JSO Exam 2023 ANSWERS

Theme: dimensions

Each question is worth 1 mark unless otherwise specified.
In sets of true/false statements, each statement is worth an equal fraction of the overall question mark.
Time allowed: 2 hours
Total number of questions = 48
Total number of marks = 63

The three questions with a blue background are optional. They ask for written explanations of previous questions. They do not contribute to a student's overall mark, but may be used to discriminate between students for the purposes of selection for the Junior Science Olympiad Spring School.

	The word 'dimension' derives from a Latin word meaning 'a measurement'. Over many centuries this has broadened to include a variety of meanings, including the size or extent of something ('the dimensions of the seat are just right'), or any component of a situation ('this is a multi-dimensional problem!'). In mathematics and physics, the number of coordinates needed to specify a point is known as its dimension, from which we get the idea of the dimensions of space, or space-time. More broadly in science, the variables involved in an experiment can be thought of as its dimensions – both independent variables that represent the input to the system, and dependent variables that represent its outcome.

1. *This question is worth 2 marks.*

A dimension can be thought of as a type of measurement. But when we measure something, we must state the units in which it is measured, otherwise the value of the measurement has no meaning.

From the list below, select an appropriate unit for each of these dimensions:

a) Mass kg
b) Weight N
c) Acceleration m/s^2
d) Volume m^3
e) Frequency Hz

metre, square metre, cubic metre, Newton, kilogram, Kelvin, Hertz, Volt, Watt, metres per second, metres per second squared.

2. Mass, length and time are frequently used dimensions. They can be represented as M, L and T.

Noting that distance is a kind of length, we can determine the dimension of **speed** to be $\frac{L}{T}$ by looking at the way speed is calculated:

$$speed = \frac{distance}{time} = \frac{L}{T}$$

The dimension of force can be represented as $\frac{ML}{T^2}$ where M = mass.
If:

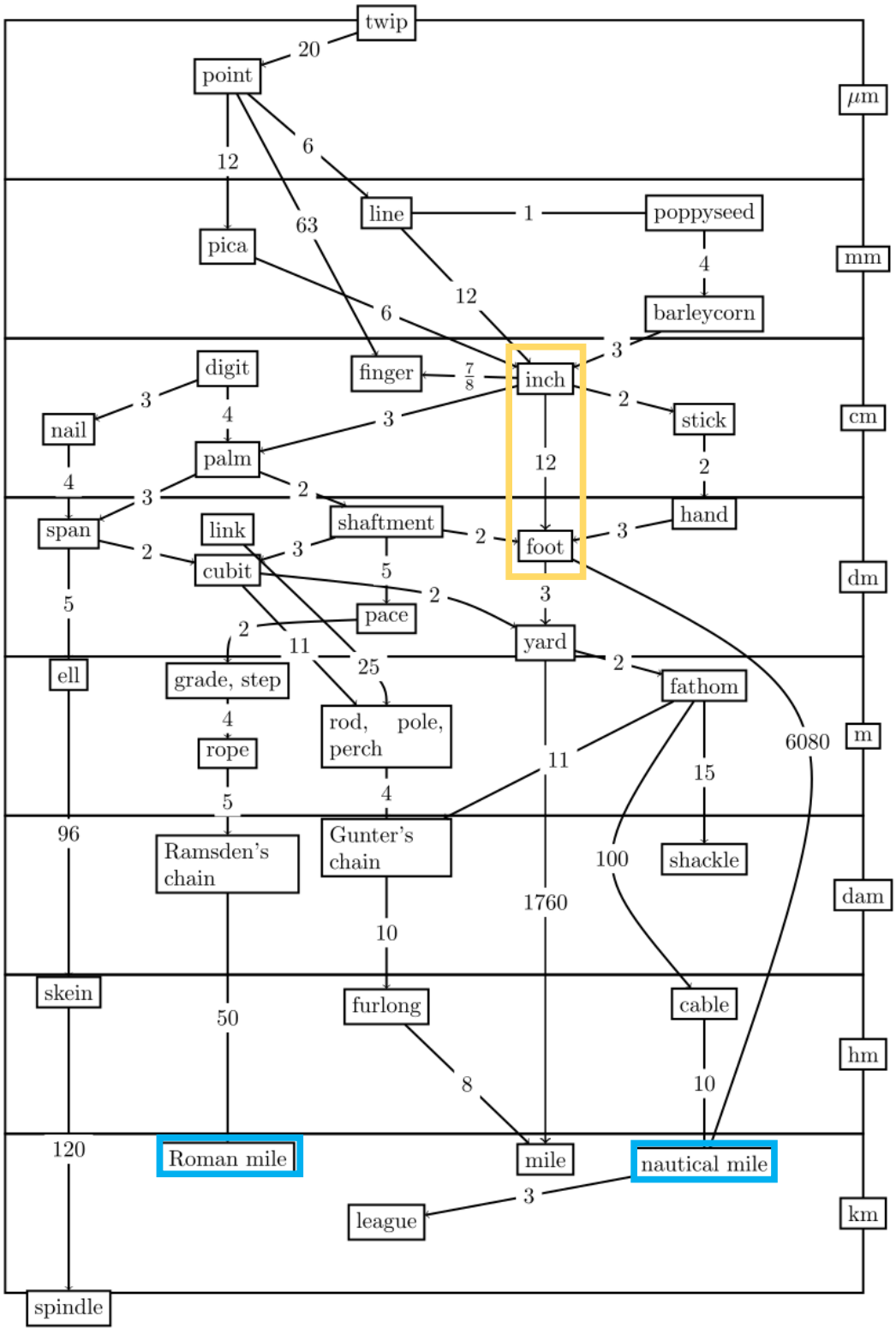
$$energy = force \times distance$$

...which of the following represents the dimension of energy?

A. $\frac{ML}{T^2}$
B. $\frac{ML^2}{T^2}$
C. $\frac{M}{T^2}$
D. $\frac{L^2}{T^2}$

3. The following diagram summarises the conversions between various units of length, most of which are no longer used. The number between each pair of units tells you the conversion factor between them, with the larger units being placed lower on the chart.

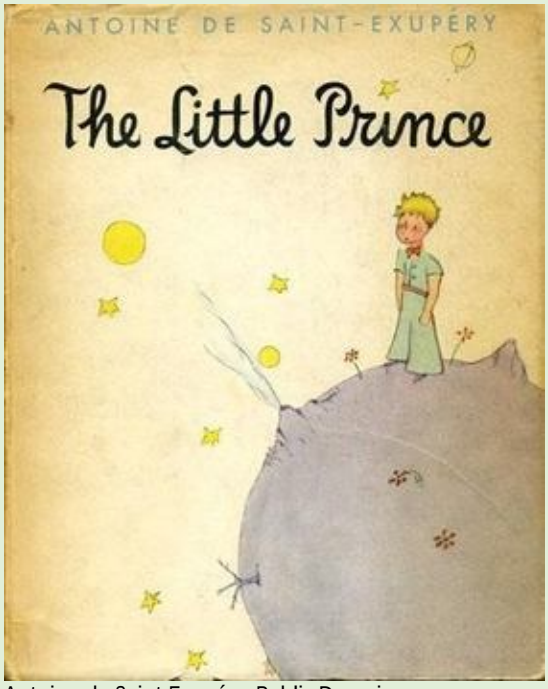
For example (highlighted in yellow), 1 foot is equal to 12 inches (or equivalently, 1 inch equals 1/12 of a foot).



42CrMo4, Christoph Päper, CC BY-SA 4.0 via Wikimedia Commons

How many nautical miles are there to 1 Roman mile (both highlighted in blue)? Provide your answer to two decimal places. 0.82.

4.	In physics, vectors are quantities for which we specify both a magnitude and a direction. Velocity and acceleration are both vectors. A cyclist is out for a ride on the beautiful bike paths of Canberra. For each of the following situations, select 'true' if the bicycle is accelerating and 'false' if it is not. The bicycle: a) Slows down: true/false. b) Turns a corner: true/false. c) Starts moving: true/false. d) Travels at constant 5 m/s: true/false.
5.	We use measurements in science to describe the properties of a substance. Properties can be divided into intensive and extensive properties. A property of a substance is intensive if it does not depend on the size of the sample. Density is an intensive property, for example: the density of copper is the same whether you have a small piece of thin copper wire, or a large copper pipe. Extensive properties are those that depend on the size of the sample. Mass is an extensive property: the mass of the small piece of thin copper wire is less than that of the large copper pipe. Label each of the following properties as intensive or extensive. a) Concentration: extensive/intensive b) Temperature: extensive/intensive c) Weight: extensive/intensive
6.	*This question is worth 2 marks.* When making measurements, it is important to understand how accurately you are making the measurement, and what the uncertainty might be in your measured value. Significant figures are often used as a way of representing how accurate a measurement is. Sam and Alex each have a bucket into which they have measured some water. Each writes the volume she has measured on a whiteboard. Sam reports that her bucket contains 10L of water, while Alex reports that hers contains 10.0L of water. Select true/false for each of the following questions: a) Both buckets must contain the same mass of water: true/false. b) Sam's bucket is most likely to contain more water than Alex's bucket: true/false. c) It is possible that Sam's bucket contains 9.45L of water: true/false. d) It is possible that Alex's bucket contains 9.45L of water: true/false. e) If 100mL of water (measured using a 100mL measuring cylinder) was added to both buckets, Alex would change the value written on her board, while Sam would not: true/false.

	Outside the world of science, the idea of dimensions also exists in stories. The plot, characters, settings, style and theme of a story are known as its literary dimensions. **The Little Prince** is a short novel written by Antoine de Saint-Exupéry and published in 1943. It is the second-most translated book in history. The theme of the book relates to curiosity and open-mindedness. The narrator of the story is a pilot stranded in the desert, who meets a small, rather otherworldly boy with golden hair – the Little Prince. The prince normally lives on a tiny asteroid, B612. He is always curious and keeps asking questions until they are answered.  Antoine de Saint-Exupéry, Public Domain.
7.	On his asteroid, the little prince has three volcanoes – two active and one extinct. This is a bit of poetic licence on the part of the author, since such a tiny asteroid would be unlikely to have molten rock inside it! Select true or false for each of the following. On Earth, volcanoes form: a) In subduction zones: true/false. b) Along transform faults: true/false. c) In continental-continental collision zones: true/false. d) Over hotspots: true/false.

8. On his asteroid, the Little Prince takes care of a rose plant. The prince encloses the rose in a glass jar to protect it from wind and weather.

User:Carisma3geni, CC BY-SA 3.0, via Wikimedia Commons Antoine de Saint-Exupéry, Public Domain.

Back here on Earth, it has been shown that some plants can survive for many years in a sealed terrarium (see picture above). Apart from one or more plants, such a terrarium must contain water, air and healthy soil (including soil organisms such as bacteria and fungi). The terrarium need never be opened, and nothing needs to be added to or removed from it.

The chemical equations for photosynthesis and respiration are as follows:

Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

In order for a sealed terrarium to remain sustainable, which of the following must be true?

A. The plant's rate of photosynthesis must be greater than or equal to the plant's rate of respiration at all times.
B. As long as the plant is able to perform some photosynthesis, the ecosystem will remain sustainable.
C. The plant's average rate of photosynthesis must be greater than the plant's rate of respiration.
D. The plant's average rates of photosynthesis and respiration must be equal over long periods of time.

9. *This question is worth 2 marks.*

Plants have small openings in their leaves called stomata (singular: 'stoma') that can open and close to regulate the flow of gases into and out of the leaves. Stomata open in the light and close in the dark.

Under each stoma is a space called the sub-stomatal cavity (Figure 1). Scientists can use tiny probes to measure the concentration of gases inside the sub-stomatal cavity.

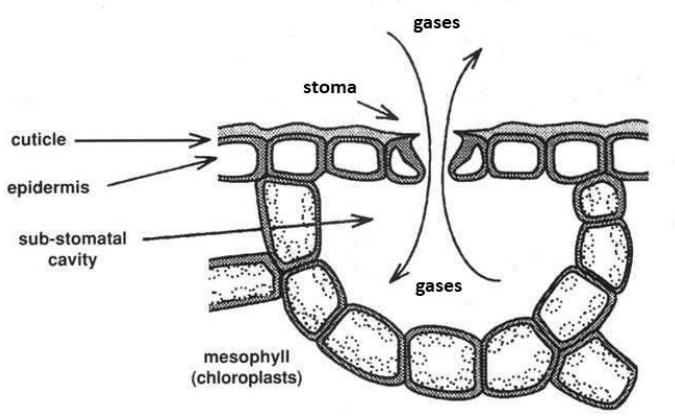


Figure 1: cross-section of a leaf showing a stoma and sub-stomatal cavity.
Adapted from https://www.fao.org/3/w5183e/w5183e07.htm

The graph below shows how the concentration of carbon dioxide in the sub-stomatal cavity varies under different light conditions. The concentration of CO_2 in the surrounding air is around 410 ppm.

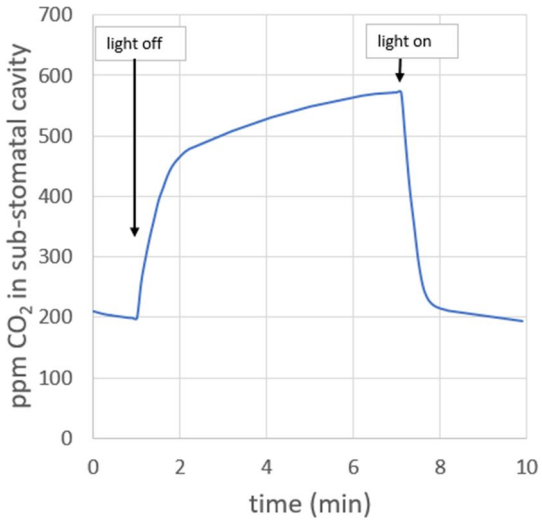


Figure 2: concentration of CO2 in sub-stomatal cavity over time under different light conditions.
Based on data from Hanstein et al, Sensors and Actuators B: Chemical, 81(1), 2001, pp107-114.

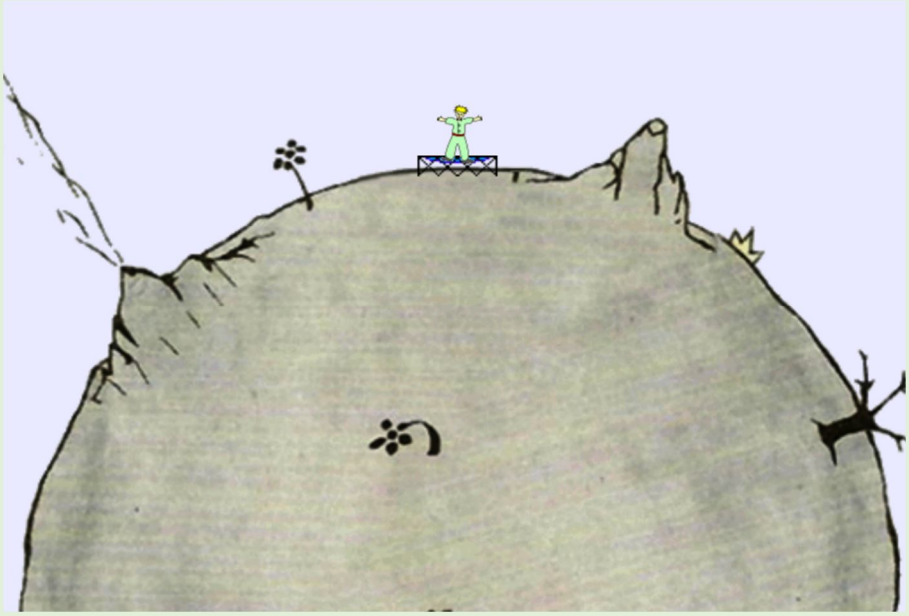
Which of the following can be inferred from the data above?

A. Water loss from transpiration is reduced by stomata closing in the dark.
B. Plants only produce carbon dioxide in the dark.
C. Carbon dioxide diffuses faster through open stomata in the light than through open stomata in the dark.
D. The respiration rate of plants increases in the dark.
E. Plants respire in the dark.

9A *Optional: explain your answer to the question above.*

Imagine that the Little Prince, on his asteroid, is bouncing on a trampoline.

Questions 10-14 all refer to this situation, but the questions do not depend on one another and can be answered separately.



Adapted from "Little Prince's Trampoline" java simulation: https://javalab.org/en/little_princes_trampoline_en/

10. Newton's 3rd law is often stated as "*for any action there is an equal and opposite reaction*". Another way to state Newton's 3rd law is:

Forces come in pairs that:

- *Are equal in size*
- *Opposite in direction*
- *Act on different objects*

Imagine the Little Prince, on his asteroid, bouncing on a trampoline. When the prince is at the lowest point in his jump, the stretched surface of the trampoline is pushing upwards on him.

If the force the trampoline exerts upwards on the prince is the "action" force, what would the "reaction" force be, according to Newton's 3rd law?

A. The weight force that acts downwards on the prince due to gravity
B. The force the prince exerts downwards on the trampoline
C. The force exerted upwards by the prince on the asteroid due to gravity
D. The force the trampoline exerts downwards on the asteroid

11. Consider again the Little Prince bouncing on the trampoline.

In the table below, choose the row which correctly represents the direction of the net force (the sum of all the forces acting) on the prince at the following three points.

Assume in all three cases that he is **in the air** (not in contact with the trampoline).

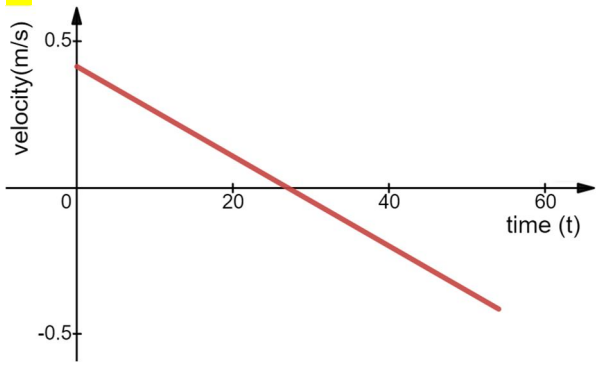
i. when he is moving upwards before reaching the top of his jump
ii. when he is at the top of his jump
iii. when he is moving downwards, after reaching the top of his jump

	1. Moving upwards	**2. At the top**	**3. Moving downwards**
Row A	↑	zero	↓
Row B	↑	↑	↑
Row C	↓	zero	↓
Row D	↓	↓	↓

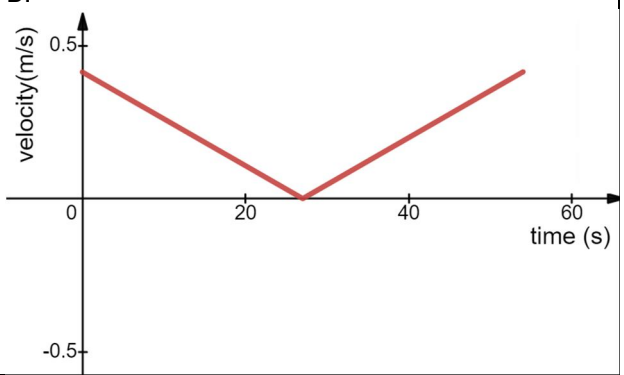
12. As the prince bounces up and down on his trampoline, his velocity (speed with direction) is changing.

Which of the following graphs could represent his velocity for the time period between leaving the trampoline surface and landing again?

A.



B.



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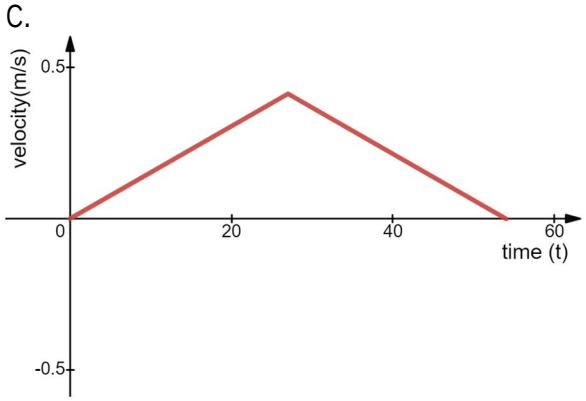
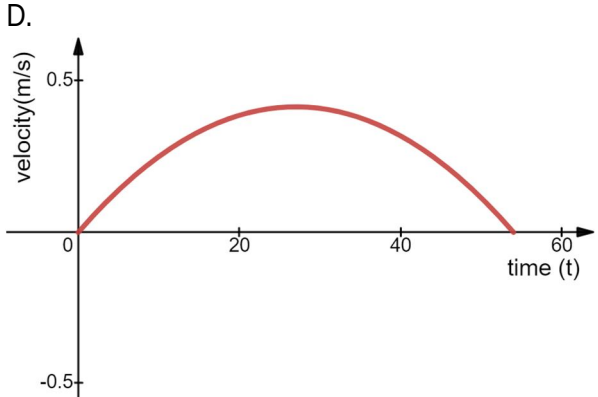


D.



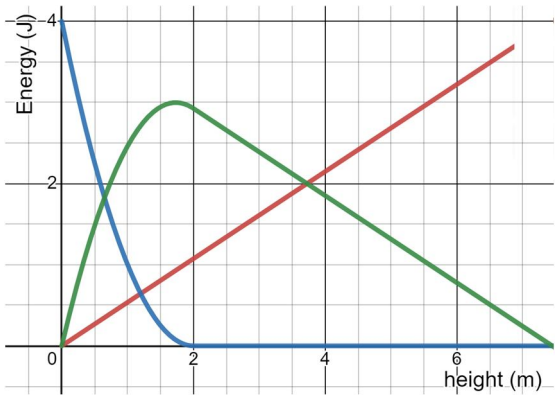
13. *This question is worth 2 marks.*

The prince's trampoline has the property that the elastic potential energy stored in the stretched surface is completely converted to kinetic and gravitational potential energy as he moves upward from the very lowest position to the highest position. In other words, no energy is transformed to other forms such as thermal energy during the jump.

The prince-trampoline-asteroid system therefore contains three types of energy: elastic potential energy, kinetic energy and gravitational potential energy.

Which of the following graphs could correctly represent how all three types of energy vary with height, from the lowest point in the prince's jump (when the trampoline is stretched) to the highest point in his jump?

A.



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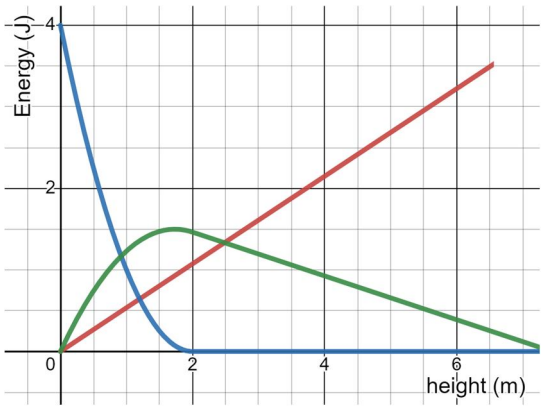
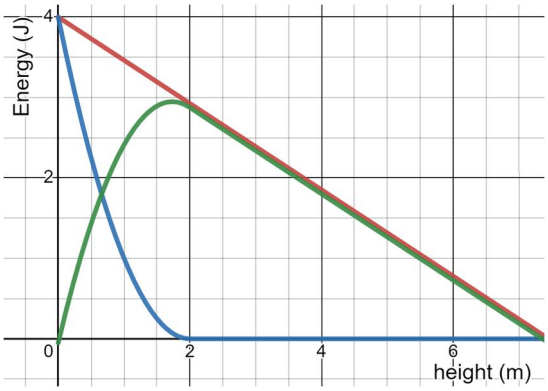
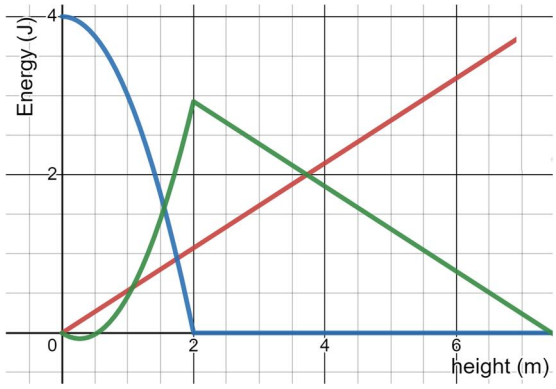


C.



D.



13A *Optional: Justify your answer, including which coloured line represents which type of energy in the system.*

14. *This question is worth 2 marks.*

The gravitational force (weight) that the prince experiences on his asteroid is proportional to the mass of the asteroid, M, and inversely proportional to the square of his distance from the centre, r.

$$F \propto \frac{M}{r^2}$$

If the prince moved to a different spherical asteroid with radius 3r, but with the same density as the original asteroid, how would his weight on the surface of the new asteroid (F_{new}) compare to his weight on the surface of the original asteroid (F_{orig})?

$Volume\ of\ a\ sphere\ = \frac{4}{3}\pi r^3$

$Density\ = \frac{mass}{volume}$

A. $F_{new} = 3F_{orig}$

B. $F_{new} = \frac{F_{orig}}{3}$

C. $F_{new} = \frac{F_{orig}}{9}$

D. $F_{new} = 9F_{orig}$

As we've already mentioned, length is a dimension.

When we combine two length dimensions, we get area (L^2), which we can think of as a plane, or two-dimensional space. Note that just because we represent area with the dimension L^2 (or with units of m^2, cm^2 etc.) doesn't mean the area itself has to be square!

When we combine three length dimensions, we get volume (L^3) or three-dimensional space.

15. Puff balls are a kind of fungus that grows a roughly spherical fruiting body. A number of species exist, some of which grow very large.

D003232, CC BY-SA 4.0 via Wikimedia Commons

In a letter sent to the scientific journal Nature in 1900, W. A. Sanford of Somerset described how his daughter had found a very large puffball with the following measurements:

- Horizontal circumference: 57 inches
- Vertical circumference (greatest): 51 inches
- Vertical circumference (smallest): 46 inches
- Weight: 14 lb 10 oz

From this data, we can estimate a range for the volume of the puffball, with a lower and an upper estimate that represent the smallest and largest volumes it could possibly be.

Mushrooms usually float in water. If we wish to calculate whether the puffball would float in water, we would need to calculate its density. Which volume estimate would it be most sensible to use to determine whether it would have floated?

A. The upper estimate, because this would give the lowest possible density of the puff ball.
B. The lower estimate, because this would give the lowest possible density of the puff ball.
C. The upper estimate, because this would give the highest possible density of the puff ball.
D. The lower estimate, because this would give the highest possible density of the puff ball.

16. *This question is worth 2 marks.*

Fungi are a large group of organisms, generally classed as a kingdom. They have features in common with plants and animals, but are distinct from both.

For each of the fungus characteristics below, state whether it is also a general characteristic of organisms of the plant and animal kingdoms.

Fungus characteristic	**Characteristic of animals?**	**Characteristic of plants?**
Is eukaryotic	Yes/no	Yes/no
Is heterotrophic	Yes/no	Yes/no
Has a cell wall	Yes/no	Yes/no
Undergoes mitosis	Yes/no	Yes/no

17. Molecules exist in three-dimensional space. How many *different* molecules could you make if you had two nitrogen atoms and four hydrogen atoms?

You do not have to use all the atoms every time, but your molecules must obey the following rules:

- each nitrogen atom must form exactly three bonds
- each hydrogen atom must form exactly 1 bond
- it is possible for one atom to form more than one bond to another atom.

Numerical answer: 5 (N_2, H_2, NH_3, N_2H_2, N_2H_4)

18. The three most common states of matter on Earth are solid, liquid and gas.

A student has summarised some properties of solids, liquids and gases in the table below. Select the row of the table that has an error in it.

Properties of the solid, liquid and gas phases of a substance.

	Solid	Liquid	Gas
A.	Holds its shape	Fills the bottom of its container	Expands to fill its container entirely
B.	Is affected by gravity	Is affected by gravity	Is not affected by gravity
C.	Particles have lowest kinetic energy	Particles have medium kinetic energy	Particles have highest kinetic energy
D.	Is not a fluid	Is a fluid	Is a fluid

19. Ionic compounds are made from ions of opposite charges, which – in their solid state - fit together in a three-dimensional lattice.

An ionic substance used in catalytic converters in cars has the formula Rh_2O_3.
What is the charge on the rhodium ions in this compound?

Select one: -3,-2,-1, 0, +1, +2, +3

20. *This question is worth 2 marks.*

A characteristic property of a liquid is its **vapour pressure**. If a liquid has a high vapour pressure, it means that it is easy for molecules to escape from the surface of the liquid phase into the gas phase, and that a high concentration of the gas will form in the air above the liquid.

The rate at which molecules evaporate from the surface of a liquid depends on how much energy is needed for a molecule to break free from the attractive forces of its fellow molecules in the liquid phase. Molecules with greater kinetic energy are more likely to break free.

It also depends on how likely it is that a molecule will find itself at the surface of the liquid.

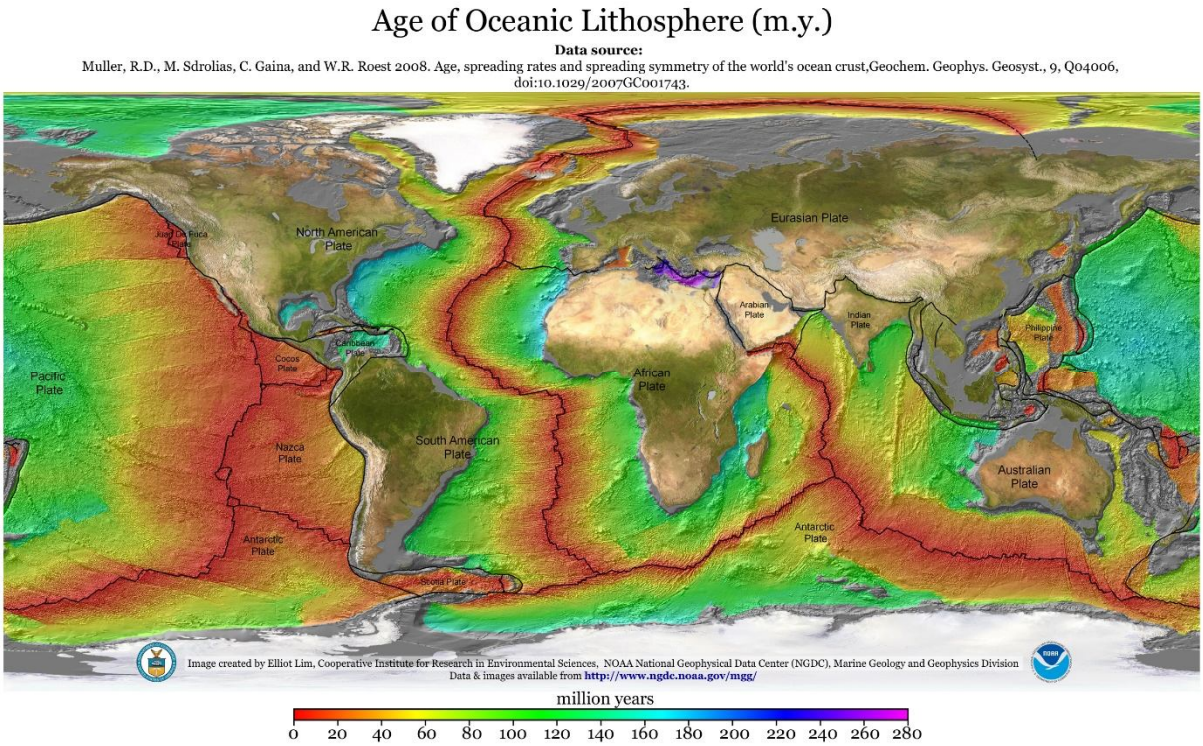
The boiling point of any liquid is the temperature at which its vapour pressure equals the surrounding air pressure.

Based on this information, select true/false for the following statements.

a) The greater the strength of the attractive forces between molecules in the liquid phase, the greater the vapour pressure of the liquid: true/false.
b) The vapour pressure of a liquid increases with temperature: true/false.
c) A flask containing a liquid is attached to a vacuum pump. When the pump is turned on, it reduces the pressure inside the container and the liquid boils at a lower temperature than before: true/false.
d) In a sample of a liquid at a constant temperature, all molecules have the same kinetic energy: true/false.
e) The rate of evaporation depends on the surface area of the liquid: true/false.

	The relationship between the **surface area** and the **volume** of an object is known as its surface-area-to-volume ratio. An object that has a large surface area but a small volume has a high surface-area-to-volume ratio.
21.	Of the following animals, which would have the highest surface-area-to-volume ratio? A. Shark B. Guinea pig C. Snake D. Bear
22.	In which of the following biological structures does the primary function NOT rely on a high surface-area-to-volume ratio? A. Villi in the intestines B. Alveoli in the lungs C. Exoskeletons in insects D. Leaves on plants E. Root hairs on plants
	This information relates to the following three questions. Thermal regulation in animals is directly affected by an animal's surface-area-to-volume ratio. The heat flow in or out of an animal can be modelled using this equation: $$rate\ of\ heat\ transfer = kA\frac{(T_1 - T_2)}{d}$$ The variables in this equation are as follows: $rate\ of\ heat\ transfer$: the speed at which heat energy is flowing into or out of the animal (measured in J s^{-1}). A: the surface area of the animal (measured in m^2). d: the thickness of the outer layer of the animal (skin/fur/fat/shell etc.) through which heat is transferred (measured in m). k: thermal conductivity of the outer layer of the animal (measured in J $s^{-1}m^{-1}\,{}^oC^{-1}$). The thermal conductivity of a material (always a positive number) reflects how easily heat is conducted through it. For instance, copper has k = 398 J $s^{-1}m^{-1}\,{}^oC^{-1}$, while air has k = 0.024 J $s^{-1}m^{-1}\,{}^oC^{-1}$. T_1 = external temperature (the temperature outside the animal, measured in ^oC). T_2 = internal temperature (the temperature inside the animal, measured in ^oC).

23.	Assume that the rate of heat transfer in the equation above has a **negative value** for an animal in a certain environment. Select options in the following sentence to make it a correct description of what is occurring. The external temperature is higher/lower than the animal's internal temperature, which causes heat to flow into/out of the animal's body.
24.	Organisms use a variety of adaptations to regulate heat flow. Thinking of the heat flow equation above, state whether each of the following adaptations has the appropriate effect on heat flow because of: • an increase in the value of A • a decrease in A, or • because of something other than a change in A. a) Elephants wallow in mud when it is hot: increase in A; decrease in A; something other than A b) Dormice curl up when they hibernate: increase in A; decrease in A; something other than A
25.	Thinking of the heat flow equation above, state whether each of the following adaptations has the appropriate effect on heat flow because of: • an increase in the value of k • a decrease in k, or • because of something other than a change in k. a) The indigenous people of Tasmania (the Palawa) smeared their bodies with seal fat in the winter: increase in k; decrease in k; something other than k b) Humans sweat in hot weather: increase in k; decrease in k; something other than k
25 A	*Optional: explain in greater detail how sweating regulates heat flow in a human.*
26.	Endothermic (warm-blooded) animals use the excess heat energy produced by the metabolism of sugars and fats to keep their body temperature stable. While the metabolic process is complicated and involves many steps, the overall effect is the same as if the fuel underwent combustion. Octanoic acid ($C_8H_{16}O_2$) is a common fatty acid found in coconut milk and goat's milk. Balance the chemical equation for the complete combustion of octanoic acid. $1\ C_8H_{16}O_2 + 11\ O_2 \rightarrow 8\ CO_2 + 8\ H_2O$

	If the dimensions of space are thought of as the first three dimensions, time can be thought of as the fourth dimension. We make many measurements that are based on time, such as speed (distance travelled per unit time), chemical reaction velocity (amount of chemical reacted per unit time) and frequency (number of occurrences of something per unit time).
27.	 https://upload.wikimedia.org/wikipedia/commons/e/e7/2008_age_of_oceans_plates.jpg Ocien was big, Public Domain, via Wikimedia Commons *(Note: in the online version of this exam, a full-size copy of this image was provided. This image can be accessed through the link above.)* The lithosphere of the Earth is the rigid, outermost rocky part of the planet, and is divided into a series of moving plates, known as tectonic plates. In the diagram above, the boundaries between these plates are shown as black lines. The colour coding in the diagram indicates the age (in millions of years) of the lithosphere that lies under the ocean. Based on the age data, which of the following plates is moving the fastest? A. The Pacific plate B. The African plate C. The North American plate D. The Australian plate
28.	According to the diagram above, in which direction is the Pacific plate moving? A. Northwards B. Southwards C. Eastwards D. Westwards

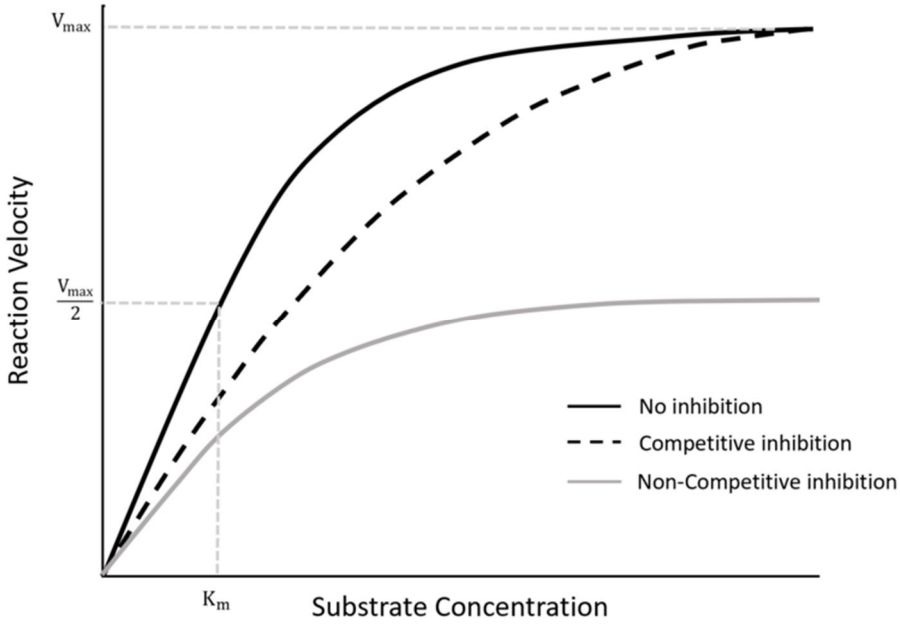
29. *This question is worth 2 marks.*

Speed is important in chemical and biochemical reactions.

A catalyst is any substance that causes a chemical reaction to go faster, without being used up in the reaction. In biology, most chemical reactions would not proceed fast enough to sustain life without the catalysts known as enzymes.

In biochemical reactions, the reactant is called a 'substrate'. The graph below shows the relationship between the reaction 'velocity' (how fast the biochemical reaction is going) and the concentration of the substrate. The concentration of the enzyme catalyst is assumed to be constant.

Competitive and non-competitive inhibition are two ways in which the functioning of the enzyme catalyst can be affected.



Hansehan, CC BY-SA 4.0 via Wikimedia Commons

Based on the graph, choose true or false for each of the following statements:

a) The reaction velocity starts off fast, but gradually slows down as substrate concentration increases: true/false.
b) The effect of competitive inhibition decreases as substrate concentration increases: true/false.
c) Non-competitive inhibition halves the final amount of product: true/false.
d) When reaction velocity reaches V_{max}, the reaction is finished: true/false.

Alongside dimensions such as length, mass and time, it is often useful to measure *numbers* of things. This is particularly important in biological systems, in which the number of 'entities' present may be of great interest. Examples of biological entities could include individual animals in a flock, different species in an ecosystem, or cells in an organ.

This type of dimension – a number of things – can also be referred to as a population, and we can represent it by the symbol N.

However, a number by itself is not very interesting. Usually, biologists want to measure a number in comparison to something else; for instance, how a number is changing over time, or how many things exist within a certain area or volume.

30. *This question is worth 2 marks.*

Four measurements are described below. From the list of dimensions below the table, select the most appropriate dimension for each measurement. Two examples are given.

Example 1: number of plants per metre in rows in a farmer's paddock (units could be *plants per metre*)	$\frac{N}{length}$
Example 2: spacing of plants in a row in farmer's paddock (units could be *metres per plant*)	$\frac{length}{N}$
a) Concentration of individual protein molecules in cell cytoplasm	$\frac{N}{length^3}$
b) Territory occupied by each eagle pair in a population	$\frac{length^2}{N}$
c) Water filtered daily by each baleen whale in a pod	$\frac{length^3}{N \times time}$
d) Rate at which virus particles pass through mask material.	$\frac{N}{time \times length^2}$

$\frac{N}{time}$

$\frac{N}{length^2}$

$\frac{N}{length^3}$

$\frac{length^2}{N}$

$\frac{length^3}{N}$

$\frac{length^3}{N \times time}$

$\frac{N}{time \times length^2}$

$\frac{N \times time}{length^2}$

31. *This question is worth 2 marks.*

On the day this question was being written, Canberra had a very rainy day, with the weather stations recording 37mm of rain falling in the 24-hour period.

Using the following information, calculate the total *number* of raindrops that fell in the Canberra area during this period.

- The area of Canberra is 814km^2.
- Assume that the average raindrop is a sphere with a **diameter** of 2 mm.
- Assume that the 37mm of rain was distributed evenly over Canberra (i.e. enough rain fell to create a puddle with a depth of 37mm over the whole of Canberra).
- $Volume\ of\ a\ sphere\ = \frac{4}{3}\pi r^3$

Your answer will be in scientific notation. Use the boxes below to enter the relevant numbers.

a) Enter your answer in scientific notation to three decimal places: 7.190 x 10^{15}

b) Now give your answer to the correct number of significant figures: 7 x 10^{15}

Chemists also need to compare numbers of things, specifically atoms and molecules. A specific number has been defined to help with this.

A **mole** refers to 6.022 x 10^{23} things, and it is used in the same way that we use a 'dozen' (12 things) or a 'gross' (144 things). However, such a large number as a 'mole' is only useful for measuring things that come in huge quantities, like atoms and molecules.
(That's where the odd name for this unit comes from: it is a shortening of the word 'molecule'.)

32. 1 mole of water molecules (6.022 x 10^{23} water molecules) occupies a total volume of 18cm^3. Which of the following options best represents the number of water molecules in a single raindrop of average dimensions?

A. 1.4 x 10^{20}
B. 1.4 x 10^{23}
C. 7.1 x 10^{-21}
D. 2.3 x 10^{-4}
E. 2.3 x 10^{-2}

Movies use two of our senses: sight and sound.

In the 1950s, two companies called Smell-O-Vision and Aromarama attempted to add an extra dimension to the experience of a movie by installing units under movie theatre seats that would release odours at relevant points during the movie. Sadly, this did not take off!

33. What is the name of the process by which odour molecules are transported through the air to the nose?

A. Diffusion
B. Concentration
C. Osmosis
D. Evaporation

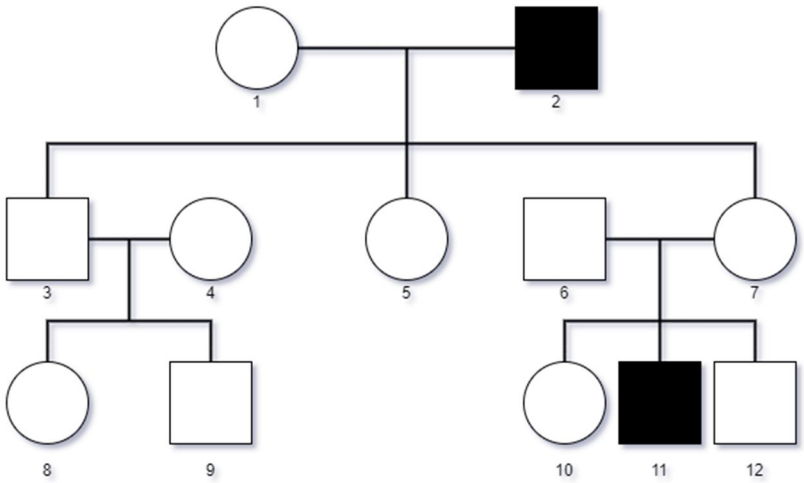
34.	Which of the following body systems is responsible for the detection of smells? A. The central nervous system B. The peripheral nervous system C. The endocrine system D. The digestion system E. The respiratory system
35.	The receptor cells that allow us to detect smell and taste rely on chemoreceptor molecules that are genetically encoded. The storage of genetic information in cells involves a variety of structures at different scales. An analogy sometimes used to explain the various genetic structures in cells is a book, which is made up of chapters, sentences, words and letters. For each of the following, circle the part of a book that represents the best analogy for the genetic structure. a) Genome: book, chapter, sentence, word, letter b) Gene: book, chapter, sentence, word, letter c) Nucleotide: book, chapter, sentence, word, letter d) Chromosome: book, chapter, sentence, word, letter

36. One human chemoreceptor gives the ability to taste a bitter chemical called PTC. This chemoreceptor is encoded by a single gene that has two common alleles. The dominant allele (B) produces a chemoreceptor that detects PTC and gives the sensation of a bitter taste; the recessive allele (b) produces a chemoreceptor that cannot detect PTC. Heterozygous individuals can detect PTC to a moderate extent.

The following pedigree tree shows the inheritance pattern of bitter-taste perception in a family.

● ■ *Female, male, who cannot experience bitter tastes.*

○ □ *Female, male, who can experience bitter tastes.*



Based on the information in the pedigree tree, consider all the statements in the table and then select the column containing the correct set of responses.

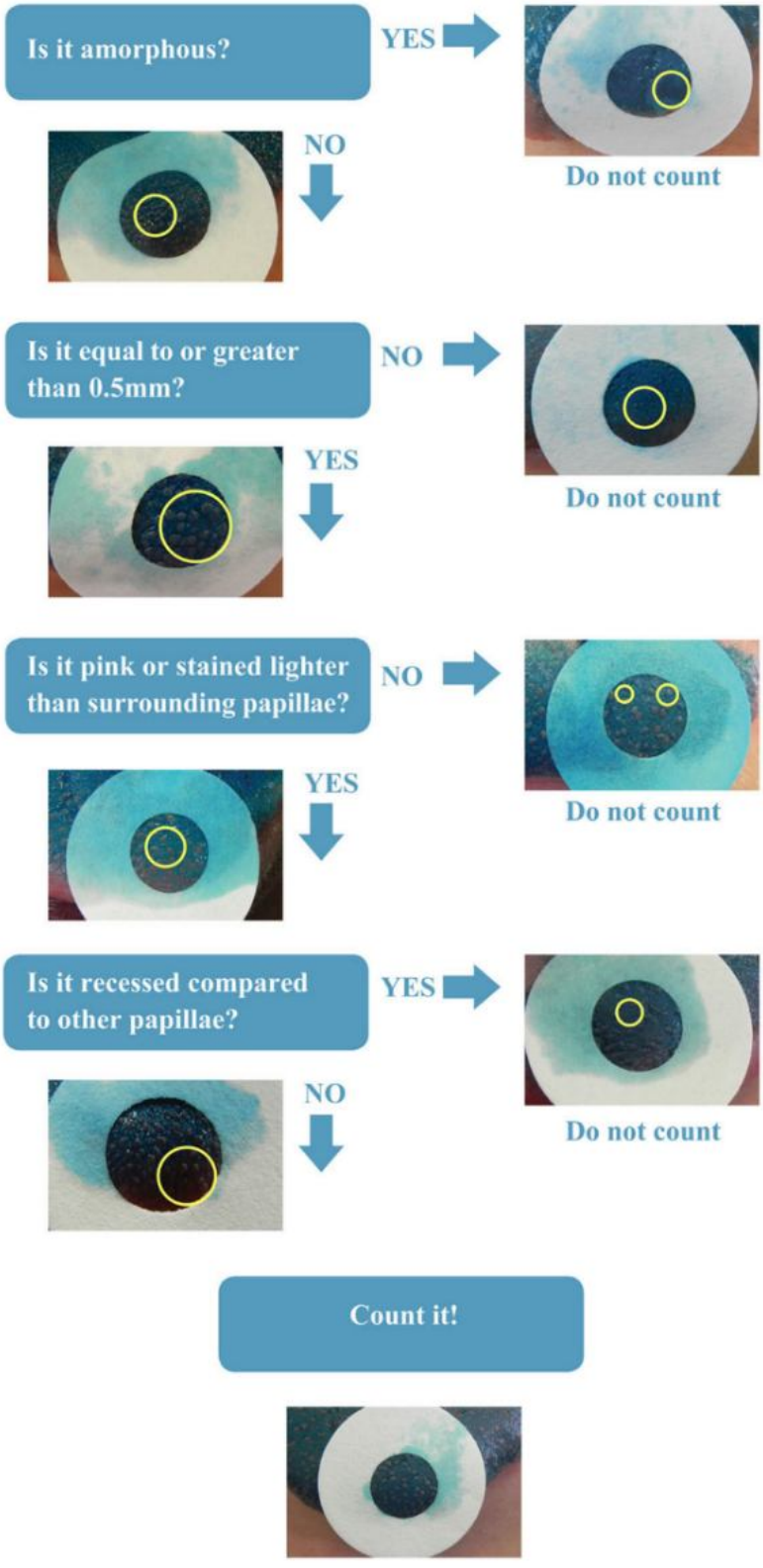
	A	B	C	D
Individual 1 experiences bitter tastes intensely.	Cannot be confirmed	False	True	Cannot be confirmed
Individuals 6 and 7 are both heterozygous	True	Cannot be confirmed	Cannot be confirmed	True
Individuals 10 and 12 experience PTC at moderate intensity.	Cannot be confirmed	True	True	False
Individual 3 experiences bitter tastes intensely.	False	True	False	Cannot be confirmed

In humans, chemoreceptor cells for taste are located on raised bumps on the tongue called papillae. For many years, biologists believed that the density of papillae on the tongue was related to how intensely a person experienced the dimensions of taste.

The Denver Papillae Protocol is a method developed to measure the density of a particular kind of papilla called fungiform papillae (FP) on human tongues. The subject's tongue is painted with blue food dye, and a piece of filter paper with a 10mm circular hole cut in it is placed over the front part of the tongue. A high-resolution photograph is taken of the tongue area exposed through the hole, and a dichotomous key is used to identify and count the number of fungiform papillae visible.

This protocol was developed to reduce variability in the counting of fungiform papillae during scientific studies.

37. The dichotomous key for the Denver Papillae Protocol is shown below.
Note: 'amorphous' means irregular in shape. 'Recessed' means lower in height.



N. Garneau et al, Frontiers in Integrative Neuroscience, 2014, CC-BY-3.0

Which of these structures would be classified as a fungiform papilla?

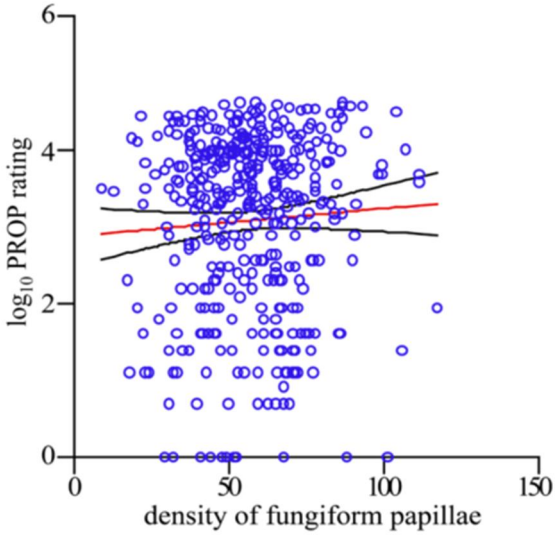
A. Round, 0.4mm wide, pink, protruding from surface of tongue
B. Amorphous, 0.7mm wide, lightly stained, recessed
C. Round, 1mm wide, heavily stained, protruding
D. Round, 1mm wide, pink, protruding

38. *This question is worth 2 marks.*

In 2014, Nicole Garneau and her colleagues at the Denver Museum of Nature and Science decided to use a citizen science study to test the hypothesis that the density of fungiform papillae on the tongue was related to an ability to experience bitter tastes intensely.

Each subject (drawn from visitors to the museum) were given a bitter chemical (PROP) to taste, and the density of fungiform papillae on their tongue was measured using the Denver Papillae Protocol.

The graph below shows the relationship between density of fungiform papillae (FP) and the intensity with which subjects experienced the bitter taste of the chemical PROP (the higher the log10 PROP rating, the more intensely they experienced the taste). Each blue circle on the graph indicates a person. The red line indicates a trendline based on the data.



N. Garneau et al, Frontiers in Integrative Neuroscience, 2014
doi:10.3389/fnint.2014.00033
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Indicate whether each of the following statements is supported by the data on the graph.

a) The higher the density of FP, the more intense the taste: supported/not supported.
b) Individuals with no FP cannot taste PROP: supported/not supported.
c) FP densities vary in this population by around a factor of 100: supported/not supported.
d) Individuals with the same FP density experience the same intensity of taste: supported/not supported.

The word 'dimensions' can also be used to describe the variables that affect a complex situation. Multidimensional problems are the norm, rather than an exception, and one of the skills of a good scientist is to identify and separate out the various dimensions in a complex problem so that relationships between individual variables can be uncovered.

Early alchemists faced this challenge as they developed humanity's first systematic studies of matter and chemical reactions.

39. The elements and compounds in the next two questions are hypothetical (i.e. not real).

Early chemists have been investigating Compound X. They have discovered that it contains atoms of two elements, A and B. Its formula is A_3B, and the ratio of element A to element B in the compound is 1:14 by mass.

What is the mass of an atom of B relative to the mass of an atom of A?

A. 4.7 times heavier
B. 7 times heavier
C. 14 times heavier
D. 42 times heavier

40. *This question is worth 2 marks. Part a) is worth 1 mark, and part b) is worth 1 mark.*

The chemists have also been working with gases D and E. They know that gases D and E react to give gas Q, and no other product.

They take D and E and react different masses of each together. Then they measure how much of each reactant gas is left once the reaction is finished. Some results are shown below.

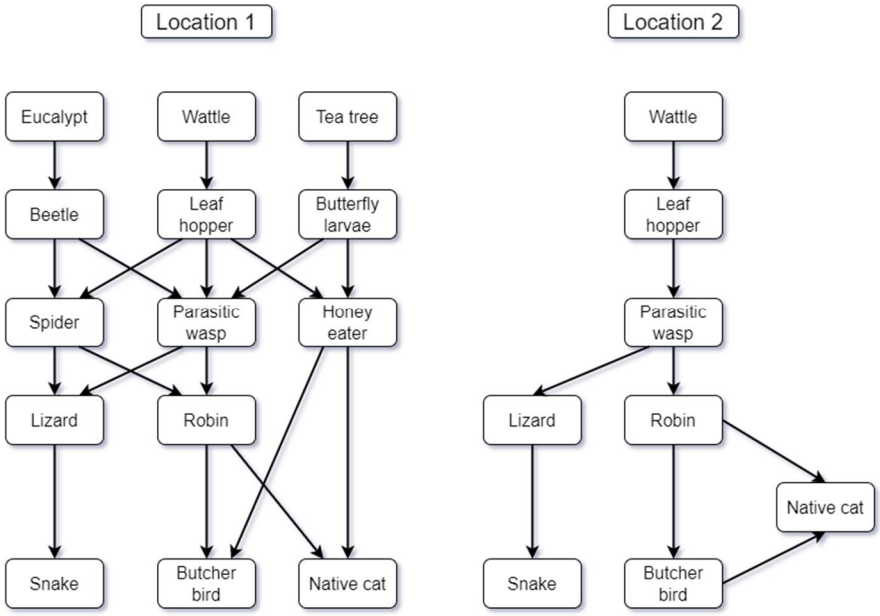
Experiment	Mass of gas at beginning of experiments		Mass of gas remaining once reaction is complete	
	Initial mass of D (g)	Initial mass of E (g)	Mass of D (g)	Final mass of E (g)
1	12	24	6	0
2	28	70		

a) What mass of the product Q was formed in Experiment 1? 30 g

b) In Experiment 2, identify which reactant gas remained after the reaction was finished, and how much of it.
Gas (circle one): D/E
Mass: 10.5 g

41. With so many biotic and abiotic factors involved, ecosystems are multi-dimensional systems.

Consider the diagram below, representing food webs in two separate locations.



Suppose the leaf hoppers died out in both locations. Select the best prediction and explanation for the effect this would have on the food webs.

A. The effect would be greater in Location 1 because there are three primary consumers.
B. The effect would be greater in Location 1 because more predators rely on the leaf hopper as a food source.
C. The effect would be greater in Location 2 because the parasitic wasp there has only one food source.
D. The effect would be greater in Location 2 because there is only one producer.

42. *This question is worth 2 marks.*

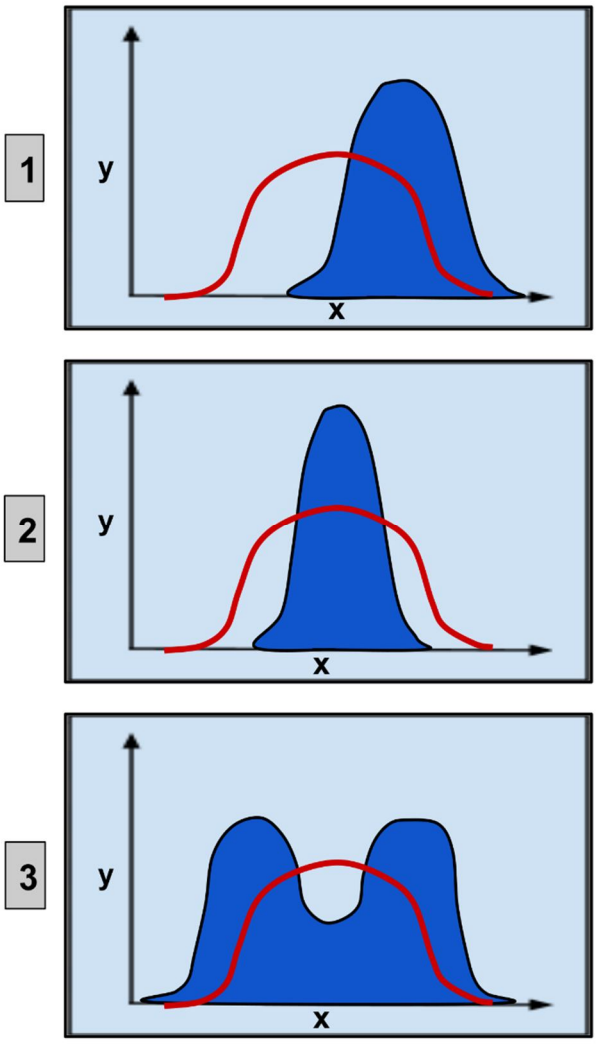
Over time, natural selection causes changes to phenotypes in a population of organisms, but there is more than one way in which natural selection can act on a population.

The graphs below are frequency distributions. Each illustrates the distribution of a phenotypic trait within a population before (red) and after (blue) a type of selection has been acting on the population for some time.

The types of natural selection illustrated in the three graphs are known as directional selection (Graph 1), stabilising selection (Graph 2) and disruptive selection (Graph 3).

x axis: variance of a trait (e.g. variation of height of pea plants in a

y axis: fraction of organisms in a population with each trait variation.



Red: original population

Blue: evolved population

Adapted from Ealbert17, CC BY-SA 4.0 via Wikimedia Commons

Read the descriptions below and indicate which type of selection is occurring in that population.

a) In Central and South America, pig-like mammals called peccaries eat the fleshy part of spiny cactus plants. The larger the number of spines on the cactuses, the less they get eaten. However, a parasitic insect exists that will lay its eggs between cactus spines if the spines are densely packed.

Graph 1/Graph 2/Graph 3

b) Sockeye salmon migrate to the same rivers in which they were born, in order to mate and lay their eggs. Between 1969 and 2003, the Alaska Department of Fish and Game collected data on the arrival time of populations of migrating sockeye salmon to their fishery. Fishing tends to happen later in the mating season, so late-arriving salmon are usually caught before they can reproduce.

Graph 1/Graph 2/Graph 3

43. Sometimes scientists designing experiments can't see the whole picture, making it hard to imagine how a particular variable could be important.

The idea that plants can detect and respond to sound has long been dismissed as fanciful. In the last two decades, however, scientists have been testing this assumption more carefully.

Which of the following is an INCORRECT statement about sound waves?

A. Sound waves are compression waves.
B. The higher the frequency of a sound wave, the lower the pitch of the sound.
C. The amplitude of a sound wave tells you about how much energy it is carrying.
D. Sound waves are mechanical waves.
E. Sound travels faster through liquids than it does through gases.

44. *This question is worth 2 marks.*

Heidi Appel and Rex Cocroft reported in 2014 that when plants of the species *Arabidopsis thaliana* (Thale cress) were attacked by the larvae of *Pieris rapae* (caterpillars of the cabbage white butterfly), the plants showed a 32% increase in the production of chemical defence substances called glucosinolates.

James Lindsey at Ecology of Commanster, CC BY-SA 2.5, via Wikimedia Commons

They observed that this increase in glucosinolates *also* occurred when a recording of caterpillars chewing was played to these plants. It did not occur when the plants were randomly subjected to sound patterns that were similar to those of caterpillars chewing in either amplitude or frequency but not both.

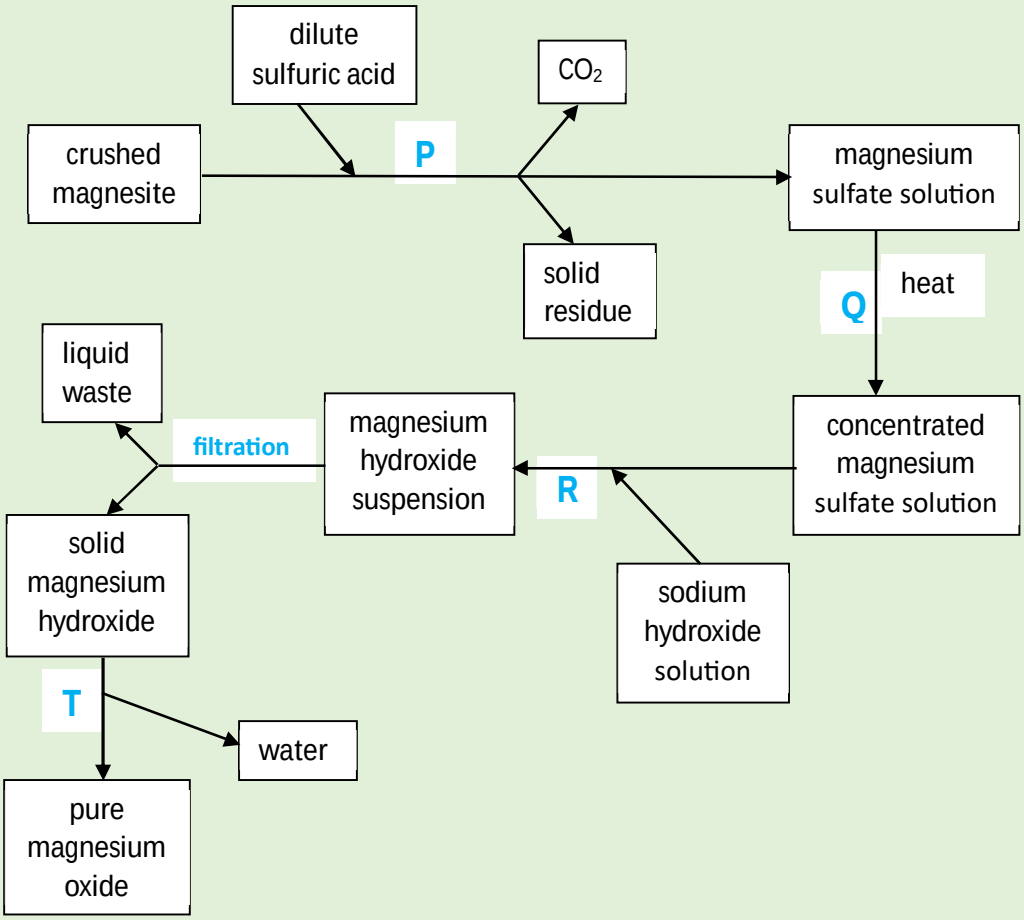
Indicate whether each of the following statements is true or false, or is supported/not supported by this evidence.

a) The production of glucosinolates in this experiment was the independent variable: true/false.
b) Arabidopsis plants are sensitive to specific combinations of amplitude and frequency in sound: supported/not supported.
c) Plants have evolved to respond to sounds linked to events likely to cause benefit or harm: supported/not supported.
d) Specific mechanical vibrations caused by sound waves may cause changes to chemical reactions within Arabidopsis plants: supported/not supported.

Graphs, diagrams and flowcharts are ways of representing multi-dimensional information on a two-dimensional page or screen.

The flow chart below represents steps in the manufacture of magnesium oxide, which can be used as an antacid medication for stomach problems. The process starts with magnesite, a mineral which is primarily composed of magnesium carbonate ($MgCO_3$).

**Note: a suspension is when fine solid particles of an insoluble substance are suspended in a liquid. Muddy water is a suspension.*

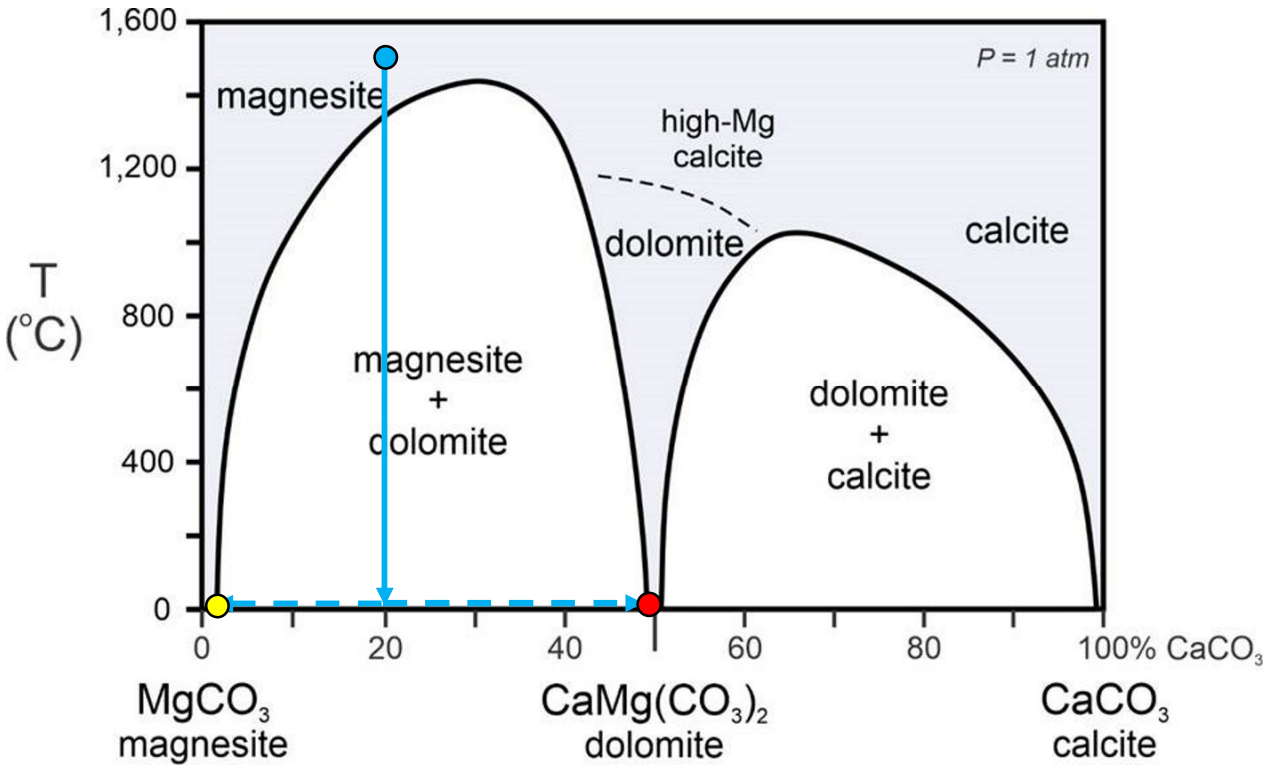


45. What is the type of chemical reaction occurring in step R?

A. Combination
B. Decomposition
C. Dingle displacement (single replacement)
D. Double displacement (double replacement)
E. Combustion

46. Apart from water, which chemical would be the primary substance present in the liquid waste after filtration of the magnesium hydroxide suspension?

A. Sodium hydroxide
B. Sodium sulfate
C. Magnesium hydroxide
D. Magnesium sulfate
E. Magnesium carbonate
F. Magnesium oxide

47.	Classify steps P, Q and T as physical or chemical changes: Step P: physical/chemical change Step Q: physical/chemical change Step T: physical/chemical change
48.	*This question is worth 2 marks.* A phase diagram is a two-dimensional representation of the phases or states present in a chemical system under different conditions of temperature, pressure and composition. This may include physical states such as solids and liquids, but can also include substances with different compositions. Figure 1 shows a phase diagram for three minerals, magnesite, dolomite and calcite, which are composed of differing ratios of magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$) and are often found together. The x-axis of the phase diagram shows the percentage of $CaCO_3$ in the mixture; the remaining percentage is made up of $MgCO_3$. The grey areas in the phase diagram indicate combinations of composition and temperature at which the mixture remains homogenous (the same composition throughout). In the white areas, the mixture separates into crystals of two different phases - one richer in $MgCO_3$, and the other richer in $CaCO_3$. The inset image in Figure 1 shows a micrograph of this phenomenon.  Figure 1: phase diagram for $CaCO_3/MgCO_3$ mixtures Adapted from Open Geology Textbook; https://opengeology.org/petrology/8-igneous-phase-diagrams-and-phase-equilibria/

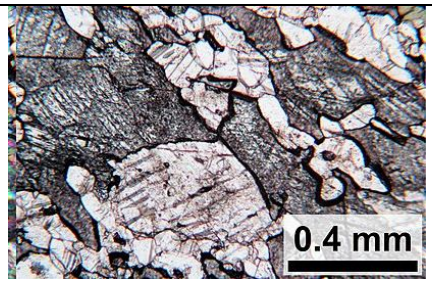


Figure 2: micrograph of calcite (dark) and dolomite (bright) crystals that have formed side-by-side by demixing of a rock sample during cooling.
kallerna, CC BY-SA 4.0 via Wikimedia Commons

Consider a 100kg sample of rock with a composition of 20% $CaCO_3$ and 80% $MgCO_3$ which is initially at 1500ºC (blue dot on Figure 1). As the mixture gradually cools to 0ºC (blue arrows), it separates into crystals of Phase A (yellow dot) and Phase B (red dot).

Once at 0ºC, the rock sample contains:

- *x* kg of Phase A, composed of 2% $CaCO_3$/98% $MgCO_3$
- *y* kg of phase B, composed of 49% $CaCO_3$/51% $MgCO_3$

To the nearest kilogram, calculate the mass *x* of Phase A crystals in the cooled rock sample: 62 kg