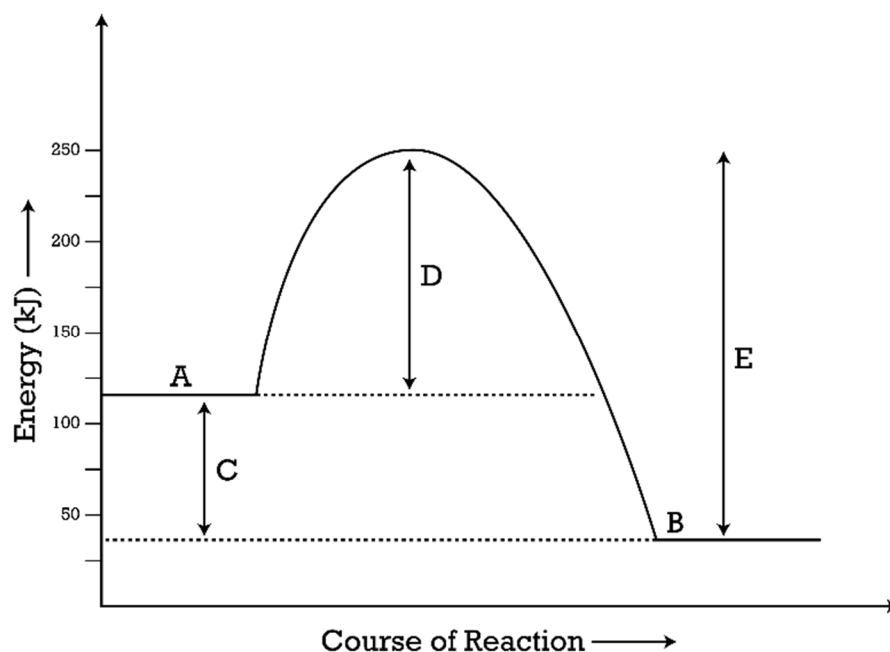
3. Which of the following lists particles from lightest to heaviest?

- A. Electron, neutron, photon, atom
- B. Electron, proton, atom, molecule
- C. Molecule, atom, nucleus, electron
- D. Electron, atom, neutron, molecule

4. Fossil fuels like coal, oil and gas contain a lot of chemical potential energy, which can be converted to heat energy by combustion. This makes combustion an exothermic reaction: a chemical reaction that releases heat energy to the surroundings.


The diagram below is a reaction energy diagram for an exothermic reaction. Five parts of the diagram are labelled A-E.

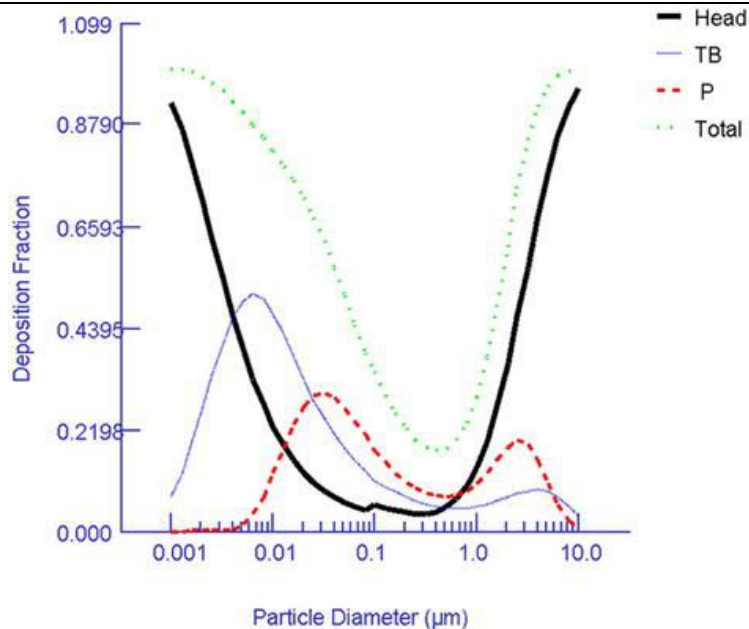
Match the correct description with each label.



(continued next page)

	<ul style="list-style-type: none"> <li>• The chemical potential energy stored in the reactant molecules (A)</li> <li>• The chemical potential energy stored in the product molecules (B)</li> <li>• The amount of energy needed to break the bonds in the reactant molecules (D)</li> <li>• The amount of energy released when bonds are made during the formation of the products (E)</li> <li>• The overall energy change caused by the reaction (C)</li> </ul>
5.	<p><i>This question is worth 2 marks (1 mark for each part).</i></p> <p>Currently, the majority of the world's electricity is produced by burning coal.</p> <p>Coal is produced over millions of years by the compression of plant matter underground. Heat and pressure cause chemical changes to the original molecules in the plants. Older coal, which has been subjected to these pressures and temperatures for a longer period of time, has a higher percentage of carbon with fewer impurities.</p> <p>Bituminous coal, lignite and anthracite are three types of coal. Their compositions can be represented by the following general formulae:</p> <p>Bituminous coal: <math>C_{137}H_{97}O_9NS</math>  Lignite: <math>C_{39}H_{35}O_{10}NS</math>  Anthracite: <math>C_{240}H_{90}O_4NS</math></p> <p>The relative masses of some atoms are given below. The relative mass of an atom is simply how much heavier it is than a hydrogen atom (which is assumed to have a mass of 1).</p> <p>Hydrogen = 1  Carbon = 12  Nitrogen = 14  Oxygen = 16  Sulfur = 32</p> <p>a) Of the three types of coal, identify the one with the highest sulfur content: (dropdown: bituminous coal/lignite/anthracite).</p> <p>b) Calculate the percentage by mass of sulfur in the coal you selected. Give your answer to 2 decimal places. 4.51% sulfur.</p> <p><b>Marking: for b), correct mass% for any of the three coal types is accepted. Half a mark is deducted if rounding is incorrect.</b></p>
6.	<p>In 1952, London experienced the Great Smog. Pollution from coal-fired power stations located within the city combined with foggy, windless weather conditions that produced a dense, unmoving cloud of polluted fog (smog) that settled over London for several days. Recent research concluded that around 12 000 people died from the effects of inhaling this smog.</p> <p>Fossil fuels, particularly coal and oil, contain significant levels of sulfur and nitrogen. When they are burnt, the polluting gases sulfur dioxide (SO<sub>2</sub>) and nitrogen dioxide (NO<sub>2</sub>) may be produced.</p> <p>If these gases are released into the atmosphere when fog is present, they can dissolve into the tiny water droplets in the air and react with the water to produce nitric acid and sulfuric acid. During the day, the water in the droplets partially evaporates and the droplets reduce in volume.</p> <p>Which one of the following options is true?  As the water droplets reduce in size:</p> <p>(continued next page)</p>

	<p>A. The concentration of acid in the droplets decreases  <b>B. The pH of the water droplets decreases</b>  C. The smog becomes less acidic  D. The water droplets become less dense</p>
7.	<p>Acid rain forms by a similar process to smog. As well as affecting crops and forests, the effects of acid rain are visible as damage to limestone statues and buildings, since acids react with the calcium carbonate that makes up limestone.</p>  <p>Wiki commons  Nino Barbieri, CC BY-SA 3.0 &lt;<a href="http://creativecommons.org/licenses/by-sa/3.0/">http://creativecommons.org/licenses/by-sa/3.0/</a>&gt;, via Wikimedia Commons</p> <p>Predict the formula of the salt that would be produced when nitric acid (HNO<sub>3</sub>) reacts with calcium carbonate (CaCO<sub>3</sub>).</p> <p><b>A. Ca(NO<sub>3</sub>)<sub>2</sub></b>  B. CaNO<sub>3</sub>  C. CaN  D. CO<sub>3</sub>NO<sub>3</sub>  E. Ca<sub>2</sub>NO<sub>3</sub></p>
Info	<p>Carbon-based fuels can undergo complete combustion, in which the carbon reacts with oxygen and is completely converted to carbon dioxide.</p> <p>Under some circumstances, insufficient oxygen may be available and <i>incomplete</i> combustion will occur. Incomplete combustion produces carbon monoxide (CO) and soot (fine particles of unburnt carbon).</p> <p>While its effects are usually not noticed immediately, <i>inhaling</i> large quantities of fine particles can cause disease in the respiratory system. This type of pollution can result from transport, indoor cooking fires, and was obvious in Australia in 2019-2020 during the bushfire season.</p>
8.	<p>Select the correct option for each of the following.</p> <p>When a human inhales:</p> <p>The diaphragm relaxes/<b>contracts</b>  The volume of the lungs <b>increases</b>/decreases  The air pressure in the lungs increases/<b>decreases</b>  Air is <b>drawn into</b>/forced out of the lungs</p>
9.	<p>At rest, humans inhale and exhale approximately 12 times per minute, each breath involving ~0.5L of air. If the air contains fine particles suspended in it, the particles can be deposited in different locations in the respiratory system.</p> <p>The graph below describes a relationship between <i>particle size</i> and <i>the fraction of particles that are deposited</i> in three different regions of the respiratory system.</p> <p>(continued next page)</p>



<https://www.ara.com/mppd/>

**Notes:**

The coloured lines on the graph represent different parts of the respiratory system:

- The black line marked 'head' represents the upper respiratory system
- The thin purple line marked 'TB' represents the tracheo-bronchial region, and
- The red dotted line marked 'P' represents the bronchiole/alveolar region.
- The green dotted line marked 'total' refers to overall deposition in the three regions combined.

Particle diameter is measured in micrometres ( $\mu\text{m}$ ). There are 1 000 000  $\mu\text{m}$  in 1m.

The x-axis of this graph is a logarithmic scale, not a linear scale, so the marks are not evenly spaced.

Based on this graph, which of the following statements is **incorrect**?

- A. Particles with diameters of 5  $\mu\text{m}$  or larger are mostly deposited in the nose, mouth, larynx and pharynx.
- B. Particles around 0.2-0.5  $\mu\text{m}$  are most likely to be breathed out again.
- C. The majority of particles with diameters around 0.1  $\mu\text{m}$  are caught in the TB region.
- D. The majority of particles caught in the TB region have diameters less than 0.1  $\mu\text{m}$

10. This question is worth 2 marks.

One solution to reducing the effects of breathing fine particles is to wear a mask – now a much more common occurrence since the COVID pandemic!

In 2021, Kodros et al published a study in which they looked at the effects of wearing masks on inhalation of fine particles. This was relevant not only to potentially disease-bearing droplets, but also to chemical air pollution such as fine carbon particles.

A simple mathematical model describing the effectiveness of a mask at preventing inhalation of particles is:

$$PF = \frac{1}{P(1 - B) + B}$$

The symbols are as follows:

(continued next page)

PF = protection factor (describes the effectiveness of the mask)

P = penetration: a number between 0 and 1, indicating the fraction of particles in a given size range that penetrate (can get through) the material of the mask.

B = bypass; a number between 0 and 1, indicating the fraction of inhaled air that goes around the mask rather than going through it.

Indicate whether each of the following statements is true or false:

- A single-layer mask would likely have a lower value of P than a multi-layer mask (true)
- The more air that bypasses the mask, the less the P value matters (true)
- $B + P = 1$  (false)
- High penetration and low bypass gives the best protection factor (false)
- B would be most affected by how well the mask fitted the user's face (true)
- The higher the protection factor, the more effective the mask (true)

11. Assume a mask with  $B = 0.1$ .  
By what factor does the protection factor change if the P is decreased from 0.6 to 0.2?

(For example, changing by a factor of 0.5 means the protection factor has halved).

- A. 0.30
- B. 0.44
- C. 1.6
- D. 2.0
- E. 2.3
- F. 3.6

12. *This question is worth 2 marks (1 mark for each part)*

Indoor cooking fires are a serious source of fine particle pollution in developing countries where electricity and gas are not readily available to houses. A low-tech solution to this problem, promoted by a number of charities, is the use of solar cookers.

A solar cooker works by concentrating energy from the sun to heat a container in which food can be cooked. A well-designed solar cooker can cook stews, boil water and bake simple cakes.

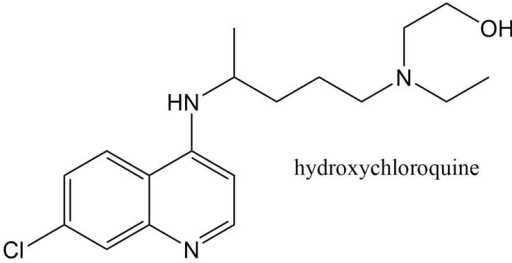
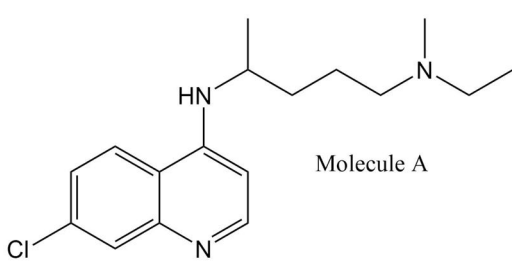
The picture below shows a very simple home-made solar cooker. A cooking pot, painted black, sits in a box. The box has thick walls so that it is well insulated, and has a clear lid to allow sunlight in. The foil flaps reflect light from the sun into the box.



a) Select true or false for each of the following statements:

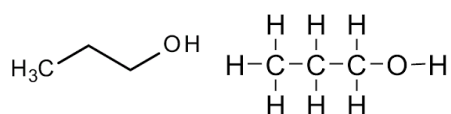
- Heat energy is transferred out of the box by radiation. (true)
- Heat energy is transferred out of the box by convection. (false)
- Heat energy is transferred out of the box by conduction. (true)

(continued next page)

	<p>b) Which one of the following statements is true?</p> <p>A. Light-coloured materials absorb more radiation than they reflect (false)</p> <p>B. Insulation slows the rate at which heat is transferred out of the solar oven box (true)</p> <p>C. Insulating materials do not conduct heat energy (false)</p> <p>D. The black colour of the pot in the solar oven attracts infrared radiation. (false)</p>
	<p>Goal 3 of the UN's 17 Sustainable Development Goals aims to improve human health. Part of this goal is that by 2030, the global epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases should be ended.</p>
13.	<p>Malaria is caused by single-celled parasitic organisms belonging to the protist kingdom.</p> <p>The most common organisms to cause malaria are <i>Plasmodium falciparum</i>, <i>Plasmodium vivax</i>, <i>Plasmodium ovale</i> and <i>Plasmodium malariae</i>.</p> <p>The <i>Plasmodium</i> life cycle takes place in mosquitos and humans. The organisms cause no negative effects to mosquitos; in humans, however, they go through several growth stages while located in the liver cells and red blood cells, leading to severe health effects.</p> <p>Select true/false for each of the following statements:</p> <ul style="list-style-type: none"> <li>• <i>Plasmodium</i> are prokaryotes (false)</li> <li>• <i>Plasmodium</i> are autotrophs (false)</li> <li>• <i>Plasmodium</i> contain membrane-bound organelles (true)</li> <li>• Parasitism is a form of symbiosis (true)</li> <li>• A key difference between predation and parasitism is the length of time over which the interaction takes place (true)</li> </ul>
14.	<p>The drug chloroquine was first discovered by German chemists and from the 1950s was widely used as a successful treatment for malaria.</p> <p>However, in the 1990s, health workers and scientists documented a gradual increase in the number of malaria cases in which chloroquine was <i>ineffective</i> as a treatment.</p> <p>Which of the following is the most likely explanation?</p> <p>A. Malaria sufferers were now excreting chloroquine before it could kill the parasite.</p> <p>B. Mutations conferring chloroquine resistance were now arising more frequently in <i>Plasmodium</i> organisms.</p> <p>C. The use of chloroquine favoured the survival and reproduction of resistant parasites.</p> <p>D. A new species of <i>Plasmodium</i> had emerged.</p>
15.	<p><i>This question is worth 2 marks.</i></p> <p>Two molecules are shown below: hydroxychloroquine (a drug similar to chloroquine), and Molecule A.</p> <div style="display: flex; justify-content: space-around; align-items: flex-end;"> <div style="text-align: center;">  <p>hydroxychloroquine</p> </div> <div style="text-align: center;">  <p>Molecule A</p> </div> </div> <p>In this kind of molecular diagram, the following rules apply (continued next page):</p>

- Straight lines indicate single bonds between atoms.
- A double line indicates a double bond, which is equivalent to two single bonds.
- Where a letter is shown, it indicates an atom of that element (i.e. H = hydrogen, O = oxygen, N = nitrogen, Cl = chlorine)
- Where a bond ends, but no letter is shown, a carbon atom is assumed to be present
- Every carbon atom must have a total of four bonds. In places where a carbon appears to have fewer than four bonds, the missing bonds are assumed to be bonds to hydrogen atoms.
- Atoms other than carbon do not have missing bonds.
- Where two letters are shown together (e.g. HN), a single bond exists between them

For example, the two diagrams below both show a propanol molecule, which contains three carbon atoms, eight hydrogen atoms and one oxygen atom.



The molecular formula of hydroxychloroquine is  $C_{18}H_{26}ClN_3O$ .

How many hydrogen atoms are in Molecule A?

24

16. The condition called **sickle cell disease** is caused by a codominant set of alleles that affect the shape of red blood cells.
- A person who is homozygous for the sickle cell allele ( $B^S B^S$ ) has sickle cell disease. Their red blood cells take on an elongated 'sickle' shape, carry less oxygen, and tend to clot abnormally.
- A heterozygous individual ( $B^N B^S$ ) has the sickle cell trait, but not the disease. These people produce both normal and abnormal red blood cells and suffer fewer complications than those with the disease.
- One of the interesting benefits of being heterozygous for sickle cell trait is that it gives partial resistance to malaria, since *Plasmodium* cannot effectively reproduce in sickle-shaped red blood cells.
- If two people who are heterozygous for sickle cell trait have children, what is the likelihood that their children will have partial resistance to malaria?
- 0%
  - 25%
  - 50%
  - 75%
  - 100%



info

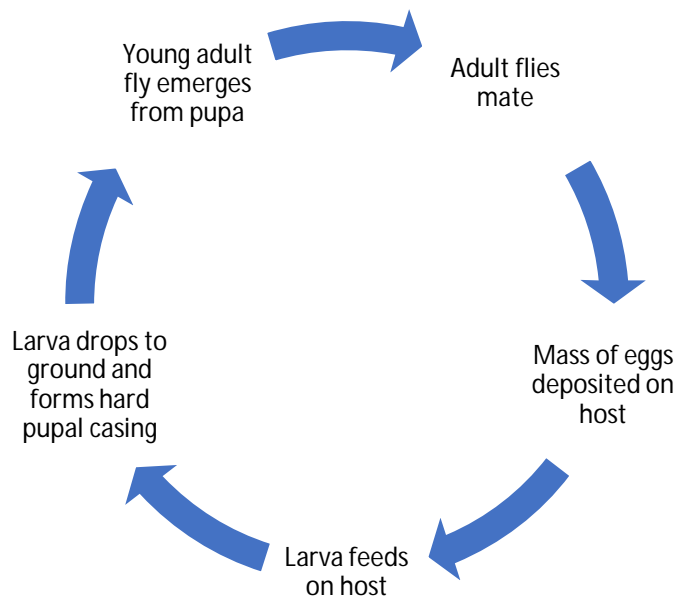
Goal 2 of the UN's Sustainable Development Goals is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. Finding ways to sustainably control plant and animal diseases and parasites is an important focus of agricultural research.

The New World Screwworm Fly (*Cochliomyia hominivorax*) is a parasitic fly that is a particular problem for wild and domestic mammals.

The fly lays its eggs in any small wound or opening on the body of a mammal. When the eggs hatch, the larvae feed on the flesh of the host. An infestation of larvae on a host animal causes large and painful wounds and may lead to death. The life cycle of the screwworm fly is shown below.



Screwworm life cycle:



17.

The full classification of the new world screwworm fly is:  
*Animalia/Arthropoda/Insecta/Diptera/Calliphoridae/Cochliomyia hominivorax*.

'Calliphoridae' represents which level of classification?

- A. Species
- B. Class
- C. Kingdom
- D. Phylum
- E. Genus
- F. Family
- G. Order

18.	<p>Using chemical sprays to kill insect pests can lead to the deaths of useful insects as well as other unwanted side-effects.</p> <p>A more sustainable method has been successfully used to control screwworm populations in Central America. This is known as “sterile insect technique” (SIT). SIT has also been effective elsewhere in controlling fruit flies (an agricultural pest) and tsetse flies (which transmit African sleeping sickness).</p> <p>In SIT, large numbers of adults of the target insect species are raised in captivity and are sterilised. An insect is regarded as ‘sterilised’ when it is alive and healthy, but is unable produce offspring. The sterilised adults are released in the affected geographic area and then compete with wild adults for mates. Since these matings do not produce offspring, the overall insect population drops.</p> <p>Which of the following statements is <b>incorrect</b>?</p> <ul style="list-style-type: none"> <li>A. Only sterilised males are needed for SIT to be effective</li> <li>B. Sterilised adults must be able to compete successfully with wild adults for SIT to be effective</li> <li>C. The release of one large batch of sterilised insects is sufficient to control the target species</li> <li>D. Matings between wild and sterilised insects must produce no eggs or eggs that don’t hatch</li> </ul>
19.	<p>Select the correct words to fill in the gaps in the following text.</p> <p>Screwworm flies reproduce via sexual reproduction, in the same general manner as most animals. The sex cells (spermatozoa and eggs) are known as <b>gametes</b>. These cells are produced by the process known as <b>meiosis</b>.</p> <p>Each body cell in a screwworm fly has five pairs of non-sex chromosomes (known as <b>autosomes</b>) and 1 pair of sex chromosomes. However, sex cells are <b>haploid</b> so each screwworm sex cell has <b>6</b> chromosomes. Fertilisation occurs when a male and female sex cell combine, forming a zygote, which has <b>12</b> chromosomes.</p> <p><b>Word options:</b>  Somatic cells  Mitosis  Meiosis  Gametes  Autosomes  Chromosomes  Haploid  Diploid  3  6  12  24</p>
20.	<p>To produce sterile screwworm flies for SIT, the pupae of screwworm larvae are treated with radiation for a short period. This causes mutations in their DNA which do not kill them but cause them to develop into sterile adults. Too high a dose of radiation would cause too many mutations and the flies would never hatch. The right dose, however, causes mutations that sterilise the flies but which do not kill them.</p> <p>The following statements relate to <b>mutations in general</b>. Which statement is <b>incorrect</b>?</p> <ul style="list-style-type: none"> <li>A. The effect of a mutation on an organism is negative</li> <li>B. A mutation is a change in the sequence of DNA in a cell</li> <li>C. Mutations can result from the breaking of chemical bonds</li> <li>D. A mutation can cause a gene to produce a different protein</li> </ul>

21. *This question is worth 2 marks.*

Important early work on sterilisation of screwworms was done in the 1950s by Bushland and Hopkins at the US Department of Agriculture.

Originally, Bushland and Hopkins did their sterilisation work using x-rays. However, they found that gamma-ray sources were cheaper to obtain than x-ray sources. Both gamma rays and x-rays are high-energy forms of electromagnetic radiation (light).

Bushland and Hopkins knew that gamma-rays would sterilise the flies, but were concerned that those flies might be less vigorous or might die sooner than those treated with x-rays.

They ran a series of experiments to see whether treating fly pupae with gamma-rays would cause sterilised flies to die sooner than if they were treated with x-rays.

For each experiment, a large collection of 6-day-old pupae was divided into groups of approximately 1000, and all insects were treated with radiation within a few hours of each other. A control group was not treated with radiation.

When the flies began to emerge, each group was placed in a separate emergence cage at constant temperature and humidity. After 12 days, the percentage of flies that had died (the percent mortality) was calculated. The table below shows the percentage of flies that died within 12 days of hatching.

*Table: percent mortality of flies held in the laboratory for 12 days, that emerged from pupae treated with x-rays or gamma-rays.*

Experiment no.	Treated with x-rays		Treated with gamma-rays		No treatment	
	Males	Females	Males	Females	Males	Females
1	73	49	83	41	32	82
2	49	40	53	72	42	60
3	43	72	42	68	35	37
4	47	48	39	47	35	35
5	54	65	45	54	29	48
Average	53	55	52	56	35	52

Study each of the following statements. Select 'true' if it is a reasonable conclusion from the data, and 'false' otherwise.

- Gamma-rays and x-rays had the same effect on mortality (**true**)
- Females always have shorter lifespans than males (**false**)
- Natural mortality varied significantly between groups (**true**)
- Radiation treatment had a larger effect on the mortality of males than females (**true**)
- The effects of systematic error are evident in the data set (**false**)

Info Both gamma rays and x-rays are high-energy forms of electromagnetic radiation (light).

There are two important equations that show the relationships between energy, frequency and wavelength for photons of light.

$$E = hf$$

$$c = f\lambda$$

E = energy in Joules  
 h = Planck's constant =  $6.626 \times 10^{-34} \text{ Js}^{-1}$   
 f = frequency in Hz or  $\text{s}^{-1}$   
 c = speed of light =  $3.00 \times 10^8 \text{ ms}^{-1}$   
 $\lambda$  = wavelength in m

22. This question is worth 2 marks (1 mark for each part)

a) A gamma-ray photon has a higher energy than an x-ray photon. Fill in the correct option for each statement below:

Gamma rays have longer/shorter wavelengths than x-rays.  
 Gamma rays have higher/lower frequencies than x-rays.

b) Bushland and Hopkins treated their screwworm pupae with gamma-ray photons from a radioactive cobalt-60 source. These photons each had an energy of  $1.9 \times 10^{-13} \text{ J}$ .

Calculate the wavelength of these photons in picometres.  
 ( $1\text{m} = 1 \times 10^{12} \text{ pm}$ )

Numerical answer = 1.1 pm (2s.f.)

23. Life on Earth is made sustainable by the presence of interlinked ecosystems that draw energy from the Sun.

Ecosystems rely on the interactions of a large number of organisms. An Arctic foodweb is shown below. Which of the following is both a primary and a tertiary consumer?

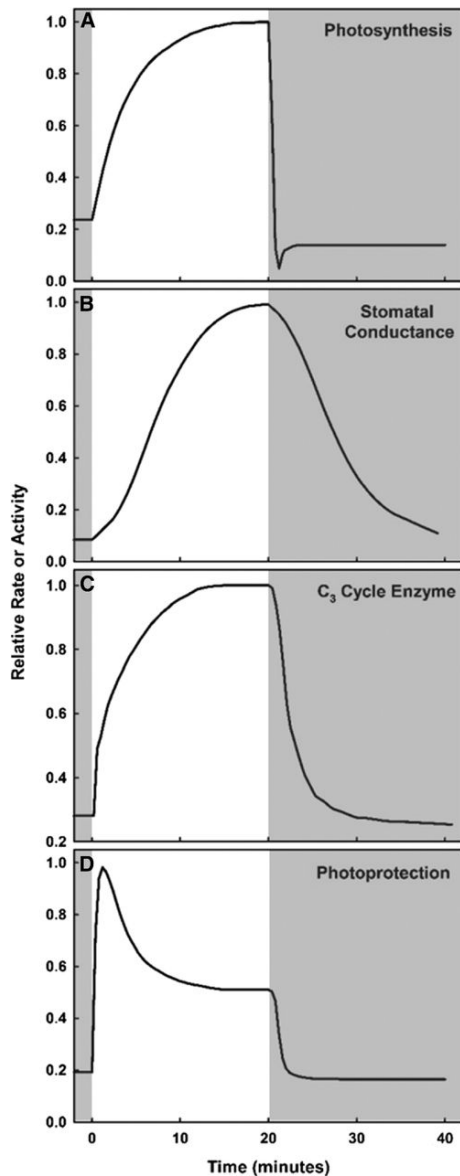
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    graph TD
      GreenPlants[Green plants] --> Bacteria
      GreenPlants --> Insects
      GreenPlants --> Worms
      Algae --> Bacteria
      Algae --> Protozoa
      Algae --> AquaticLarvae[Aquatic larvae and worms]
      Insects --> Spiders
      Insects --> Ptarmigans
      Spiders --> ArcticFoxes
      Ptarmigans --> ArcticFoxes
      AquaticLarvae --> Fish
      Fish --> Birds
      Fish --> Seals
      Seals --> ArcticFoxes
      Seals --> PolarBears
      Birds --> ArcticFoxes
      PolarBears --> ArcticFoxes
      Bacteria --> Protozoa
      Protozoa --> ArcticFoxes
  
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(continued next page)

	<ul style="list-style-type: none"> <li>A. Arctic foxes</li> <li><b>B. Aquatic larvae</b></li> <li>C. Bacteria</li> <li>D. Fish</li> <li>E. Ptarmigans</li> </ul>
24.	<p>Carbon is a crucial element on Earth. It gets transformed from one form to another, and it flows constantly between various reservoirs. For instance when oil, a fossil fuel, is burnt, carbon is transformed from liquid hydrocarbons in the geosphere to carbon dioxide gas in the atmosphere. This gas can then move from the atmosphere into the hydrosphere by dissolving from the air into the ocean.</p> <p>Which of the following would cause a net flow of carbon <b>out of</b> the atmosphere due to processes occurring in a forest ecosystem?</p> <ul style="list-style-type: none"> <li>A. The respiration rate of soil organisms increased.</li> <li>B. The combustion rate of forests increased.</li> <li>C. The decomposition rate of leaf litter increased.</li> <li><b>D. The growth rate of trees increased.</b></li> <li>E. The rate at which trees were cut down increased.</li> </ul>
25.	<p>The average temperature of the Earth's atmosphere is increasing due to increasing concentrations of carbon dioxide in the atmosphere.</p> <p>Which statement is <b>incorrect</b>?</p> <ul style="list-style-type: none"> <li>A. Carbon dioxide can absorb infrared radiation.</li> <li>B. The warmer an object is, the more infrared radiation it emits.</li> <li><b>C. Greenhouse gases block ultraviolet light from reaching the Earth.</b></li> <li>D. Carbon dioxide allows visible light to pass through it.</li> </ul>
26.	<p>Which of the following is the principal reason the climate is warmer at the equator than at the poles?</p> <ul style="list-style-type: none"> <li>A. The equator is closer to the sun than the poles.</li> <li><b>B. A given amount of sunlight is spread over a larger area at the poles.</b></li> <li>C. There are more heat-trapping clouds at the equator</li> <li>D. Convection cells distribute heat from the equator towards the poles.</li> </ul>
27.	<p>The process of photosynthesis could be described as the basis of life on Earth – without it, almost all ecosystems would cease to be sustainable.</p> <p>Which of the following is the best description of the energy change that occurs during photosynthesis?</p> <ul style="list-style-type: none"> <li><b>A. Light energy from the sun is transformed to chemical potential energy in fuel molecules.</b></li> <li>B. Thermal energy is transferred from sunlight into sugar molecules.</li> <li>C. Chemical potential energy in fuel molecules is transformed into heat energy.</li> <li>D. Chemical potential energy in chemical bonds is used to drive other chemical reactions.</li> <li>E. Light energy from the sun is transformed into kinetic energy in sugar.</li> </ul>

Info	<p>Some students are designing an investigation. Their aim is to determine the effect of an abiotic factor on the rate of photosynthesis in aquatic plants.</p> <p>Their method is as follows:</p> <ol style="list-style-type: none"> <li>1. An 8cm length of pondweed (<i>Elodea</i>) was cut.</li> <li>2. A 1.0% solution of sodium hydrogen carbonate was prepared. (Note: the sodium hydrogen carbonate acts as a source of carbon dioxide for the aquatic plant.)</li> <li>3. The pondweed was placed in a test tube and submerged in sodium hydrogen carbonate solution.</li> <li>4. The test tube was placed outside in the sun and a timer was started.</li> <li>5. The light intensity was measured with a lightmeter.</li> <li>6. The number of bubbles of oxygen emerging from the cut stem of the pondweed was counted for 10 minutes.</li> <li>7. The test tube was brought into the shade.</li> <li>8. The light intensity was measured in the shade.</li> <li>9. The timer was restarted and the number of bubbles emerging was again counted for a 10 minutes.</li> <li>10. The data was collated and analysed.</li> </ol>
28.	<p><i>This question is worth 2 marks</i></p> <p>a) What is the correct independent variable in this experiment?</p> <ol style="list-style-type: none"> <li>A. Location</li> <li><b>B. Light intensity</b></li> <li>C. Rate of photosynthesis</li> <li>D. Total number of oxygen bubbles</li> <li>E. Number of oxygen bubbles produced per minute</li> </ol> <p>b) What is the correct dependent variable in this experiment?</p> <ol style="list-style-type: none"> <li>A. Location</li> <li>B. Light intensity</li> <li>C. Rate of photosynthesis</li> <li>D. Total number of oxygen bubbles</li> <li><b>E. Number of oxygen bubbles produced per minute</b></li> </ol>
29.	<p><i>This question is worth 2 marks.</i></p> <p>While the students are evaluating their method, one of them comes across some research on how photosynthesis varies in leaves that are exposed to sudden changes of light and shade; e.g. when moving spots of sunlight fall on leaves in the under-storey of a forest.</p> <p>Four graphs from this research are shown below. In each graph, the white background indicates the time during which the leaves were exposed to bright light. A grey background indicates the leaves were in low light.</p> <p>(continued next page)</p>



<https://academic.oup.com/plphys/article/176/2/990/6117319?login=true>

#### Notes:

- Graph A refers to the rate of photosynthesis in a leaf.
- Graph B: stomata have high conductance when they are open (i.e. gases can flow through them at a high rate). The exact shape of this graph depends on the plant species, and also on whether the plant is in a high-water or low-water environment.
- Graph C: C<sub>3</sub> cycle enzyme refers to the activity of one of the key parts of the photosynthesis system.
- Graph D: Too much light falling on a leaf can damage leaf tissues. The photoprotection system converts excess high-energy light into lower-energy heat that can dissipate (leave the leaf) harmlessly.

Indicate whether each of the following statements is true or false:

- When moving to low light, photosynthesis is initially limited by stomatal conductance (**false**)
- The C<sub>3</sub> cycle enzyme is responsible for the absorption of light to drive the photosynthesis system (**false**)
- The dip in photosynthesis just after moving to low light is because the photosynthesis system shuts down in low light. (**false**)
- A plant experiencing drought would likely have its rate of photosynthesis limited by stomatal conductance (**true**)
- A photoprotection system that was slow to respond would mean the plant was less efficient in changing light conditions. (**true**)

30.	<p><i>This question is worth 2 marks.</i></p> <p>The students then evaluate their method, looking for ways to improve it.</p> <p>For each of the following possible changes, indicate which of the following effects it would have on the data:</p> <ul style="list-style-type: none"> <li>– reduce random error</li> <li>– reduce systematic error</li> <li>– reduce both random and systematic error</li> <li>– have little or no effect</li> <li>– reduce the reliability of the data.</li> </ul> <p>When you consider each option, assume it is the <i>only</i> change made to the method.</p> <ul style="list-style-type: none"> <li>• Use a more accurate balance to prepare the sodium hydrogen carbonate solution to 1.00% concentration (little or no effect)</li> <li>• Use a white lamp of adjustable brightness instead of sunlight and shade (reduce random error)</li> <li>• Use a different plant in the bright light and the low light (reduce reliability)</li> <li>• Allow the plant to sit for 30 minutes at a given light level before starting to collect data (reduce systematic error)</li> <li>• Collect and measure oxygen production over 1 hour rather than 10 minutes. (reduce both random and systematic error)</li> </ul>
Extra Q	<p>Explain your answer to the final statement in the previous question.  <i>(Question did not contribute to overall mark, but was used to help discriminate between top students for selection into the JSO Spring School).</i></p>
Info	<p>While sustainability is fundamental to life here on Earth, it is also crucial if humans are to explore space. For instance, NASA's Artemis program plans to have a human base on the Moon in the next decade. For this to be possible, such a settlement would need to be as self-sufficient and sustainable as possible.</p> <p>China's Lunar Exploration Program Chang'E (named after the Chinese moon goddess) has sent five missions to the moon. The most recent was Chang'E-5, which landed on the moon on 1 December 2020 and returned to Earth on 16 December 2020.</p>
31.	<p><i>This question is worth 2 marks (1 mark for each part).</i></p> <p>When Chang'E-5 returned to Earth, it was carrying 61.1 ounces of lunar soil.  1 gram = 0.035274 ounces</p> <p>Convert 61.1 ounces to grams.</p> <p>a) Give your answer to one decimal place.  Numerical answer: 1732.2 g</p> <p>b) Give your answer to the correct number of significant figures.  Numerical answer: 1730 g</p>
32.	<p>Recently, the scientists analysing the Chang'E soil published a proposal to use the soil as a photocatalyst for a process they are calling 'extraterrestrial photosynthesis'.</p> <p>'Extraterrestrial photosynthesis' could be used to improve the sustainability of human settlements on the Moon. The process would involve the following steps:</p> <ol style="list-style-type: none"> <li>1. Continually collect the gases breathed out by humans in the habitation module</li> <li>2. Separate out the carbon dioxide from the gas mixture</li> <li>3. Using solar energy, and the lunar soil as a catalyst, convert the carbon dioxide into useful oxygen and fuels (e.g. methane)</li> </ol> <p>(continued next page)</p>



In step 3 of the process, carbon dioxide is combined with hydrogen to produce methane (a useful fuel) and water. Balance the chemical equation of this process:

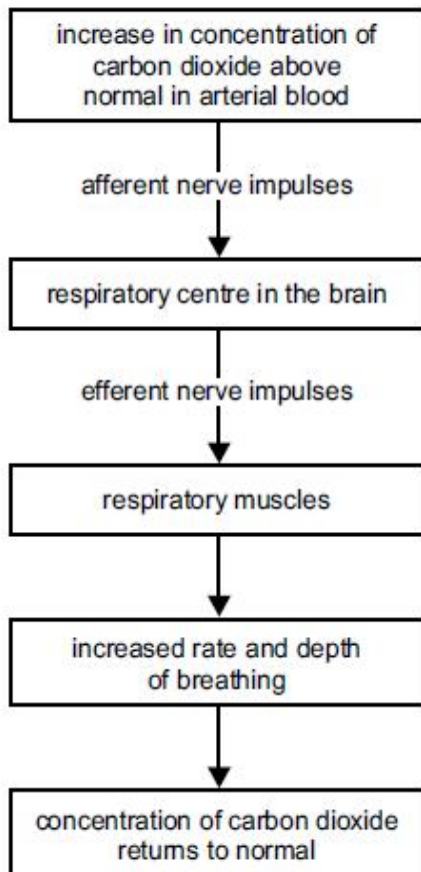


33. For extraterrestrial photosynthesis to be sustainable, it must be possible to efficiently separate out carbon dioxide from the exhaled gases of the human inhabitants of the lunar settlement.

For each of the following gases, select 'true' if it is present in an exhaled human breath in an Earth atmosphere? (Select 'false' otherwise.)

- Carbon dioxide (true)
- Chlorine (false)
- Hydrogen (false)
- Nitrogen (true)
- Oxygen (true)
- Water (true)

34. The following diagram depicts carbon dioxide regulation in mammals:



When the concentration of carbon dioxide returns to normal it would be reasonable to conclude that the:

- A. Respiratory muscles stop contracting.
- B. Rate and depth of breathing decrease.
- C. Number of afferent nerve impulses increase.
- D. Respiratory centre in the brain fails to send efferent nerve impulses.

35. This question is worth 2 marks.

Chemists often measure quantities of chemicals using the unit called the 'mole'. The mole is a way of counting numbers of atoms or molecules.

Imagine Gas X.

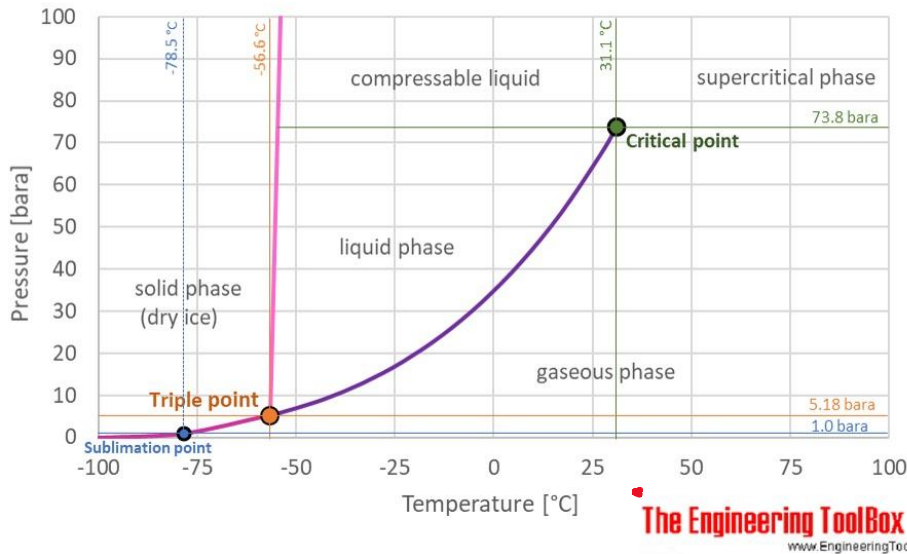
- 1.00 mole of gas X contains  $6.02 \times 10^{23}$  molecules of X.
- Under certain conditions of temperature and pressure, 1.00 mole of gas X occupies a volume of 24.36L and has a density of  $0.00164 \text{ g/cm}^3$ .
- A 10cm x 10cm x 10cm cube has a volume of 1L.

Calculate the mass of one molecule of gas X.

- A.  $1.12 \times 10^{-25} \text{ g}$
- B.  $1.12 \times 10^{-28} \text{ g}$
- C.  $1.51 \times 10^{22} \text{ g}$
- D.  $2.47 \times 10^{-20} \text{ g}$
- E.  $2.47 \times 10^{-23} \text{ g}$
- F.  $6.64 \times 10^{-23} \text{ g}$
- G.  $6.64 \times 10^{-26} \text{ g}$

36.

Carbon dioxide phase diagram



[https://www.engineeringtoolbox.com/CO2-carbon-dioxide-properties-d\\_2017.html](https://www.engineeringtoolbox.com/CO2-carbon-dioxide-properties-d_2017.html)

The figure above is a 'phase diagram' for carbon dioxide. It shows the state or 'phase' of carbon dioxide at any given combination of temperature and pressure. The pink and purple lines indicate the conditions at which CO<sub>2</sub> changes from one state to another.

If we start with CO<sub>2</sub> at 20°C and 1 bara (normal atmospheric conditions), which of the following changes would cause CO<sub>2</sub> to condense into the liquid phase?

- A. Increase the pressure by 30 bara and decrease temperature by 20°C
- B. Keep the pressure the same and decrease the temperature by 100°C.
- C. Increase the pressure by 70 bara and increase the temperature by 5°C
- D. Increase the pressure by 80 bara and decrease the temperature by 80°C

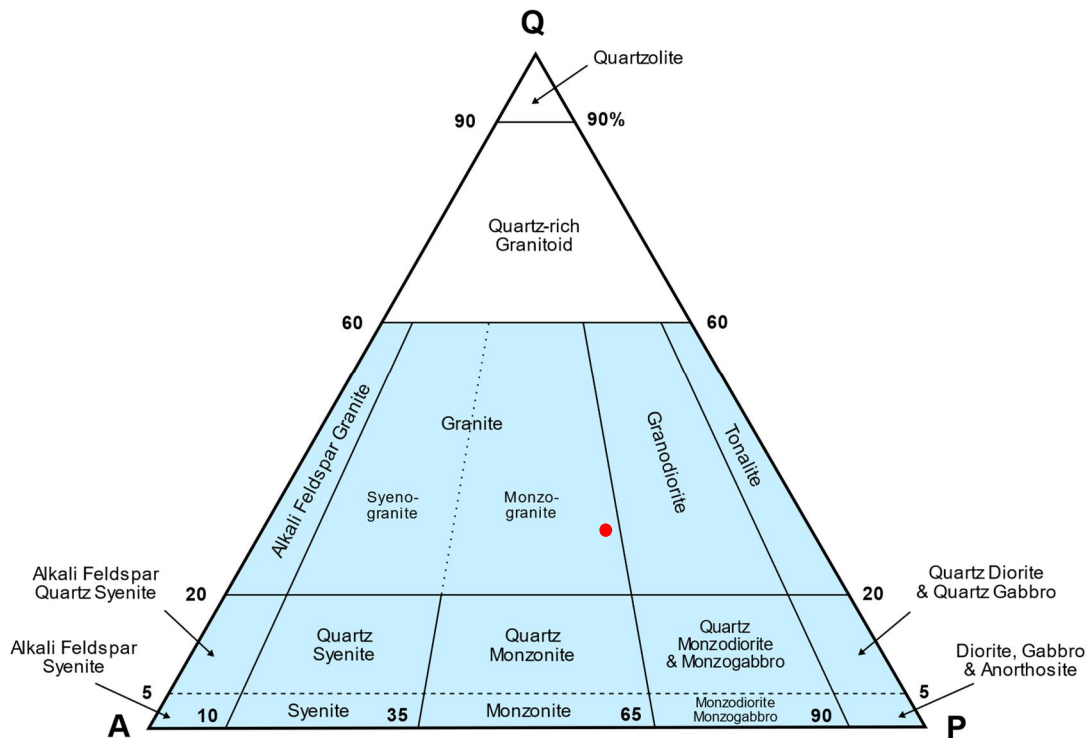
info The mining of metal ores is crucial to our current standard of living. However, mining processes produce unsustainable levels of waste and pollution. Scientists and engineers are examining these processes to find ways to reduce their impact on health and the environment.

37. When the Chang'E lunar soil sample was analysed, it was found to bear a resemblance to Earth soil and contained a mixture of rock types and minerals, including many igneous rocks.

Which of the following are **igneous rocks**? For each, choose 'true' if it is an igneous rock, and 'false' if it is not.

- Granite (true)
- Limestone (false)
- Quartz (false)
- Pumice (true)
- Sandstone (false)
- Obsidian (true)
- Slate (false)

38.



*This question is worth 2 marks (1 mark for each part)*

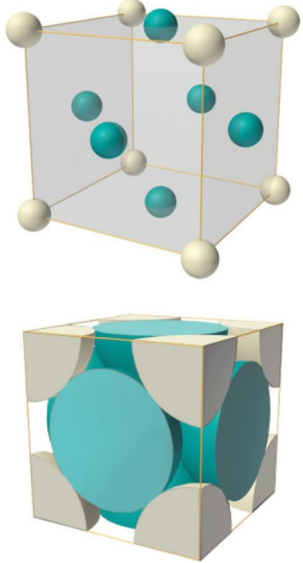
Igneous rocks of certain types can be classified according to their mineral composition using a QAP diagram. The diagram organises rocks based on their content of three key minerals: quartz (Q), alkali feldspar (A) and plagioclase (P). In this diagram, any other minerals present in the rock are ignored, and the Q, A and P content are assumed to add up to 100%.

To read the diagram, read the percent of Q first; the remainder of the rock is then split between A and P. For instance, the red dot indicates monzo-granite, characterised by 30% Q, with the remaining 70% of the rock composed of 60% A and 40% P.

- a) Based on this information, what is the overall percentage of P in the sample of monzo-granite indicated by the red dot?

28%

(continued next page)

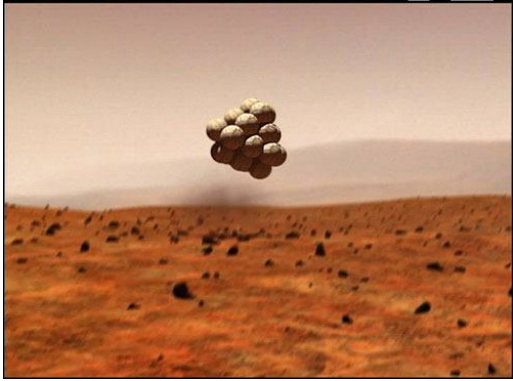
	<p>b) A rock is analysed and is found to have an overall composition of 15% Q, 9% A and 76% P. Identify the rock.</p> <p>A. Alkali feldspar granite  B. Alkali feldspar quartz syenite  <b>C. Quartz syenite</b>  D. Alkali feldspar syenite  E. Syenite</p>
39.	<p>The vast majority of minerals involve oxygen in some form. The most common isotope of oxygen is oxygen-16, but oxygen-17 and oxygen-18 are also stable isotopes.</p> <p>a) How many neutrons are in the nucleus of an oxygen-17 atom?</p> <p>Numerical answer: <b>9</b></p> <p>When it reacts with other elements to form a compound, oxygen often forms the oxide ion: <math>O^{2-}</math></p> <p>b) How many electrons are in an oxide (<math>O^{2-}</math>) ion?</p> <p>Numerical answer: <b>10</b></p>
40.	<p>One of the minerals found in the Chang'E-5 lunar soil sample was chromite. On Earth this is an important source of chromium, which is used in the production of stainless steel, paints, paper and in the processes of electroplating and leather tanning. Unfortunately – as for many mining operations – the by-products of chromite mining and processing have serious environmental and health effects.</p> <p>Iron can form the following ions: <math>Fe^{2+}</math> or <math>Fe^{3+}</math>  Chromium can form the following ions: <math>Cr^{2+}</math>, <math>Cr^{3+}</math>, <math>Cr^{4+}</math>, <math>Cr^{5+}</math> and <math>Cr^{6+}</math>.  Oxygen is always present in minerals as the oxide ion: <math>O^{2-}</math></p> <p>Compounds are neutral substances (i.e. without charge). Given the formula of chromite is <math>FeCr_2O_4</math>, what is the charge on the iron ion and the two chromium ions in chromite? (dropdown selection)</p> <p>The charge on the iron ion is: <b>2+/3+</b>  The charge on each of the chromium ions is: 2+/<b>3+</b>/4+/5+/6+</p>
41.	<p>Copper is widely used in electronics. In copper metal, atoms are arranged with a crystalline geometry known as 'face-centred cubic'. The diagram below shows a representation of the unit cell of copper. The 'unit cell' is the smallest repeating unit in a crystal.</p>  <p>(continued next page)</p>

	<p>The upper diagram shows the arrangement in space of the atoms in a face-centred cubic unit cell. There is an atom at each of the eight corners of the cube (coloured grey), and one in the centre of each of the six faces (coloured green). However, none of the atoms is entirely contained within the unit cell.</p> <p>The lower diagram shows how much of each atom is within the unit cell.</p> <p>What is the total number of copper atoms within one unit cell? Numerical answer: <b>4</b></p>
42.	<p>An atom's nucleus contains 60 neutrons. When it forms an ion with a 2+ charge, it has 44 electrons. What is the correct name and mass number of this atom?</p> <p>A. palladium-60 <b>B. palladium-106</b> C. molybdenum-60 D. molybdenum-106</p>
43.	<p><i>This question is worth 2 marks.</i></p> <p>Like all chemical substances, the properties of minerals are determined by the nature of the atoms or ions that make them up.</p> <p>The size of a single atom or ion is determined by the force of attraction between the negatively charged electrons in that atom and the positively charged nucleus.</p> <p>The stronger this force of attraction is, the more the electrons will be pulled in towards the nucleus, and the smaller the atom will be. A strong force of attraction also means that it requires a lot of energy to remove an electron from an atom.</p> <p>The following relationship can be used to describe the force of attraction between the nucleus of an atom and an electron in the same atom:</p> $F = k \frac{(q_{\text{nucleus}} q_{\text{electron}})}{r^2}$ <p>F is the force of attraction between the nucleus and the electron. k is a constant and has a positive value. <math>q_{\text{nucleus}}</math> is the overall positive charge of the nucleus of the atom (this depends on the number of protons in the nucleus). <math>q_{\text{electron}}</math> is the charge on the electron. Electrons have a charge of -1. r is the distance between the electron and the nucleus.</p> <p><i>Note that a valence electron is an electron in the outermost electron level of an atom.</i></p> <p>Indicate whether each of the following statements is true or false.</p> <ul style="list-style-type: none"> <li>• A greater distance between electron and nucleus would lead to a weaker attractive force between them <b>(true)</b></li> <li>• More protons in the nucleus would pull electrons closer in <b>(true)</b></li> <li>• In an oxygen atom, an electron in the first electron level would feel the same attractive force as an electron in the outermost electron level <b>(false)</b></li> <li>• It is easier to remove a valence electron from a large atom like francium than a small atom like lithium <b>(true)</b></li> <li>• It is easier to remove any electron from a large atom like francium than a small atom like lithium <b>(false)</b></li> </ul>

Extra Q Explain your answer to the last two statements in the previous question.  
*(Question did not contribute to overall mark, but was used to help discriminate between top students for selection into the JSO Spring School).*

44. Looking further afield than the Moon, your generation is likely to be the first to see a human set foot on Mars, and any attempt at living on Mars will have many sustainability challenges to face. So far, humanity's contact with Mars has been through uncrewed missions.

The Opportunity rover landed on Mars in 2004. In the last stage of its descent, the rover/lander module unit was encased in a protective structure of inflated bags. This allowed it to bounce safely upon impact with the surface of the planet.



Which of the following shows the sequence of energy transformations that take place before, during and after an object bounces off the ground? (Assume no friction.)

- A. GPE  $\rightarrow$  KE  $\rightarrow$  elastic potential energy  $\rightarrow$  KE  $\rightarrow$  GPE
- B. KE  $\rightarrow$  elastic potential energy  $\rightarrow$  KE
- C. GPE  $\rightarrow$  KE  $\rightarrow$  chemical potential energy  $\rightarrow$  KE  $\rightarrow$  GPE
- D. Elastic potential energy  $\rightarrow$  KE  $\rightarrow$  thermal energy

45. The total mass of the Opportunity rover and its lander module was 544kg. On Earth, the value of  $g$  (gravitational field strength, or acceleration due to gravity) is  $9.8 \text{ ms}^{-2}$ , while on Mars it is  $3.7 \text{ ms}^{-2}$ .

Which of the following does the mass of an object depend on?

- i. The number of atoms in the object
- ii. The type of atoms in the object
- iii. The gravitational force acting on the object

- A. i only
- B. ii only
- C. iii only
- D. i and ii
- E. i, ii and iii

46.	<p>At the moment that Opportunity hit the surface of Mars, the force that Opportunity exerted on Mars was (greater than/equal to/less than) the force that Mars exerted on Opportunity.</p> <p>The resulting acceleration of Opportunity was (greater than/equal to/less than) the acceleration of Mars.</p>
47.	<p>Encased in its protective bags, Opportunity (with a total mass of 544kg) struck the surface of Mars with a velocity of <math>11.0\text{ms}^{-1}</math>.</p> <p>Assuming 10% of its energy was lost as heat during the bounce, calculate the maximum height it reached when it bounced back up into the air. Assume no friction and give your answer to 1 decimal place.</p> <p><b>Information:</b>  Acceleration due to gravity (gravitational field strength) on Mars = <math>3.7\text{ms}^{-2}</math>  <math>KE = \frac{1}{2}mv^2</math>  <math>GPE = mgh</math></p> <p>Maximum height reached = <math>14.7\text{m}</math></p>
48.	<p>One of the most recent rovers to land on Mars is NASA's Perseverance rover, which reached the red planet on February 18, 2021. Perseverance was carrying a small drone, named Ingenuity – the first drone ever to fly on Mars.</p> <p>Ingenuity is essentially a small helicopter. When its rotors turn, an upwards force (thrust) is applied to the helicopter. The magnitude of this force can be calculated with the following equation:</p> $F = \frac{\rho X v^2}{2}$ <p>In this equation:  <math>\rho</math> = the density of the air in which the helicopter is flying, measured in <math>\frac{\text{kg}}{\text{m}^3}</math>  <math>v</math> = the speed of the air pushed down by the rotors, measured in <math>\frac{\text{m}}{\text{s}}</math>  Although force is usually measured in Newtons, its units can also be represented as <math>\frac{\text{kgm}}{\text{s}^2}</math>.</p> <p><math>X</math> represents another relevant variable. What are the units of <math>X</math> in this equation?</p> <p>A. <math>\frac{\text{kg}}{\text{ms}^2}</math>  B. <math>\frac{\text{kgm}}{\text{s}^2}</math>  C. <math>\frac{\text{s}^2}{\text{kgm}}</math>  D. <math>\frac{1}{\text{m}^2}</math>  E. <math>\text{m}^2</math>  F. <math>\text{m}</math></p>
Extra Q	<p>Propose what <math>X</math> could represent in relation to the helicopter.</p> <p><i>(Question did not contribute to overall mark, but was used to help discriminate between top students for selection into the JSO Spring School).</i></p>

49.	<p>In its first flight, Ingenuity rose vertically upwards from the surface of Mars, first accelerating to a height of 1.5m, then decelerating until it reached a height of 3m, where it hovered. Its rotors were continuously spinning during the ascent.</p> <p>Which of the following describes the forces acting on Ingenuity during this ascent?</p> <p>A. The upwards thrust force and downwards force of gravity are constant throughout.</p> <p>B. The upwards thrust force must be greater than the downwards force of gravity throughout, to allow Ingenuity to move upwards.</p> <p>C. Only the constant downward force of gravity is acting on Ingenuity.</p> <p>D. The upwards thrust force is first greater than and then less than the downwards force of gravity during Ingenuity's climb.</p>
50.	<p>After climbing to a height of 3m, Ingenuity then hovered, unmoving in the air, for 30 seconds. Calculate the thrust force provided by its rotors during this hover.</p> <p><b>Information:</b> Mass of ingenuity: 1.8kg Acceleration due to gravity (gravitational field strength) on Mars = <math>3.7 \text{ ms}^{-2}</math> <math>W = mg</math></p> <p>Numerical answer: 6.7 N</p>