2024 JUNIOR SCIENCE OLYMPIAD EXAM

JUNIOR YEAR 9 & 10

TO BE COMPLETED BY THE STUDENT. USE CAPITAL LETTERS.

First Name: …………….....…..………… **Last Name**………………………………….

Date of Birth: .…../…..../...…..

□ Male   □ Female   □ Unspecified

Year 7 □   Year 8 □   Year 9 □   Year 10 □   Other: …….

Name of School: …………………………………….…………………...**State:** ……...

Examiners Use Only:

2024 JUNIOR SCIENCE OLYMPIAD EXAM

9 & 10

Time Allowed

Reading Time: 10 minutes

Examination Time: 120 minutes

INSTRUCTIONS

- Attempt all questions in ALL sections of this paper.

- Permitted materials: non-programmable, non-graphical calculator, pens, pencils, erasers and a ruler.

- Answer all questions on the MULTIPLE CHOICE ANSWER SHEET PROVIDED. Use a pencil.

- Marks will not be deducted for incorrect answers.

MARKS

- 1 mark for each question unless otherwise specified
- Total marks for the paper   56 marks

Integrity of Competition

If there is evidence of collusion or other academic dishonesty, students will be disqualified. Markers' decisions are final.

1	**(1 mark)**

As extreme environments go, stars are a good place to start. Stars are massive balls of plasma held together at extreme pressures and temperatures by gravity.

The diagram below is a **Hertzsprung-Russell diagram**, which classifies stars according to their luminosity (proportional to how much energy they emit every second) and their surface temperature.

Note 1: the colour of a star is determined by its temperature: the hotter an object is, the bluer the light it emits.

Note 2: the relative sizes of the stars on the diagram are represented by the size of the circles.
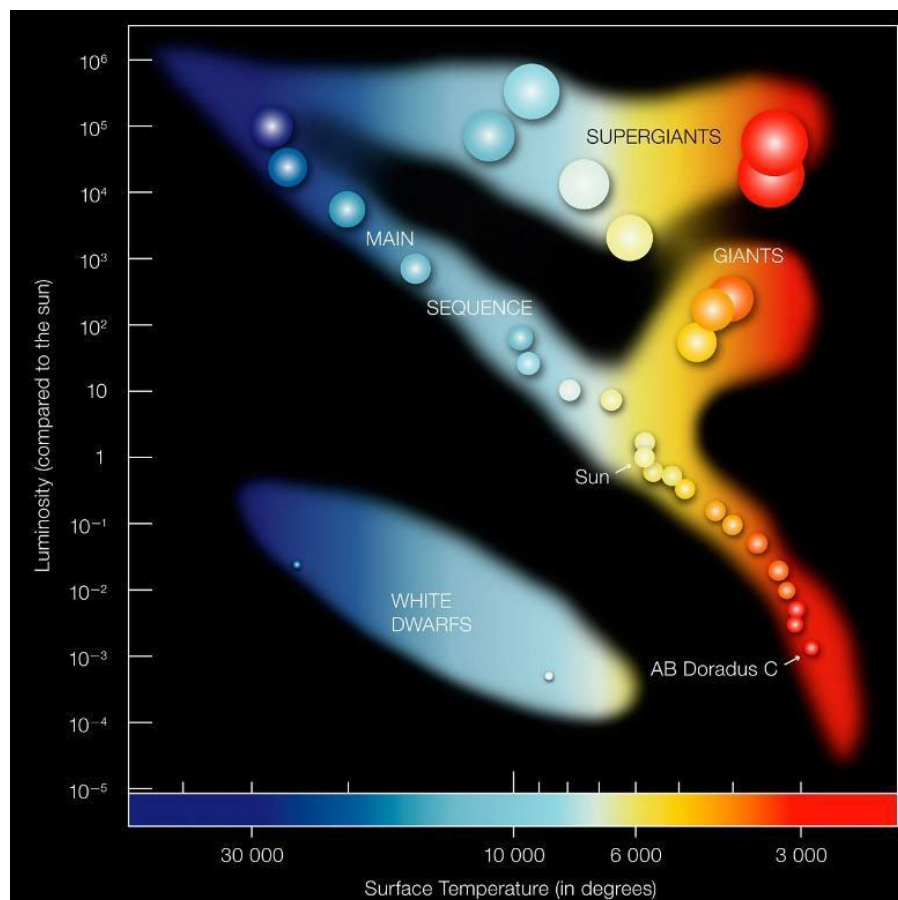
Image credit: European Southern Observatory.

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

    A. Stars classified as giants are brighter and cooler than the sun.
    B. Stars on the 'main sequence' show a trend of decreasing luminosity with increasing temperature.
    C. The Sun is about 1000 times as luminous as AB Doradus C.
    D. A small star will be less luminous than a large star of the same temperature. |

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2	(1 mark, 0.25 marks for each correct answer.)

A star's luminosity is determined by the power it emits.

How bright an object appears to be (the intensity of light from the object) depends on the energy it emits per second (its power, P) and distance from the observer (d), as:

$$Intensity = \frac{P}{4\pi d^2}$$

Xan is standing in her backyard observing two stars. Star A appears brighter to her than Star B, and she is thinking about what this means about the two stars.

Based on Xan's observation, indicate whether each of the four statements below is **possible** or **not possible**.

Star A has a higher luminosity than Star B and is further away.	Possible / not possible.
Star A has a lower luminosity than Star B and is further away.	Possible / not possible.
Star A has a higher luminosity than Star B and is closer.	Possible / not possible.
Star A has a lower luminosity than Star B and is closer.	Possible / not possible.

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| 3 | (1 mark)

A neutron star can form when a massive star runs out of fuel. The compressive forces during the collapse are so great that protons and electrons are crushed together and the resulting object – the neutron star – is made entirely of neutrons.

The gravitational field strength on the surface of an object can be represented by this equation:

$$gravitational\ field\ strength = \frac{GM}{r^2}$$

where G is a constant, M is the mass of the object, and r is the radius of the object.

A neutron star has a mass about 5×10^5 times greater than the Earth, and a radius about 1×10^{-3} times that of the Earth.

How much stronger is the gravitational field strength on the surface of a neutron star than on the surface of the Earth?

    A. About 5×10^2 times stronger
    B. About 5×10^5 times stronger
    C. About 5×10^8 times stronger
    D. About 5×10^{11} times stronger. |

| 4 | (1 mark)

Neutron stars are often observed at the centre of a nebula (a cloud of gas and dust).

A pulsar is a highly magnetised rotating neutron star that emits beams of electromagnetic radiation from its poles. The magnetic field of a pulsar acts as a brake to its rotation, slowing it down. As it slows down, it emits energy as light to its surroundings.

The **period** of a pulsar is the length of time it takes to complete a rotation.

Some years later, Xan – now an astronomer – finds two neutron stars. They have the same mass, and when she initially observes them, they have the same period. Over time, she observes that the period of the first pulsar is increasing rapidly, while the period of the second pulsar is only increasing slowly.

    A. The first pulsar probably has a stronger magnetic field and is surrounded by a brighter nebula
    B. The first pulsar probably has a stronger magnetic field and is surrounded by a dimmer nebula. |

|	
	C. The first pulsar probably has a weaker magnetic field and is surrounded by a brighter nebula
	D. The first pulsar probably has a weaker magnetic field and is surrounded by a dimmer nebula.
5	(1 mark) Light is a kind of electromagnetic wave. As well as visible light, stars and other objects in the universe emit electromagnetic waves of many other kinds, including x-rays, ultraviolet, infrared and radio waves. Radio waves have long **wavelengths**. Electromagnetic waves consist of oscillating electric and magnetic fields. The energy carried by the wave depends upon the **amplitude** of the electric field. More sensitive detectors are required to detect low-amplitude waves. To detect distant objects in the universe, we use a variety of extremely sensitive detectin methods. The **Square Kilometre Array-Low** (SKA-Low) is a new radio telescope currently being constructed in the desert in Western Australia. It consists of arrays of "Christmas tree"-style antennae (see photo below) designed to detect faint radio waves from very distant sources. *Image credit: SKA Observatory*

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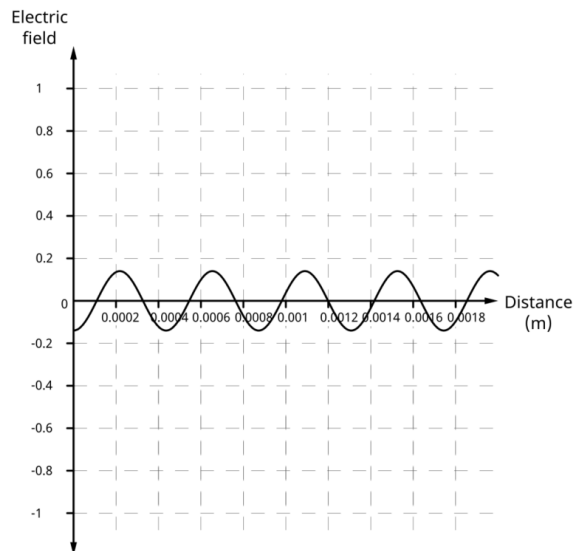The radio waves the telescope is designed to detect have:

- Electric fields with very low amplitude.
- Wavelengths approximately two times the length of the metal arms on the antennae in the photo.

Which of the following could represent the radio waves that the SKA-Low telescope is designed to detect?
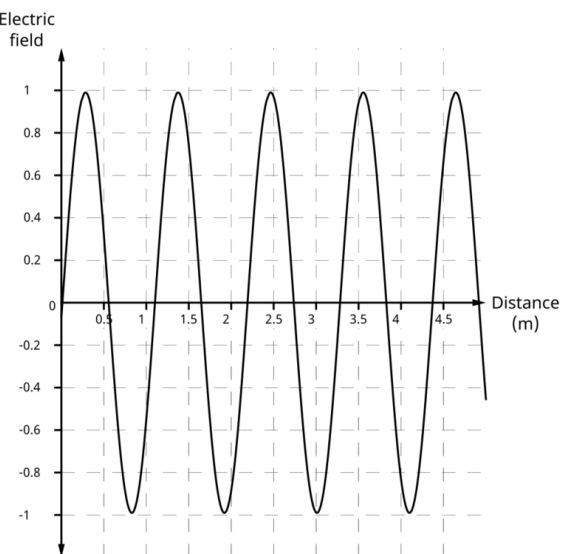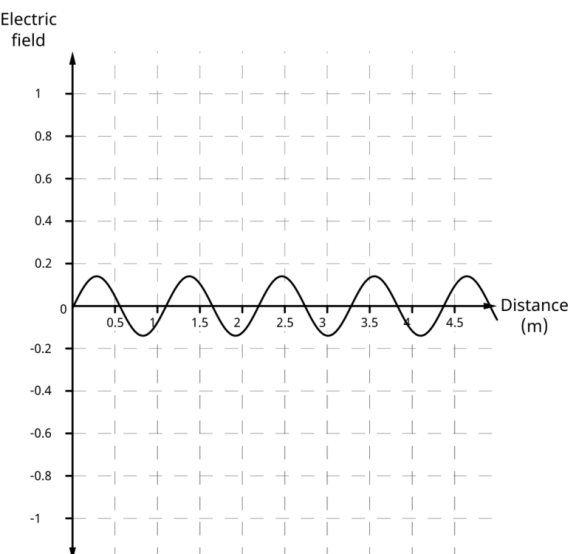
A.
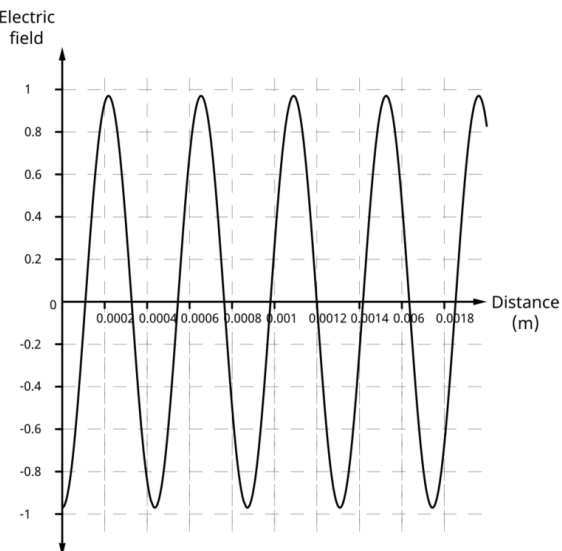
B.

C.

D.

6	(1 mark) The relationship between the speed v, wavelength λ, and the frequency f, of a wave is: $$v = f\lambda$$

The frequency of a wave is the number of cycles that occur each second and is measured in Hertz (Hz). The speed of radio waves is the same as the speed of visible light, $v = 3 \times 10^8 \, ms^{-1}$.

Which of the following radio wave frequencies is the SKA-Low telescope designed to detect?

A. $2.7 \times 10^2 Hz$
B. $2.7 \times 10^4 Hz$
C. $2.7 \times 10^6 \, Hz$
D. $2.7 \times 10^8 \, Hz$

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7 | (1 mark)
The SKA-Low is also designed to detect very rapid radio wave bursts. One type of rapid radio burst is thought to originate from **magnetars**, which are neutron stars with the strongest magnetic fields of any known object.

In December 2004, a "starquake" in magnetar SGR-1806−20 released electromagnetic waves that were powerful enough to disrupt radio communications on Earth. It is thought to be the largest explosion observed in this galaxy by humans since the SN1604 supernova observed by Johannes Kepler in 1604.

Due to the finite speed of light it takes some time for the electromagnetic radiation to travel from the star to Earth.

The distance from Earth to the magnetar SGR-1806−20 is 13 000 parsecs.
1 parsec = 3.26 light years (a light year is how far light travels in 1 year).

How many years prior to 2004 did the starquake occur?

This information relates to the following 5 questions.

The process which generates the extreme energies of main sequence, giant and supergiant stars is nuclear fusion, which is one kind of **nuclear reaction**.

Nuclear reactions produce some of the most extreme conditions of temperature and pressure observed by humans.

Isotopes of an element contain the same number of protons in the nuclei of their atoms, but different numbers of neutrons. If a particular isotope is unstable, its nucleus undergoes a nuclear reaction, or 'radioactive decay' in order to lower its energy, and become more stable.

When the nucleus decays, it releases energy in the form of either energetic particles, or electromagnetic waves (e.g. gamma rays).

8

(1 mark)

Alpha decay is a common kind of nuclear reaction.

In alpha decay, an **alpha particle** is ejected from the nucleus of the parent atom.

An alpha particle consists of two protons and two neutrons. The atom that is left after the alpha particle has been ejected is called the 'daughter atom'.

Which of the following would be the daughter atom from the alpha decay of $^{226}_{88}Ra$?

    A. $^{222}_{86}Rn$

    B. $^{224}_{86}Rn$

    C. $^{230}_{90}Th$

    D. $^{228}_{90}Th$

9

(1 mark)

Ejected alpha particles collide with other atoms in their surroundings. Eventually they pick up stray electrons and become stable neutral atoms.

What type of atom does an alpha particle end up as?

    A. a helium atom
    B. a beryllium atom
    C. it depends on the type of nucleus the alpha particle was originally ejected from
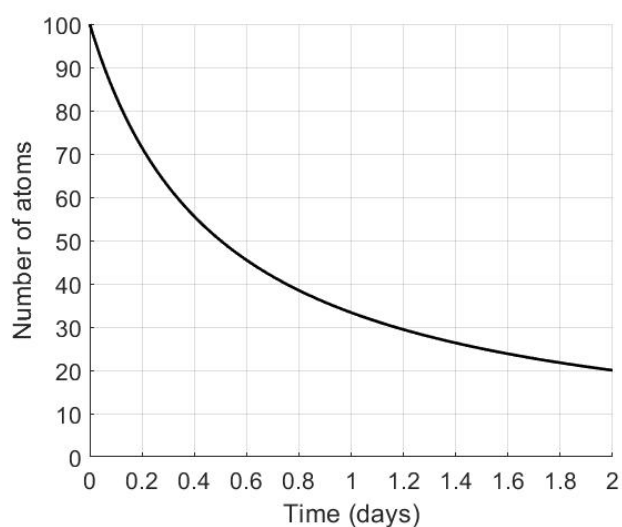   D. a proton

| 10 | (1 mark)

The **half-life** of a radioactive isotope is the time it takes for exactly half of the atoms in a sample to undergo radioactive decay.

Radioactive decay is a **first-order** process. This means that the half-life is a constant value, no matter how much of the radioactive material you have.
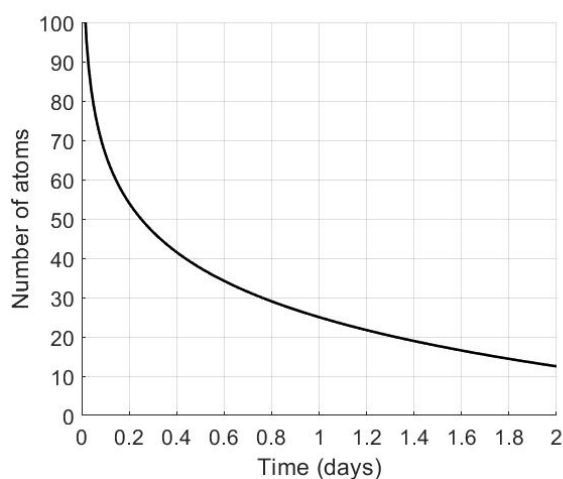
It is impossible to know when an individual atom will decay. However, if you have a sample of a radioactive isotope containing many atoms, the half-life value for that isotope allows you to predict how many atoms will have decayed after a particular time has elapsed.

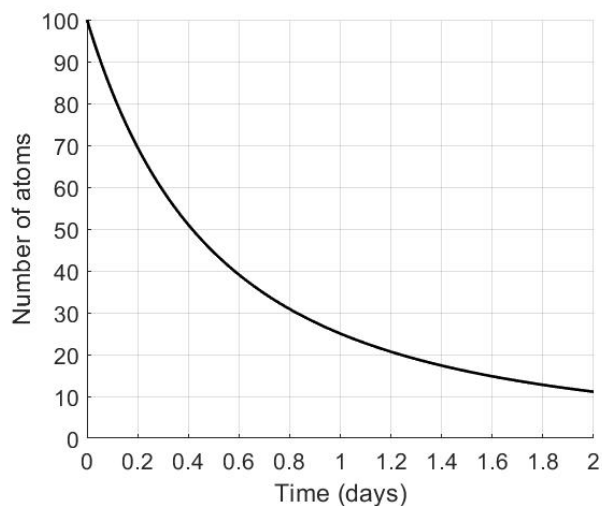Which of the following graphs shows a first-order process?

A.

B.

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C.

D.

E.

| 11 | (2 marks; 1 mark for correct numerical answer, 1 mark for correct number of sig figs)

The standard unit of energy is the Joule (J).

However, the energy changes involved in nuclear decay are commonly reported using an energy unit called the **electron volt** (eV).

1 eV = 1.602 x 10^{-19} Joules
1MeV = 1 mega eV = 1 x 10^6 eV
1MJ = 1 megajoule = 1 x 10^6 J

1.000g of uranium-235 contains 2.562 x 10^{21} atoms.
If 1.000g of uranium-235 undergoes complete alpha decay, 1920 MJ of energy is released.

Calculate the energy emitted by the alpha decay of a single atom of uranium-235 in MeV. Give your answer to the correct number of significant figures. |

| 12 | (1 mark)

Nuclear decay can also be used to determine the ages of ancient artefacts.

The most common isotope of carbon is carbon-12. However, a small proportion of carbon atoms are carbon-14, which is unstable and undergoes beta decay. This isotope is used in radiocarbon dating of ancient artefacts. |

On the scale of the history of life on Earth, carbon-14 has a relatively short half-life of 5730 years. Nevertheless, throughout Earth's history, there has been a roughly constant proportion of carbon-14 on the planet.

Which of the following is a plausible reason for this?

A. All carbon-14 atoms must have been generated when the Earth was formed.
B. Carbon-14 is being circulated in the carbon cycle.
C. Carbon-14 atoms are produced at a constant rate by living organisms
D. Carbon-14 is constantly replenished from other carbon isotopes by cosmic ray interactions in the atmosphere
E. Carbon-14 atoms are preserved in a stable form in rocks.

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13 | (1 mark)
In early 2024, researchers D. Datta and S. Bajpai reported the discovery of an extremely large snake fossil in Kutch, India. They named the snake *Vasuki indicus*. Evidence suggests it is related to a group of ancient giant snakes that also includes Australian specimens such as *Wonambi naracoortensis* and *Yurlunggur camfieldensis*.

The fossil was incomplete, so the exact length of the snake could not be directly measured, but based on their data, Datta and Bajpai proposed it to be the largest snake that has ever existed. They made this analysis by comparing the fossil to existing data linking the size of a snake's vertebra to the total length of the snake.

The following graph shows the relationship between the postzygapophyseal width (a part of the vertebra) and the total body length of snake species existing today.

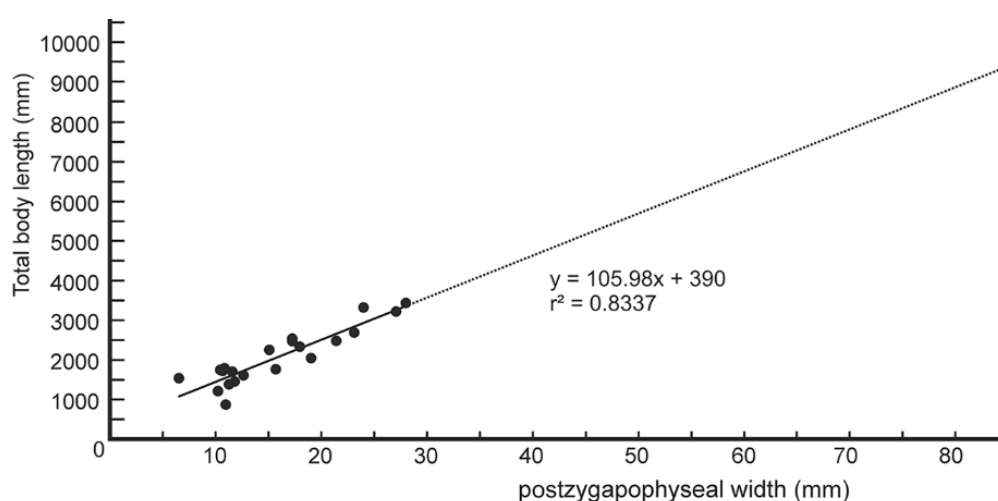A trendline has been drawn through the data points, and the equation of the trendline is given on the graph.

Image credit: Datta and Bajpai, Scientific Reports 14, 8054 (2024). CC-BY-4.0.

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Given that the postzygapophyseal width for the Vasuki fossil was 110mm, calculate a predicted value for the total body length of *Vasuki*.

Give your answer to the nearest whole metre.
Numerical answer:

This information relates to the following 4 questions.

Chemical explosions (as opposed to nuclear explosions) are the result of chemical reactions that are extremely exothermic and occur at extremely fast rates.

Nitroglycerin is a common explosive with the chemical formula $C_3H_5N_3O_9$. When used as an explosive, it undergoes the following reaction, producing four different gaseous products.

$4\ C_3H_5N_3O_{9\ (l)} \rightarrow 12\ CO_{2\ (g)} + 10\ H_2O_{(g)} + 6\ N_{2\ (g)} + O_{2\ (g)}$

14 | (1 mark)
How is the reaction of nitroglycerin classified?

    A. Decomposition reaction
    B. Detonation reaction
    C. Combustion reaction
    D. Combination reaction
    E. Displacement reaction
    F. Precipitation reaction

15 | (1 mark)
A small amount of nitroglycerin is exploded in a closed container. Which of the following is the most accurate description of the contents of the container after the explosion?

    A. A mixture of elements and compounds made up of molecules.
    B. A pure substance, made up of molecules.
    C. A mixture of compounds, made up of elements.
    D. A mixture of elements, made up of atoms.
    E. A mixture of compounds, made up of molecules.

16	(1 mark) If 75 molecules of nitrogen are produced during this reaction, how many molecules of nitroglycerin must have reacted?

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17 (1 mark)

The table shows the relative weight of each molecule involved in the reaction of nitroglycerin.

Molecule	Relative mass
$C_3H_5N_3O_9$	227
CO_2	44
H_2O	18
N_2	28
O_2	32

Calculate the mass of nitrogen (in grams) that is produced when 1.0g of nitroglycerin explodes.

Give your answer to 2 decimal places.

Numerical answer:

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18 (1 mark)

Chemical kinetics is the study of rate or speed of chemical reactions, and is a key area of chemistry.

The **rate** of a chemical reaction is determined by how **frequently** reactant molecules collide with one another..

Safe and relatively non-flammable substances can be rendered extremely flammable by soaking in liquid oxygen: this causes the rate of combustion to become extremely high.

Which of the following is the most accurate description of why this occurs?

    A. The concentration of oxygen molecules is increased.
    B. There is a greater number of oxygen molecules present.
    C. The temperature of the reaction is increased.
    D. The surface area of the substance is increased.

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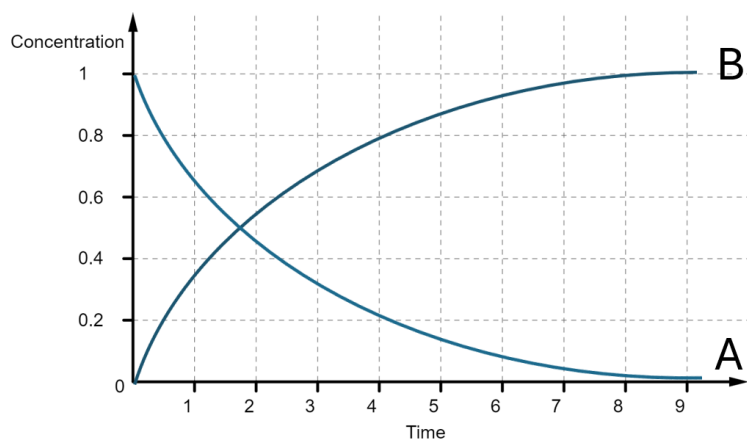
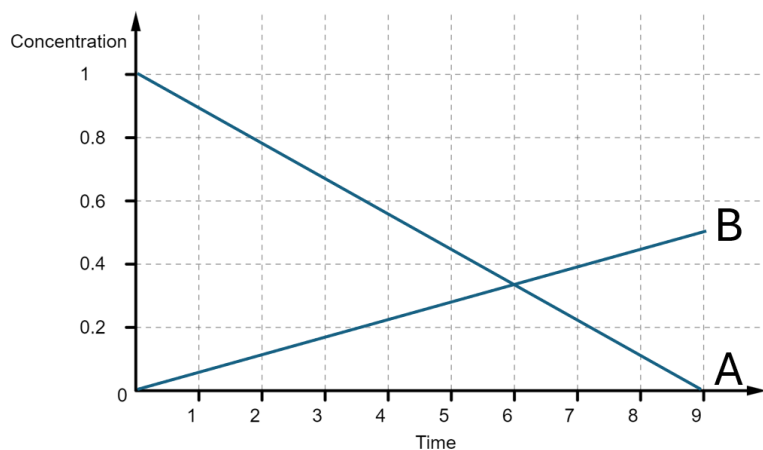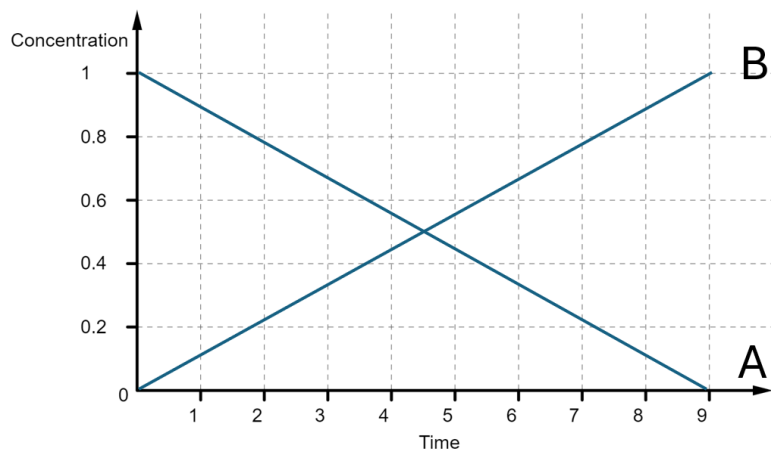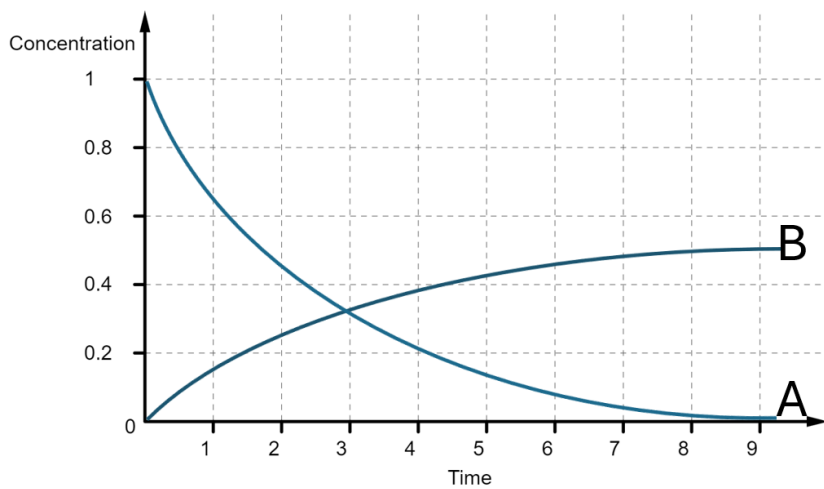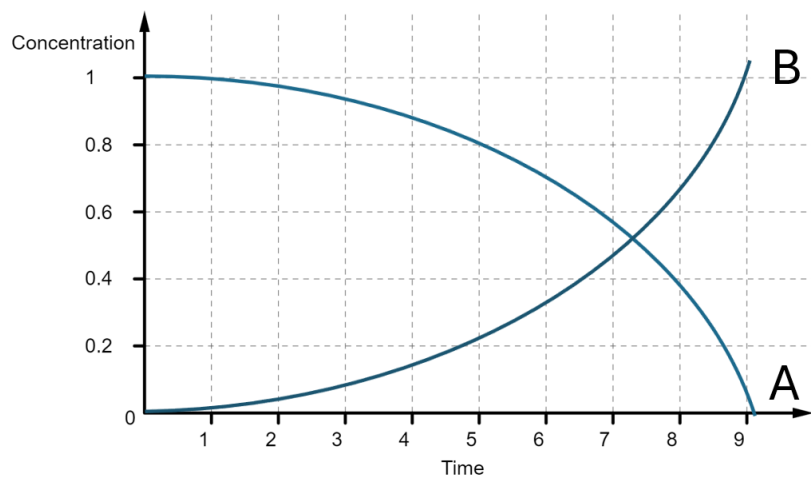| 19	(1 mark) Consider the following hypothetical chemical reaction: $2A \rightarrow B + C$ A scientist starts with a flask containing a solution of A. Which of the following graphs best represents the change in concentration of A and B during the course of the reaction? Assume that the reaction is kept at constant temperature. A. B. C.

(cont. on next page)

D.

E.

F.

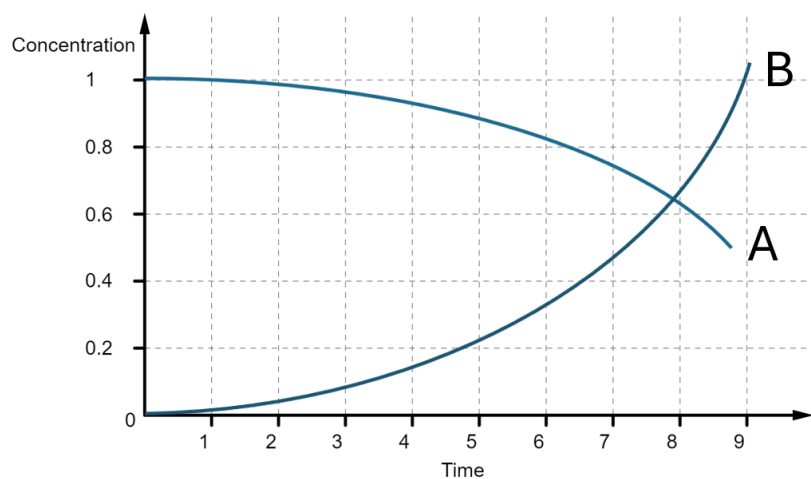|	
20	(1 mark)

An ecological hypothesis known as Bergmann's Rule predicts that animals that inhabit cooler climates are generally larger than close relatives from warmer climates.

A 2024 paper in Nature Communications by Lauren Wilson and colleagues used fossil records of dinosaurs to investigate Bergmann's Rule. The figure below is from their paper.
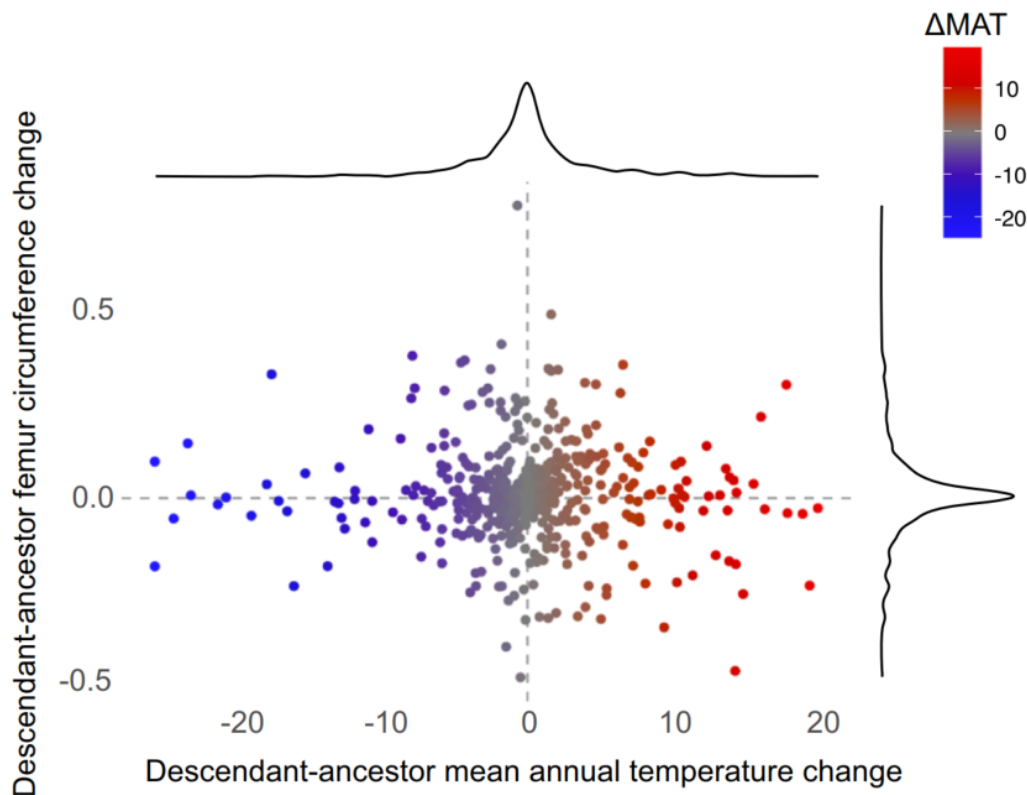

Image credit: Wilson et al (2024) Nature Communications 15:2864; CC BY 4.0

Each dot on the graph represents a pair of related dinosaurs – an ancestor and a descendant. The x-axis represents the *difference in mean annual temperature* (ΔMAT) between the locations where those dinosaurs lived. A positive value means the descendant lived in a warmer location than the ancestor.

The y-axis is a measure of the difference in circumference of the femur (thigh) bone of the animals. A positive value means the descendant had a larger femur than its ancestor. A larger femur implies a larger animal.

In their paper, the authors stated that their data does not support Bergmann's Rule.

If the data *had* supported Bergmann's rule, which of the following correctly describes the trend that would be shown in the graph?

The data would stretch from:
    A. Bottom left to bottom right
    B. Bottom left to top right

C. Top left to top right
D. Top left to bottom right

| 21 | (1 mark)

Aldemar Acevedo and his colleagues study frogs in the *Pristimantis* genus, which live in central and South America. They are considered to be the world's most diverse genus of vertebrates, containing 596 described species.

One of the features of *Pristimantis* frogs that Acevedo studies is **sexual size dimorphism**, or the difference in size between males and females.

In the graph below, each data point represents one species within the genus. The x- and y-axes represent average size for the females and males respectively.
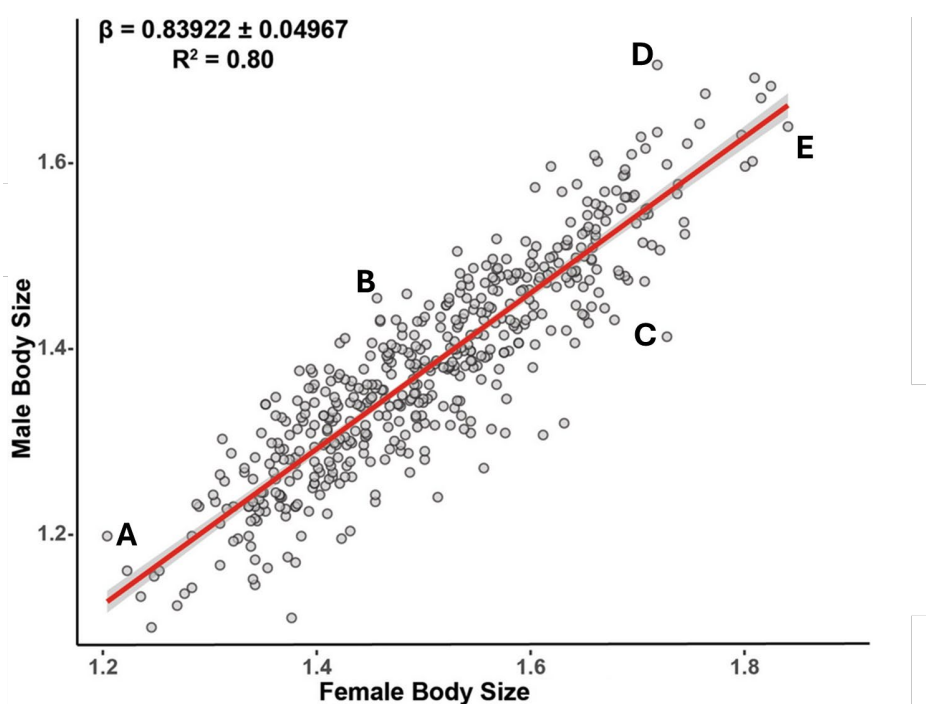
Image credit: Acevedo et al (2022) Scientific Reports, 12:18106, CC BY 4.0

Looking at the overall trend of the graph, which statement is true?

A. Males of a species tend to be bigger than females of that species.
B. Females of a species tend to be bigger than males of that species.
C. For a given species, males and females are roughly equal in size.
D. There is no correlation between male size and female size within species.

22	(1 mark) Consider the five letters (A-E) on Acevedo's graph in the previous question. Of the five species indicated by the letters, which would show the biggest size difference between males and females? A. B. C. D. E.

23	(1 mark)
	
	Humans have developed technology that allows us to survive in extreme environments such as Antarctica.
	
	Image credit: NASA, public domain.
	
	The photo shows Jo, a scientist in Antarctica about to pull on a sled carrying her equipment over the ice. The sled is initially stationary.
	
	Which of the following are **true** statements about what Jo must do to get the sled to start moving?
	
	    I. The force Jo applies to the sled must be momentarily larger than the force the sled exerts back on her.
	    II. She must apply a force greater than the weight of the sled.
	    III. She must apply a force to the sled that is larger than the frictional force acting on the sled.
	
	  A. I only
	  B. II only
	  C. III only

D. I and II
E. I and III
F. II and III
G. All statements are true

24	(1 mark) In the motion diagram below, the dots represent the **position of the sled at equal intervals of time**, as Jo pulls the sled from right to left. The location of the sled at four moments in time are marked t_A, t_B, t_C and t_D. final position initial position t_D t_C t_B t_A At which time is the magnitude of the acceleration (the rate at which the speed changes) the largest? A. t_A B. t_B C. t_C D. t_D
	This information relates to the following 2 questions. In the photo, Bob, a scientist, is riding a skidoo (snowmobile) which is towing a radar sled with a cable.

Image credit: *NASA, public domain.*

Initially, the skidoo pulls the sled across the ice to the left at an increasing speed.

At time t_0 the connector attaching the sled to the skidoo suddenly snaps so the sled is no longer connected to the skidoo.

- The sled continues to move to the left for some time after time t_0, gradually slowing down before coming to rest.
- The scientist does not alter the controls on the skidoo in the moments after time t_0.

25 (1 mark)
Which of the following diagrams could represent the forces acting on the sled **after** the connector snaps at t_0?
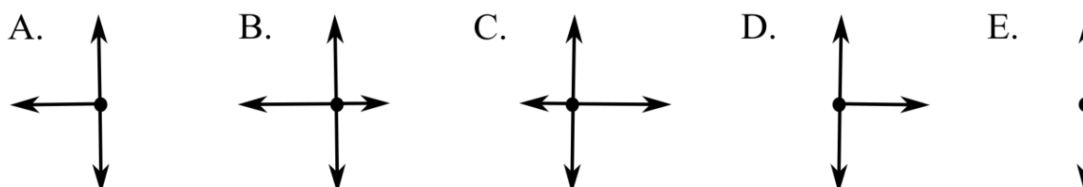
26 (1 mark)
Which of the following graphs could represent the velocity versus time of the skidoo and the radar sled just before and after t_0 ?
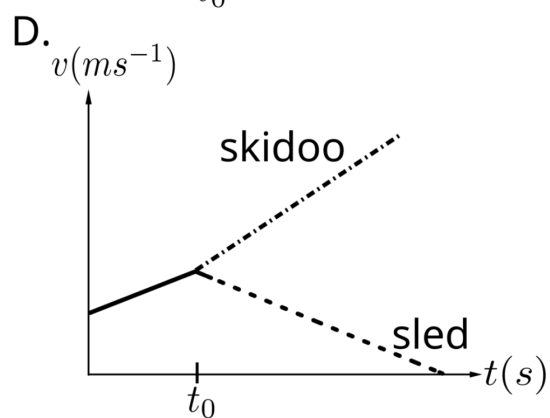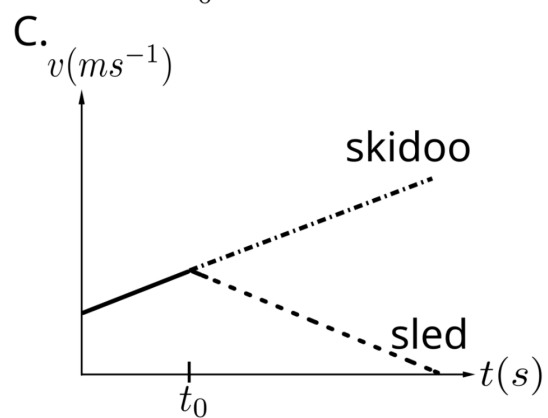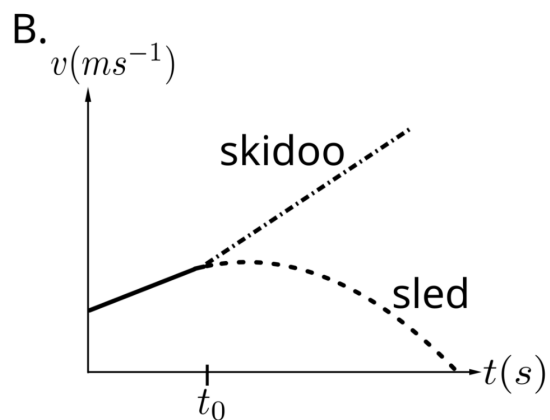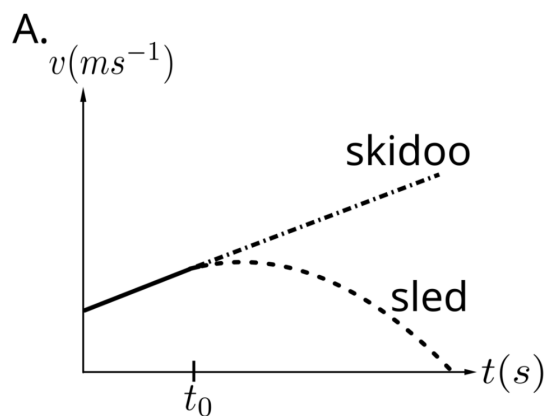
27	(1 mark)

Image: Cliff Simpson-Davis

A midwinter swim is a tradition for scientists in the Australian Antarctic Expedition. Salt water freezes at a lower temperature than freshwater, and the temperature of the water in the bath is -2°C.

People rapidly lose thermal energy (heat) when immersed in water. One way in which this occurs is by convection: the movement of a fluid (a liquid or a gas) past the skin.

The rate of thermal energy loss due to convection is:

$$q_{conv} = hA(T_C - T_F)$$

Symbol	Definition	Value
h	Convective heat transfer coefficient	For water: $h_W = 12500 \ Wm^{-2}K^{-1}$ For air: $h_{air} = 20 \ Wm^{-2}K^{-1}$
A	Surface area of the person	
T_C	Core temperature of the person	$T_C = 37^o C$
T_F	Temperature of the fluid (liquid or gas)	

In the midwinter swim, a scientist wearing minimal clothes walks through Antarctic air ($T_{air} = -22^o C$) and jumps in a pool with freezing salty water ($T_W = -2.0^o C$).

Calculate the ratio of the rate of heat loss when the person is swimming compared to when they are walking through the air:

$$\frac{rate \ of \ heat \ loss \ in \ water}{rate \ of \ heat \ loss \ in \ air} = \frac{q_{conv}(water)}{q_{conv}(air)}$$

A. 1400
B. 410

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C. 14

D. 50

E. 1.4

| 28 | (1 mark)

When mammals are exposed to cold temperatures, the homeostatic mechanisms in their bodies respond to maintain their internal temperature.

Which of the following would occur when the scientist takes his icy bath?

The blood vessels in his skin:

A. Dilate, allowing blood to keep the skin warm.

B. Constrict, forcing blood to flow through the vessels in the skin.

C. Dilate, causing blood to pass through the cold skin more quickly.

D. Dilate, preventing blood flow near the surface of the skin.

E. Constrict, reducing heat loss from blood near the surface of the skin. |

| 29 | (1 mark)
Indicate whether each of the following statements is true or false.

Statement	True or false?
I. Temperature is a measure of the average kinetic energy of particles.	True/false
II. When a cold object comes into contact with a hot object, cold flows from the cold object into the hot object.	True/false
III. Heat cannot be transferred by convection in a solid.	True/false
IV. Conduction of heat happens when particles collide with each other.	True/false

| 30 | (2 marks)

A person's *survival time* when immersed in cold water is the time until their core temperature is reduced from $37^o C$ to $28^o C$.

One of the factors that can affect a person's survival time is their *surface to volume* ratio, A/V.

The surface area, A, of a person may be estimated using the mathematical model:
$A = 0.007184 \times m^{0.425} H^{0.725}$

m = mass (in kg)
H = height (in cm).
A = surface area (in m^2).

$$density = \frac{mass}{volume}$$
The average density of a person is $985 kgm^{-3}$.

The graph shows core temperature versus time for a number of different values of A/V for a water temperature of $T_W = 20^o C$.
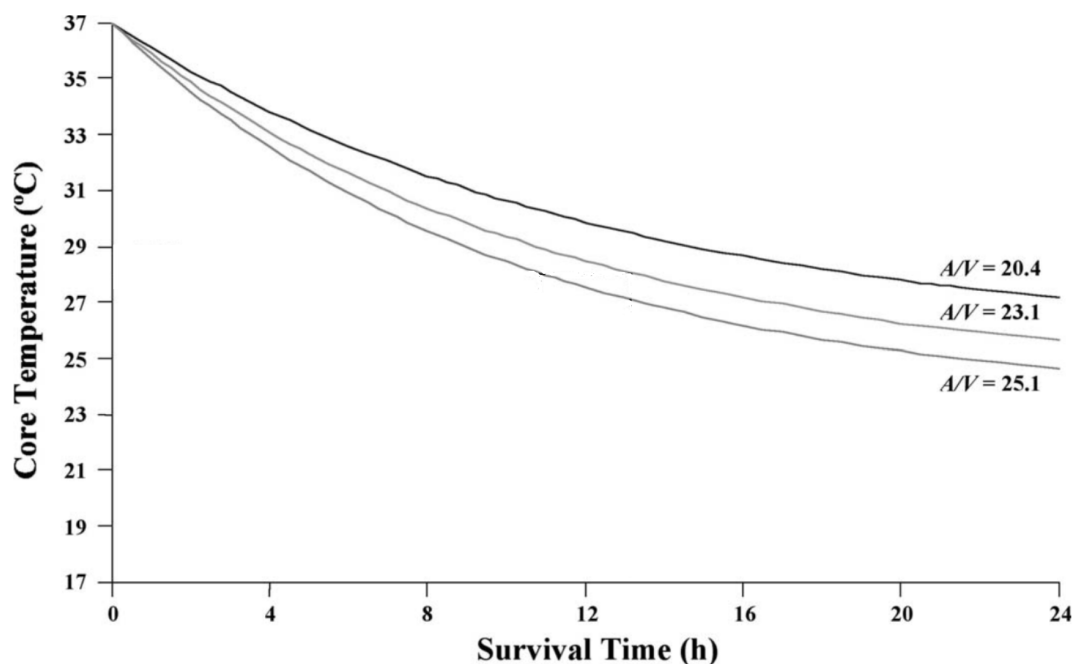

Image credit: Tarlochan and Ramesh (2005) Biomedical Engineering: Applications, Basis and Communications 17 (4) 159-166. CC-BY-4.0. |

Use the graph to estimate the survival time of a person with mass 72.0kg and height 169cm in 20^oC water.

A. 11hr
B. 13hr
C. 15hr
D. 17hr
E. 19hr
F. 21hr
G. >24hr

31 | (2 marks)
(Marking note: 2 marks if correct answer A selected; 1 mark if partially correct answer E selected).

The temperature difference between the inside of a person (their 'core') and skin surface when they are immersed in cold water causes heat to flow out of the person and their core temperature to fall.

The rate at which heat flows due to conduction is determined by the thermal resistance of the layers of their skin as shown below, analogous to electrical resistors connected in series in an electrical circuit.

An equivalent circuit diagram representing the thermal resistance of the system
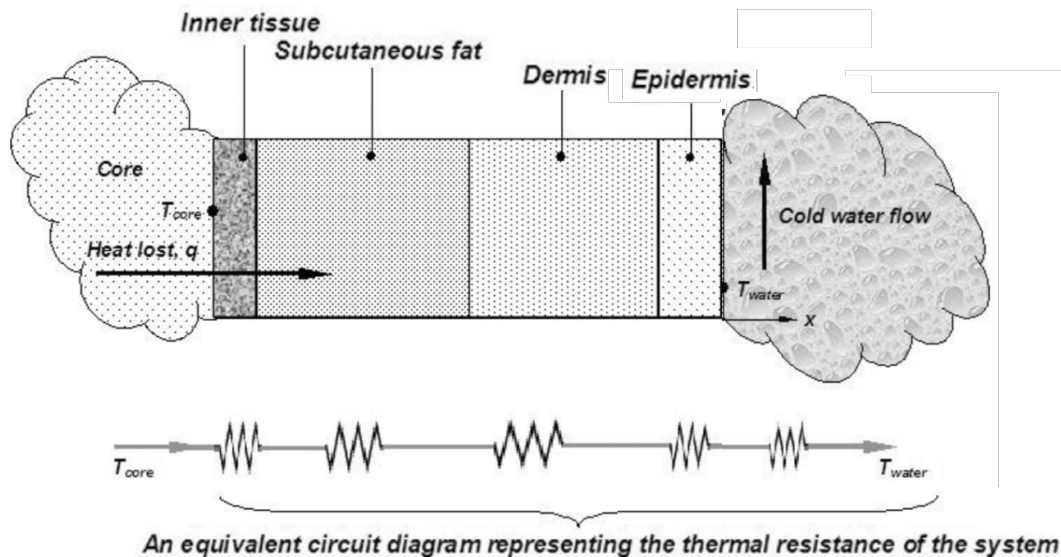
Image credit: Tarlochan and Ramesh (2005) Biomedical Engineering: Applications, Basis and Communications 17 (4) 159-166. CC-BY-4.0.

The electrical resistance (R) of a resistor is related to the electrical conductivity via

$$R = \frac{L}{conductivity \times A}$$

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Where L is the length of the resistor and A the cross-sectional area.
If several resistors are in series then the total resistance is the sum of the individual resistances.

Using an analogous approach, determine the total thermal resistance of a person whose surface area is $A = 1.7m^2$. Use the properties of the tissue layers given in the table below.

Structure	Thickness (mm)	Thermal conductivity (Wm^{-1}K^{-1})
Epidermis	0.08	0.24
Dermis	2	0.45
Subcutaneous fat	5	0.19
Inner tissue	30	0.5

   A. $5 \times 10^{-2} W^{-1} \text{K}$
   B. $2 \times 10^{-2} W^{-1} K$
   C. $0.5 \times 10^{-2} W^{-1} K$
   D. $0.2 \times 10^{-2} W^{-1} K$
   E. $50 \times 10^{-2} W^{-1} K$
   F. $20 \times 10^{-2} W^{-1} K$

This information relates to the following 3 questions.

Apart from voluntarily swimming in freezing water, another extreme activity undertaken by humans is bungee jumping.

In bungee jumping, participants' legs are attached to an elastic cord. They jump off a tall structure, bounce several times, eventually coming to rest.

Image credit: Face Adrenalin, CC BY 3.0 via Wikimedia Commons

| 32 | (1 mark)

Adrenaline (also known as epinephrine) is released by the adrenal glands in situations of extreme stress or excitement (such as just prior to bungee jumping).

Which of the following are **true** statements?
 I.   The endocrine system creates and releases hormones such as adrenaline
  II. The sympathetic nervous system controls "fight or flight" responses
  III. The parasympathetic nervous system controls "fight or flight" responses

  A. I only
  B. II only
  C. III only
  D. I and II
  E. I and III |

| 33 | (1 mark)
The graph below shows the length, L, of a bungee cord as a function of the force, F, applied to stretch it. |
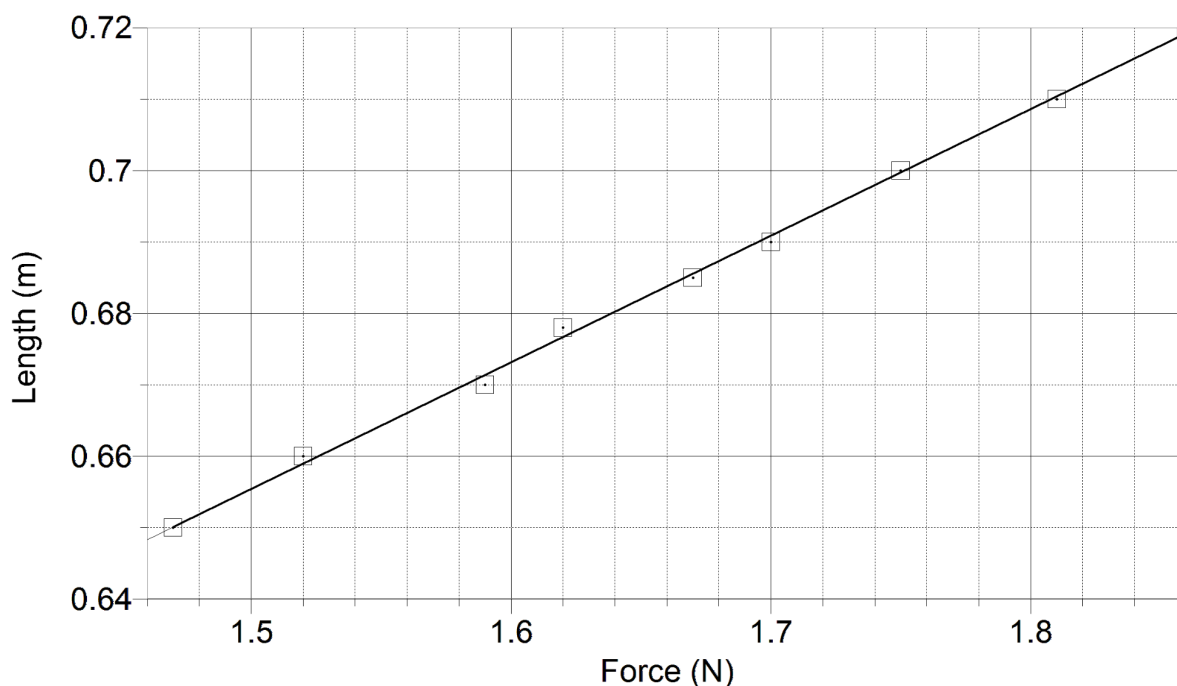
The **spring constant** is a measure of how difficult it is to stretch a bungee cord, and is given by the equation

$F = k(L - L_0)$

where L_0 is the length of the cord with no force applied to it.

Use the gradient of the line of best fit plotted on the graph to determine the spring constant of the bungee cord.
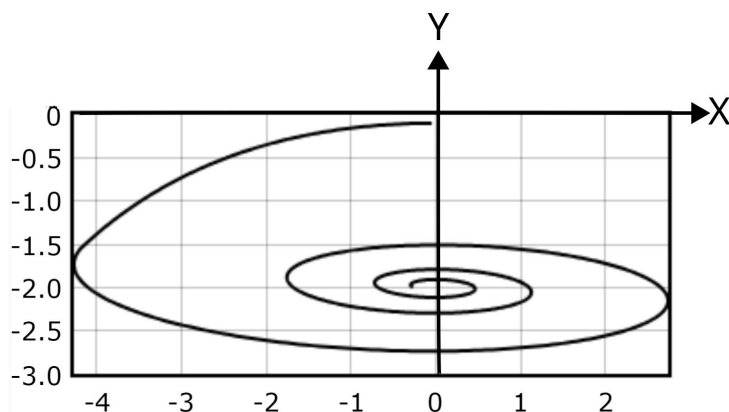
   A. 5.6 m/N
   B. 5.6 N/m
   C. 2.4 m/N
   D. 2.4 N/m
   E. 2.3 N/m
   F. 2.3 m/N
   G. 0.18 m/N
   H. 0.18 N/m

---

34 (1 mark)

Dan, a bungee jumper, jumps off the bridge shown and bounces up and down several times. Each time the maximum height decreases until he eventually comes to rest.

A graph of the motion as a function of two variables is shown below.

What do the X and Y axis represent?

The variable plotted on the X axis is:

        A. Vertical velocity

        B. Time

        C. Vertical displacement from the bridge.

The variable plotted on the Y axis is:

        A. Vertical velocity

        B. Time

        C. Vertical displacement from the bridge.

This information relates to the following 7 questions.

Extremophiles are organisms that can live and reproduce in conditions that would be lethal to most lifeforms. Organisms classed as extremophiles are generally bacteria or archaea, but this group also includes some protists and multicellular organisms, such as tardigrades.

Many types of extremophiles exist, each adapted to survive in a particular environment. For instance, thermophiles can live at very high temperatures; acidophiles can tolerate very acidic environments, and halophiles live in extremely salty water.

Haloquadratum walsbyi is a single-celled organism from the Archea kingdom that is found in water bodies with high salt concentration. It has the unusual feature of being rectangular in shape, and its name, *Haloquadratum* or "salt square", reflects this.

H. walsbyi was first found in a brine pool in the Sinai peninsula in Egypt, and has since been found in hypersaline lakes and water bodies all over the world, including Lake Tyrell in Victoria.

H. walsbyi is often found growing in association with *Dunaliella salina*, a single-celled halophile alga. The image below shows cells of these two species in water from Lake Tyrell in Victoria.
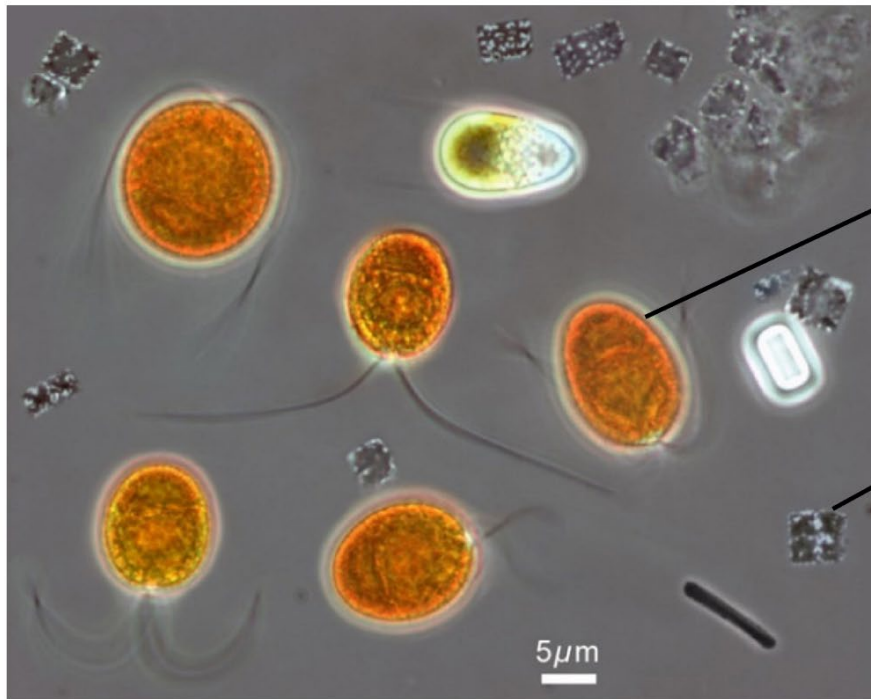
Dunaliella salina

Haloquadratum walsbyi

5µm

Image credit: Mike Dyall-Smith et al. CC BY-SA 4.0, via Wikimedia Commons

35

(1 mark)

Cells of the alga *Dunaliella salina* produce large amounts of a chemical called **glycerol** to help maintain their internal osmotic pressure. Some of this glycerol is excreted into the surrounding water.

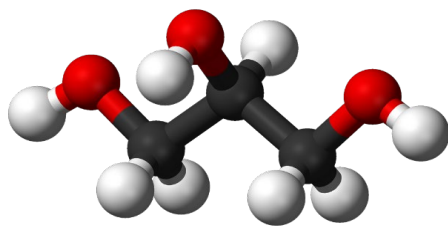*Haloquadratum walsbyi* harvests glycerol as food for its own use.

Based on this information, which of the following terms can be used to describe the ecological relationship between *Haloquadratum walsbyi* and *Dunaliella salina*?

    I.   Symbiotic
    II.   Commensal
    III.   Parasitic

A. I only
B. II only
C. III only
D. I and II
E. I and III
F. II and III
G. I, II and III

| 36 | (1 mark)

Glycerol, the molecule excreted by *Dunaliella salina*, has the formula $C_3H_8O_3$. The molecule is shown above.

Glucose has the formula $C_6H_{12}O_6$.

The chemical reaction that occurs during respiration is a kind of combustion reaction. When an organism uses glucose for respiration, the following chemical reaction occurs:

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$
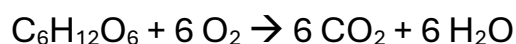
Some organisms can use other carbon-based molecules in a similar way.

If **glycerol** is used for respiration, how many molecules of oxygen are required to produce the same number of CO_2 molecules as are produced from 1 molecule of glucose? |

| 37 | (1 mark)

On the surface of cells of *H. walsbyi* there is a high density of a particular protein called bacteriorhodopsin. This protein is structurally similar to vision proteins in the retinal cells of the human eye. *H. walsbyi* uses its bacteriorhodopsin to harvest light energy which it then uses to drive its own cell processes.

Organisms can be classified according to the way they obtain carbon and energy from their environment.

	Obtains energy from:	
Obtains carbon from:	**Chemical reactions**	**Light**
CO_2 in the environment	Chemoautotroph	Photoautotroph
Carbon-based molecules from other organisms	Chemoheterotroph	Photoheterotroph

Which of the following statements is true?

   i.   *H. walsbyii* is a photoheterotroph |

ii.   A photoautotroph would not undergo respiration

iii.   Humans are chemoheterotrophs

A. I only
B. II only
C. III only
D. I and II
E. I and III
F. II and III
G. I, II and III

---

38 | (1 mark)

An object will float in a liquid if it has a lower average density than the liquid. Salty water is denser than fresh water.

H. walsbyi cells contain numerous small gas bubbles called **vacuoles** (seen as bright spots in the Lake Tyrell photograph above). The vacuoles are usually located around the edges of the cells and help them stay oriented horizontally to the surface of the water.

When floating *H. walsbyi* cells are subjected to high pressures, they sink.

Which of the following statements are true?

  I.   The presence of vacuoles could be an adaptation that allows the cells to capture more light.

 II.   High pressures could cause the gas vacuoles to collapse.

III.   An *H. walsbyi* cell in fresh water would require fewer vacuoles to remain floating at the surface than one in salty water.

A. I only
B. II only
C. III only
D. I and II
E. I and III
F. II and III
G. I, II and III

| 39 | (1 mark)

It took 24 years after the discovery of *H. walsbyi* for it to be successfully grown in the laboratory.

Microbiologists found it very hard to create a nutrient solution that would support the growth of the cells. Among other ingredients, the successful solution is prepared with extremely high concentrations of sodium chloride and magnesium chloride.

What is the formula of magnesium chloride?

    A. MgCl
    B. $MgCl_2$
    C. Mg_2Cl
    D. Mg_2Cl_2 |

| 40 | (1 mark)

The density of an object is calculated as:

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

A salt solution is prepared by dissolving 190g of magnesium chloride in enough water to make up 1.00L of solution. The density of this solution is 1.14g/mL.

Calculate the mass of water, in grams, needed to make this solution. |

| 41 | (1 mark)

One way of characterising organisms is to measure the **GC content** of their DNA. This involves analysing the DNA molecules and measuring the percentage of nucleotides that are either guanine or cytosine.

H. walsbyi has a GC content of 52%.

What percentage of nucleotides in the DNA of *H. walsbyi* are adenine? |

This information relates to the following 3 questions.

A common technique used to monitor the growth rate of microorganisms like is to measure the **optical density** of the solution in which they grow. The technique relies on the fact that individual particles present in the water scatter incoming light in all directions, resulting in less light travelling through to the detector.

The equipment for an optical density measurement is set up as shown below.
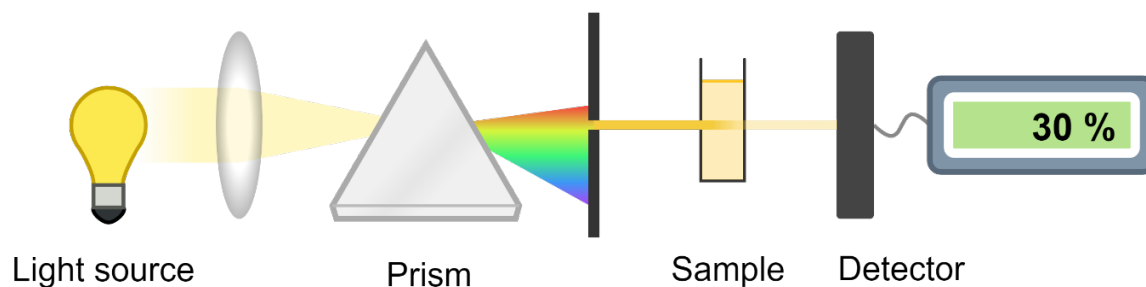
The prism is used to select different wavelengths of light.

The bacterial growth solution is placed in the light beam and the percentage of light transmitted through the solution to the detector is measured.

The transmission value is converted to an optical density value: a high optical density value means a small percentage of light was transmitted through the sample.

42	(1 mark)

Fahad is using the optical density technique to measure the growth rate of bacterial cells.

In doing so, what assumption must he make?

   A. The percentage of light transmitted is directly proportional to the number of bacterial cells present
   B. The percentage of light transmitted is affected by the number of bacterial cells present.
   C. The percentage of light transmitted is only affected by the intensity of the light source.
   D. The percentage of light transmitted is not affected by the number of bacterial cells present.

| 43 | (1 mark)

Which of the following would **decrease** the measured value of the optical density?

    I.   An increased path length (the distance through the sample that the light must travel)
   II.   An increased concentration of cells
  III.   Cells sticking together rather than remaining separate.

    A. I only
    B. II only
    C. III only
    D. I and II only
    E. II and III only
    F. I and III only
    G. I, II and III |
|---|---|
| 44 | (1 mark)

What would Fahad need to do if he wanted to use an optical density measurement to determine the actual concentration of cells (number of cells per millilitre) in the solution?

    A. Measure the optical density for a series of cell solutions of known concentration and compare the unknown to this data.
    B. Nothing: the optical density tells you the concentration of cells directly
    C. Measure the optical density for a known solution with the expected cell concentration.
    D. Plot optical density versus time and calculate the gradient of the curve. |

| 45 | (1 mark)

Understanding the past climate of our planet can help us make sense of current and future climate changes. Hence, a lot of research looks at ways to accurately estimate the past climate of the Earth, including periods of extreme heat and cold.

One method of gathering information on past climate conditions on Earth makes use of microfossils such as **foraminifera**.

These tiny, abundant and diverse marine organisms have been extensively studied and the time periods during which many species existed are well known. Their presence in a rock provides evidence of the time at which the rock sediment was laid down and the chemical composition of their shells gives information on climate conditions.
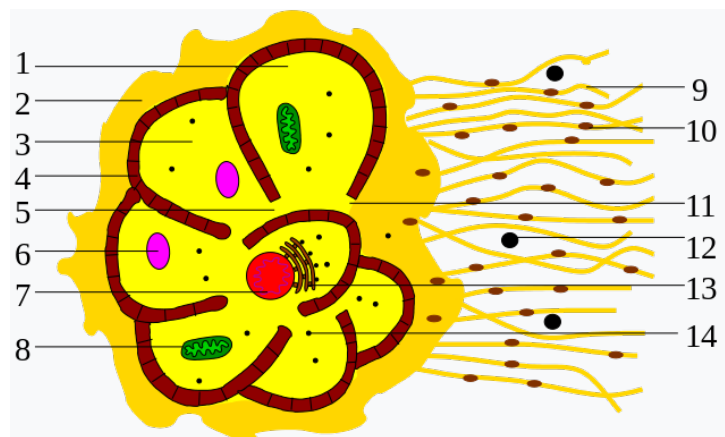

Image credit: Franciscosp2; CC BY-SA-4.0, via Wikimedia Commons.

The diagram above shows a foramnifera organism.

Labels: 1 – endoplasm; 2 – ectoplasm; 3 – chamber; 4 – pores; 5 – foramen; 6 - food vacuole; 7 – nucleus; 8 – mitochondria; 9 - granureticulose pseudopodia; 10 – granules; 11 – aperture; 12 - food particle; 13 - Golgi apparatus; 14 - ribosomes.

Based on the diagram, the foramnifera is:

    A. A eukaryote and an autotroph

    B. A prokaryote and an autotroph

    C. A eukaryote and a heterotroph

    D. A prokaryote and a heterotroph |

46	(1 mark)
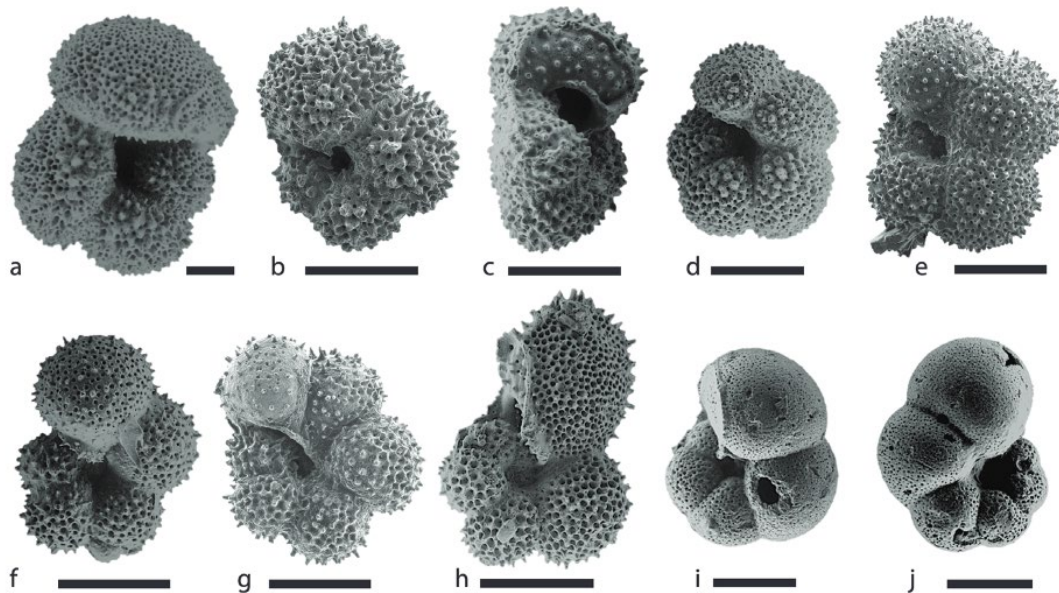
Image credit: United States Geological Survey; public domain, via Wikimedia Commons.

The micrographs above show fossils of ten planktic foraminifera found in sediments from the Eocene era (56 to 34 million years ago). The black scale bar under each micrograph measures 150 micrometres (0.015 cm).

a) Indicate which of the 10 foramnifera above (a-j) is the largest specimen.

b) The height of the largest specimen is closest to:

A. 1cm
B. 0.1cm
C. 0.01cm
D. 0.001cm

| 47 | (2 marks)

Foramnifera shells can provide information on past climate through the ratios of different isotopes captured in the shell material.

With two fewer neutrons, atoms of the isotope oxygen-16 (O-16) are lighter than those of oxygen-18 (O-18).

Water molecules can contain an atom of either of these isotopes. Water molecules containing O-16 (H_2O-16) require less energy to evaporate than water molecules containing O-18 (H_2O-18).

This means water vapour in the air has a slightly higher proportion of H_2O-16 than the liquid water it evaporated from. Additionally, when precipitation (rain and snow) occurs, the heavier H_2O-18 tends to condense first.

Water vapour in the Earth's atmosphere largely comes from evaporation near the equator. Moist air circulates from the equator to the poles; much of the moisture is removed as precipitation before it reaches the poles. Continental icesheets such as that on Antarctica are formed from precipitation.

The marine organisms called foramnifera build tiny calcium carbonate shells. Calcium carbonate has the formula $CaCO_3$, and oxygen atoms in the carbonate ion can come from the surrounding ocean water.

Based on this information, which of the following statements are true?

  I.   Water in the oceans has a higher proportion of O-18 than water vapour in the air.
  II.   The melting of ice caps at the end of ice ages causes a decrease in the proportion of O-18 in the oceans.
  III.   Foramnifera shells formed in the ocean during ice age periods have a higher proportion of O-18 than those formed during warm periods.

    A. Statement I only
    B. Statement II only
    C. Statement III only
    D. Statements I and II
    E. Statements II and III
    F. Statements I and III
    G. All three statements. |

| 48 | (1 mark)

The global climate includes many feedback loops (positive and negative). In a positive feedback loop, the feedback causes the original effect to increase in intensity, leading to extreme results. In a negative feedback loop, the feedback reduces the original effect, preventing or delaying extreme effects.

A thermostat is an example of a negative feedback loop: the thermostat turns the heater on when the room temperature is cold and turns it off when it is warm.

The following three processes are all known to occur on Earth. Identify which of them represent negative feedback loops.

As the temperature of the atmosphere increases:

   I. The ocean absorbs heat from the atmosphere.
   II. Ice melts, decreasing the average amount of sunlight reflected back into space from the surface of the Earth.
   III. The solubility of CO_2 in the oceans decreases.

   A. Statement I only
   B. Statement II only
   C. Statement III only
   D. Statements I and II
   E. Statements II and III
   F. Statements I and III
   G. All three statements. |

| 49 | (1 mark)

Despite all the feedback loops, not every process that occurs on Earth is involved in climate. Which one of the following processes is not involved in Earth's climate system?

   A. The formation of metamorphic rocks.
   B. The formation of soil.
   C. The formation of limestone.
   D. The formation of glaciers.
   E. The growth of forests.
   F. The development of permafrost. |

This information relates to the following 2 questions.

Dengue (pronounced *den-ghee*) fever is a viral disease that is transmitted between humans by several species of mosquito.

People infected with the dengue virus often show mild or no symptoms, but in a small proportion of cases the disease develops into severe dengue, previously known as dengue hemorrhagic fever, which can be fatal. In this form of the disease, blood plasma (but not red blood cells) leaks from blood vessels, leading to shock and potentially death.

50

(1 mark)

In the last two years, the incidence of dengue fever in Central and South America has shown a dramatic increase. This is believed to be due to climate change.

The graph below shows the total number of deaths (blue columns) and case fatality rate (orange line) due to dengue in Central and South America in the first thirteen weeks of 2024.
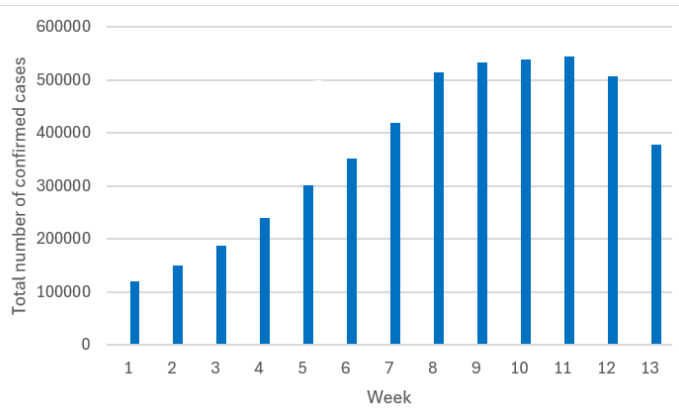
$$case\ fatality\ rate = \frac{number\ of\ deaths}{number\ of\ confirmed\ cases} \times 100$$
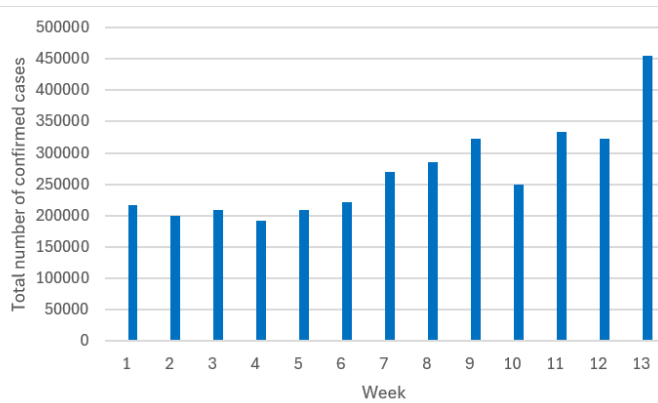

Image credit: Pan-American Health Organisation, 2024.

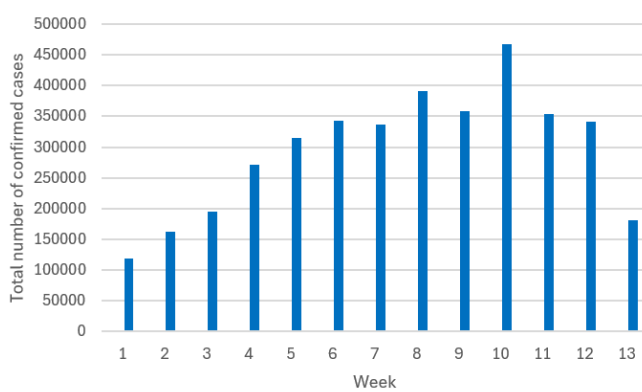Which of the column graphs below best represents the **total number of confirmed cases** over this time period?
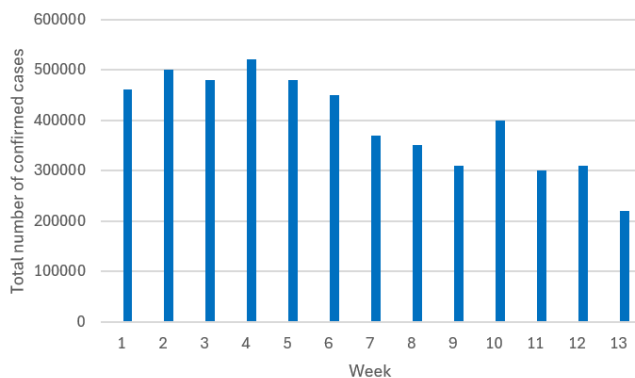
A.

B.

C.

D.

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| 51 | **(1 mark)**
In seeking ways to reduce the transmission of dengue by mosquitoes, a strain of temperature-sensitive mosquitoes is being investigated. |

In seeking ways to reduce the transmission of dengue by mosquitoes, a strain of temperature-sensitive mosquitoes is being investigated.

Some of these mosquitoes carry an allele that means the mosquito larvae die if they are exposed to temperatures of greater than 41°C when they are incubated.

The following genotypes exist:

Genotype	Percentage of larvae that die when incubated above 41°C
TT	5%
Tt	6%
tt	100%

A homozygous temperature-sensitive female is bred with a heterozygous male. The resulting larvae (F1 generation) are allowed to incubate at 42°C.

The surviving F1 larvae are interbred and the same procedure is repeated.

What percentage of the F2 generation larvae will survive the treatment?

This information relates to the following question.

Scientists are also studying the evolutionary relationships between different species of mosquito.

Scientists use **phylogenetic trees** to represent possible evolutionary relationships between organisms. Modern phylogenetic trees are based on DNA analysis.

By reading a phylogenetic tree, you can determine the most recent common ancestor of two organisms. Species are more closely related if they have a more recent common ancestor.
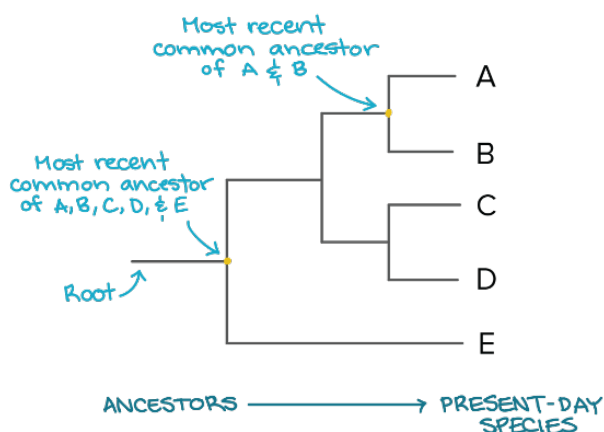

Image credit: Khan Academy, CC BY 4.0

The length of the arms in the tree does not indicate evolutionary distance. For instance, in the diagram above, A and B may be more closely related to each other than C and D are to each other.

Lastly, the order in which the species are shown in a phylogenetic tree doesn't matter, as long as the connections within the tree remain the same.   For instance, the four trees below are equivalent.
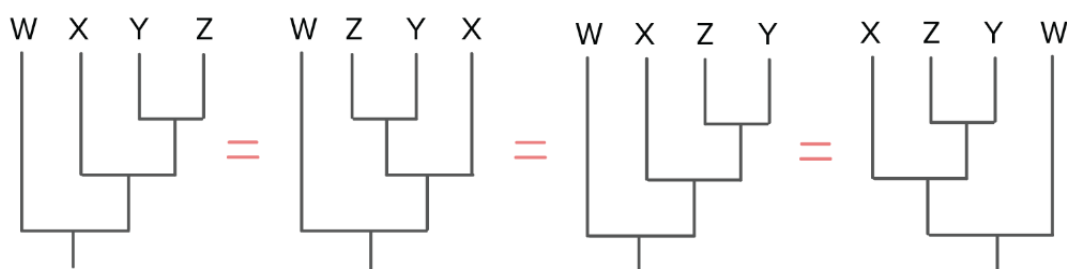

Image credit: Khan Academy, CC BY 4.0

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52 | (1 mark)

In a particular study, scientists want to determine how closely related five different mosquito species are.
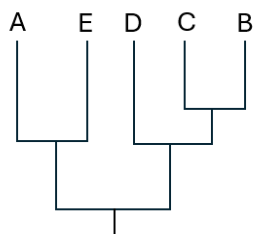
They extract DNA from each of the mosquito species and compare the DNA sequences. They assign a 'distance' value of 1-6 to each pair of species. The smaller the distance value, the more closely related those two species are.

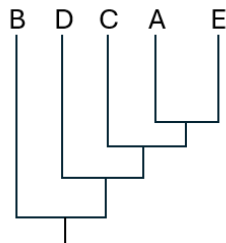The table below shows the distance values for each pair of mosquito species.

	Species A	Species B	Species C	Species D	Species E
Species A	0	6	3	6	1
Species B		0	5	1	6
Species C			0	5	3
Species D				0	6
Species E					0

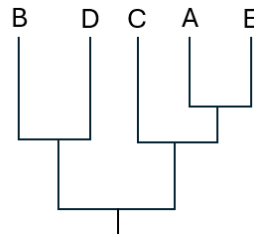Which of the following trees is best supported by the information in the table?

A.

A E D C B

B.

B D C A E

C.

B D C A E

D.

A E C B D

End of exam