**Welcome to the National Scientific Thinking Challenge, 2026.**

Please read these points carefully:

- This is **not** an exam!

- If you want to, you are welcome to use a pen and paper to make notes and you can use a calculator. (You do not have to.)

- Before you can answer each question you need to read some information. All of the information you need is typed in blue, like this. The questions are typed in **bold black** and your answer selection is in black.

- Do not press the "SUBMIT" button until you have finished all of the questions!

- There are six sections for you to try, covering different areas of science.

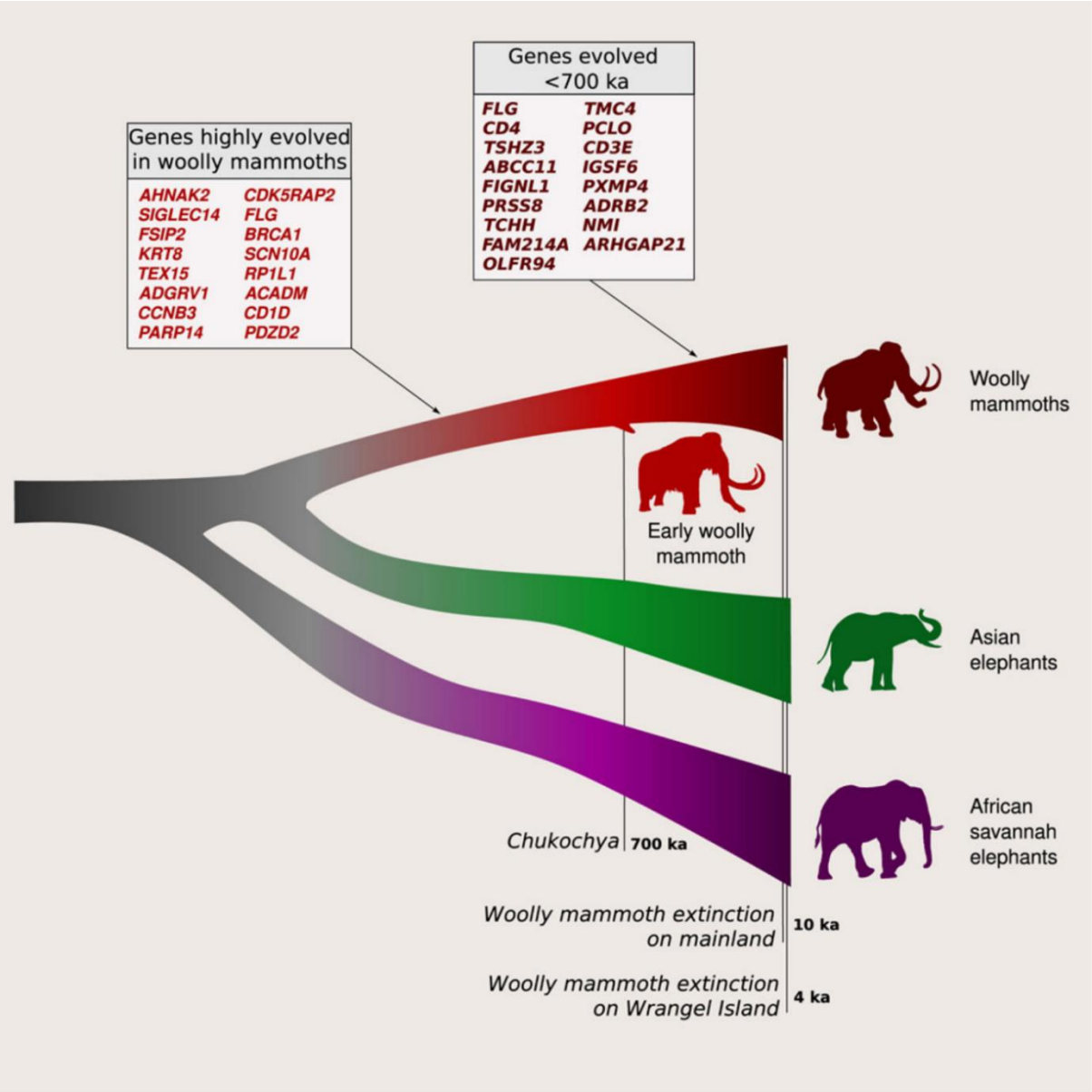
- The questions are multiple-choice, but the order of the answers for each question is randomised for each user. (So, if you select answer A and your friend selects answer C, you could both be correct!) **Also, in this case, the order of the answers will not be the same as the order of the answers on the screen. Just take your time!**

Although the questions are supposed to be challenging, we want to encourage you and this is not an exam. There are 47 questions to be attempted in 50 minutes. Take your time and enjoy!

## Section 1/6

This question is about elephants and how studying their DNA can help us to learn more about them and protect them.

The DNA from elephants was compared with the DNA from woolly mammoths. (DNA can be collected from skin and teeth of mammoths preserved in permafrost.) Look at this diagram that was published in the Journal *Current Biology* in 2013:




*(Wrangel Island* lies about **140 km north of the Chukotka Peninsula** in **Siberia**. *Mainland* refers to Siberia, Russia.)

"Chukochya" refers to the remains of a woolly mammoth preserved in ice at that location: a remote region of Siberia in Far Eastern Russia.

The abbreviation "ka" means "thousands of years ago". So, 700ka means 700 thousand years ago.

*Reference: David Díez-del-Molino et al. Genomics of adaptive evolution in the woolly mammoth. Current Biology, published online April 7, 2023; doi: 10.1016/j.cub.2023.03.084*

Dr. Díez-del-Molino and colleagues compared the genomes (complete DNA sequences) of 23 woolly mammoths (preserved in permafrost) with 28 modern-day Asian and African elephant genomes.

*Wrangel Island location*


Woolly Mammoth, artist's impression. *Source: Britannicca.*

**Question 1: From the information shown on the diagrams above, which extant (living) species of elephant has been found to be the closest living relative of the extinct woolly mammoth? (Sharing over 99% of their DNA.) Hint: look at how the image diagram above branches, a bit like a tree.**

African Savannah Elephants

Manatees

The Asian Elephant

This information is not shown on the diagram.

**Question 2: What could scientists hope to learn by comparing the DNA of mammoths found at Chukochya with the DNA of mammoths which had died more recently and were found on the mainland?**

Due to the excellent preservation of mammoth remains in ice, the researchers could see how big the mammoths were.

The DNA analysis could reveal details about the diet of the woolly mammoth species.

This question is misleading. The scientists were simply explaining that all the samples were from woolly mammoths.

To identify genes that changed during the existence of the woolly mammoth as a species – this might show how the species had adapted to its environment over time.

Scientists have discovered that woolly mammoths shared 99% of their DNA with their closest living relatives alive today. Look at this list of possible genes (instructions) that might be different in mammoths compared to living elephants:

Choice 1: Gene **FGFR2**: This gene influences **hair development**.

Choice 2: Gene **UCP1** (uncoupling protein 1): This gene, important for heat generation in brown fat.

Choice 3: Gene **FLG** which **encodes for profilaggrin**, a large precursor protein found in the outermost layer of the skin (epidermis) which helps **aggregate keratin fibers** in skin cells, forming a strong, protective barrier.

Choice 4: Genes regulating **insulin signaling** and **fat storage**.

**Question 3: Which of choices above are genes most likely to be different in woolly mammoths compared to living elephants? (Hint: mammoths were adapted for survival in extremely cold conditions and modern elephants are adapted for warm conditions.)**

Choices 1, 2 and 4 only

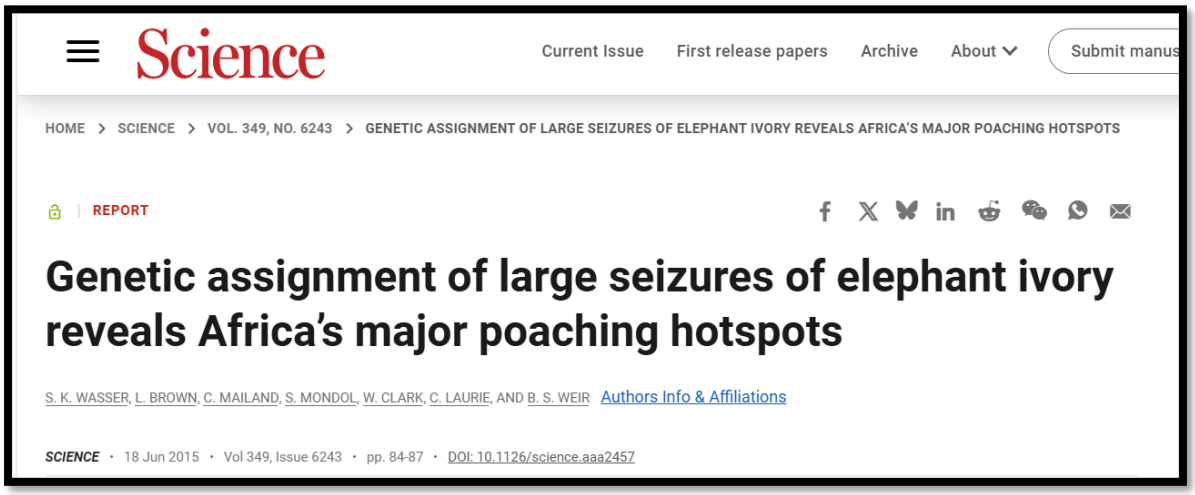
Choices 1 and 2 only

All of them

Choice 3 only

Next, we will consider elephant conservation and, specifically, how science is used to track ivory (elephants' tusks), that is being sold illegally, back to where the elephant lived, in order to stop poaching (killing elephants for their tusks) there.

Illegal ivory poaching threatens the wild elephant population but there have been some very big steps made to stop this. In 2015, an important research paper was published in the prestigious journal, "Science". Here is the title:




**Question 4: In 2015 the elephant population in Africa was estimated to be 415,000 [1] and in 2024 it was estimated to be 550,000 [2] what percentage increase does this represent?**

(550,000 ÷ 415,000) x 100 = 133%

(415,000 ÷ 550,000) x 100 = 75%

550,000 - 415,000 = 135,000 And, (135,000 ÷ 415,000) x 100 = 33%

2024 – 2015 = 9 And, (9 ÷ 2015) x 100 = 0.45%

*(Source 1: The State of the World's Elephant Populations, Our World in Data, Source 2: Statistics, Savetheelephants.org)*

Elephants are scared of bees. The charity Save the Elephants has found that beehive fences have an 80% success rate in keeping elephants away from

farmland and areas of human habitation. As of 2024 there are more than 14,000 beehive fences in 101 locations across 24 countries in Africa and Asia.

This map was reported in the paper published in the journal *Science*. It refers to ivory seized in the Philippines between 1996 and 2005.

The blue squares and the **green** crosses show locations where elephant DNA was sampled. Non-invasive DNA sampling means fresh elephant dung (faeces) can be used, causing no stress to the animals.

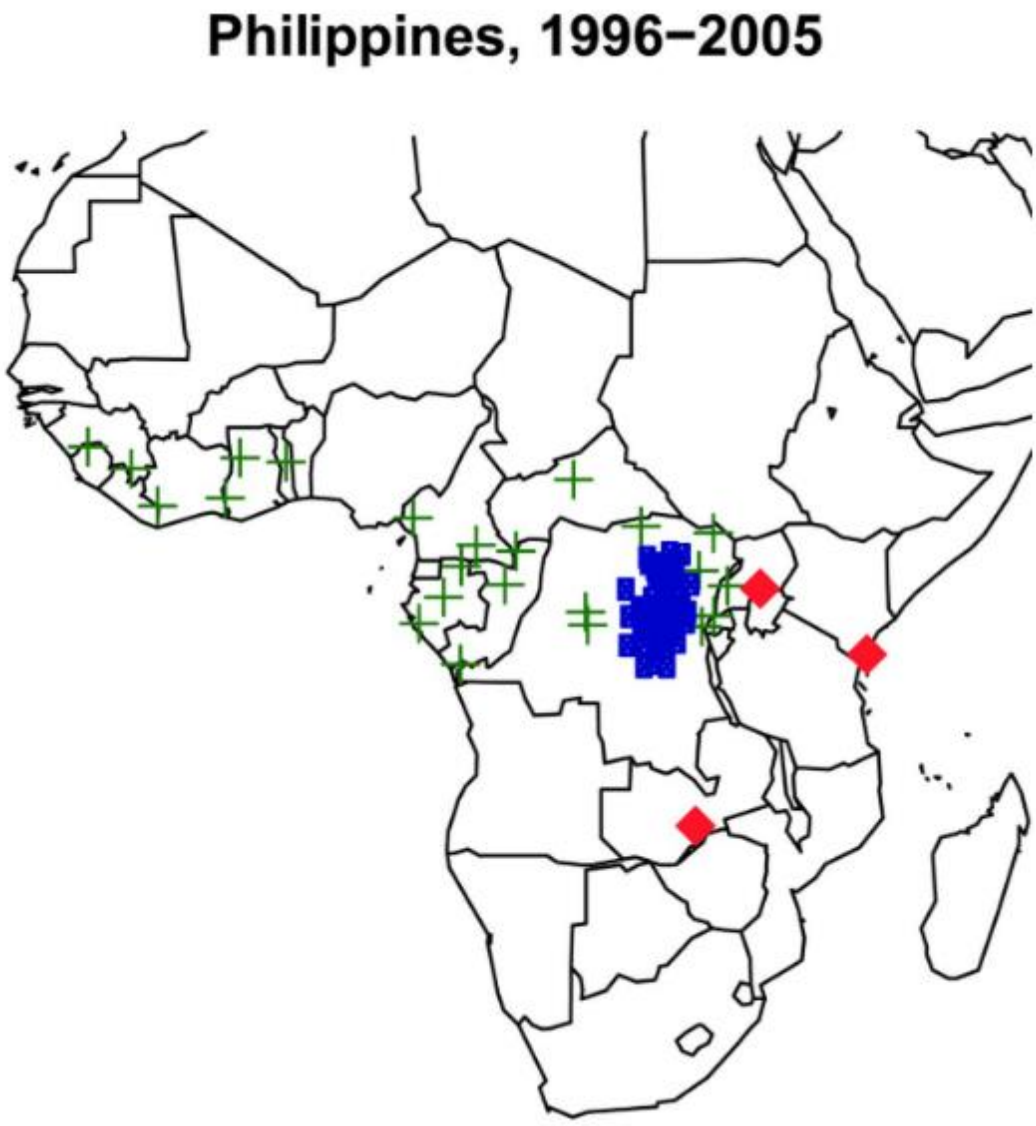



Fig. 1 Philippines seizures from 1996 to 2005 showing their geographical assignments

Information to understand this map:

The word ***assignment*** is used to mean "traced back to". It means the ivory, found in the Philippines, was *assigned* or *traced back to* elephants from a specific location.

**Blue squares** represent ivory assignments.

**Green** crosses represent locations of forest elephant reference samples used in the assignments.

**Red** diamonds represent initial transit locations out of Africa: Uganda, Kenya, Zambia. (Places where the ivory left Africa to be sold.)

This is a political map of Africa to help us make sense of the map published by the scientists. Please note that on this map the red squares simply show the capital cities and have no relevance to the questions being asked here.


**Question 5: using the two maps of Africa above, to which African country was the ivory that was seized in the Philippines, traced back to?**

Ghana

Botswana

The Democratic Republic of Congo

Gabon

(Note: the ivory sales referred to here were **illegal**. The Philippines banned the sale of ivory in 1989.)

**Question 6: using the two maps above, what can you tell about forest elephants in Ghana?**

There was no elephant poaching in Ghana between 1996 and 2005.

There are definitely elephants in Ghana

You cannot draw any conclusions about forest elephants from the information shown on the maps.

No ivory from these elephants was found in ivory shipments seized in the Philippines between 1996 and 2005.

The next map shows information about ivory being sold illegally in Singapore. Note: Singapore banned the sale of ivory completely in 2021.


*Political map, for reference only.*

*Maps showing information relating to illegally sold ivory seized in Singapore:*

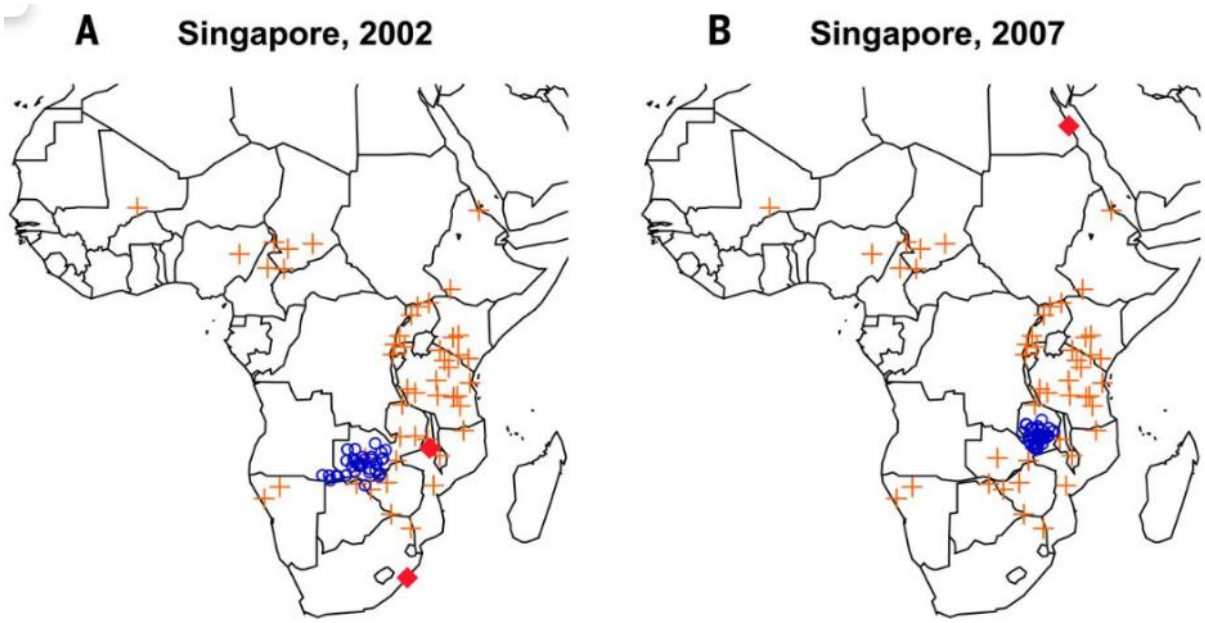



**Fig 2: Singapore seizures from 2002 and 2007**

(Please note that the ivory sales referred to here were **illegal**. The Philippines banned the sale of ivory in 1989.)

**Blue** circles represent ivory assignments.

Orange crosses represent locations of savannah elephant reference samples used in the assignments.

Red diamonds represent initial transit locations out of Africa: Seizure (A) = Malawi via South Africa: seizure (B) = Egypt

**Question 7: Use the maps showing the "Singapore Seizures" of ivory and the accompanying information above. From which African country did the ivory seized in Singapore come from?**

Zambia

Angola

Congo

Mali

**Question 8: From the maps showing the "Singapore Seizures", you can see the transit locations. This means the place from which the ivory was shipped out of Africa to Singapore. Why might it be more likely that illegal ivory shipments would be sent from a coastal port rather than an airport?**

There is less security at a coastal port than an airport

Sending things by sea is slower than by air

Sending things by sea has lower carbon emissions than compared to sending things by air.

A shipment of ivory is large and heavy, so it is easier to send it by ship.

**Question 9: How could the ability to track ivory that is seized in one country back to where it came from be used to save the lives of elephants?**

You can use this information to study the size of elephant populations to see if poaching is causing the number of elephants to drop.

It shows where to concentrate anti-poaching efforts, and it raises awareness of the issue of poaching.

The maps can be used to lead poachers in the wrong directions.

The information on these maps is now at least 20 years old. It is of no use at all.

*For interest:*

China (traditionally, the largest market for ivory) banned the sale of ivory in 2018.

The UK's Ivory Act came into force in 2022.

**A.I. helping elephants to keep out of trouble:**

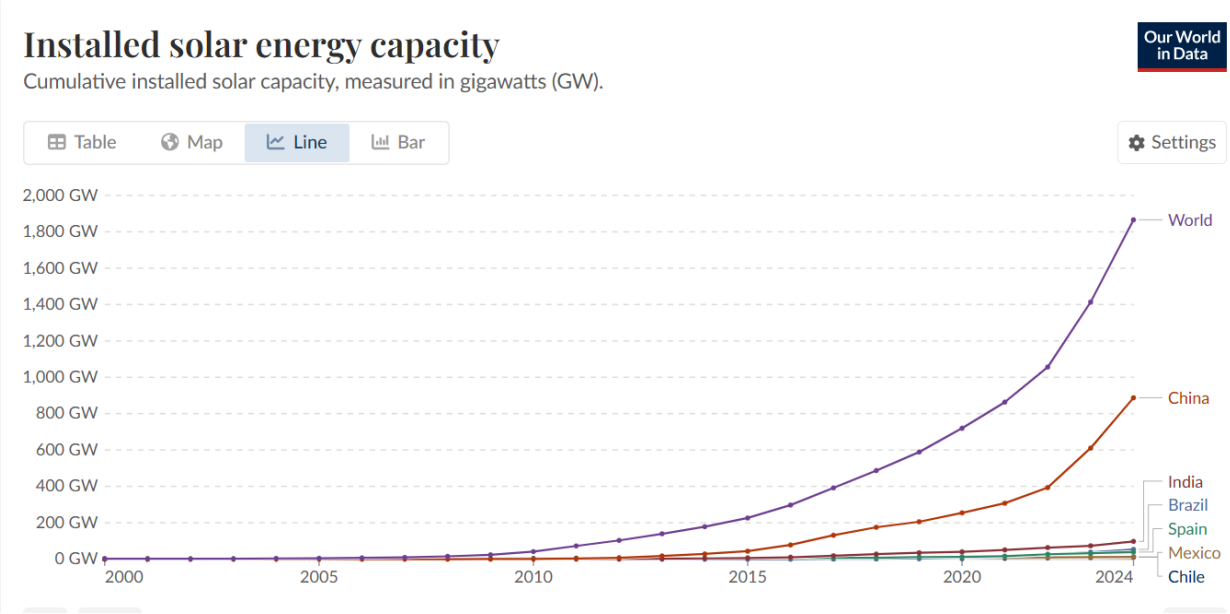
Engineer-turned-conservationist Seema Lokhandwala has developed an **AI-powered** device that can **recognise sounds made by elephants** and play sounds like tiger roars or buzzing bees **to drive herds away from villages** near India's Kaziranga National Park. Early field trials show the device is about 80% accurate in detecting elephants and 100% effective in deterring them.

**End of Section. Do not press "submit", just carry on!**

## Section 2/6

This question is about solar power - electricity generated directly from sunlight using solar, or "photovoltaic", panels.

The website OurWorldInData published this graph:




GW stands for gigawatts. 1 GW = 1 billion watts. (The UK has an average daily requirement of around 30 GW of electrical power.)

This graph shows **Total solar energy capacity.** That is total solar (on- and off-grid) electricity installed capacity, measured in gigawatts. This includes solar photovoltaic and concentrated solar power.

**Solar energy capacity** refers to the maximum amount of electricity that a solar energy system can produce under ideal conditions.

Here are more precise values of solar energy capacity relating to the whole World and the 6 countries to have installed the most solar energy capacity by 2024:

| 2024<br>in gigawatts | |
|---|---|
| World | 1,866.31 GW |
| China | 887.10 GW |
| India | 97.58 GW |
| Brazil | 53.12 GW |
| Spain | 38.59 GW |
| Mexico | 11.99 GW |
| Chile | 10.90 GW |

**Question 10: Using the information provided, approximately what percentage of the total electrical power generated by solar panels globally was produced by China in 2024?**

You cannot answer this from the data provided. The numbers refer to the total solar energy capacity, not the total amount of electricity generated from solar power.

(887.10 ÷ 1866.31) x 100 = 47.5%

You cannot answer this question from the data provided. There is insufficient information about other countries to allow a comparison to be made.

(1866.31 ÷ 887.10) x 100 = 212.6%

**Question 11: In 2024, the UK's total solar capacity was 17.88 GW. What is this as a fraction of China's total solar energy capacity?**

17.88 ÷ 1866.31 = 0.0095, or approximately one hundredth

97.58 ÷ 887.10 = 0.1, or one tenth

17.88 ÷ 887.10 = 0.02, or one fiftieth

It is not possible to answer the question from the information provided.

**Question 12: China's mean (average) daily electricity demand is around 850 GW and that of the UK is around 30 GW. How might this change how we compare China's solar energy capacity to that of the UK?**

It shows us that the UK is very efficient in its use of electricity.

This information only strengthens the conclusion that China is far ahead of the UK in terms of the ability to generate electricity by solar power.

Taking this information into account, we can see that China is (850 ÷ 30 =) 28 times better at generating electricity from solar power than the UK.

It shows that the UK doesn't need be able to generate as much electricity as China. Also, these data only show us part of the story, because they do not take into account electricity generated by other renewable sources, such as wind power.

India's mean (average) electricity demand was **176 GW** in 2024. We are told that in 2024, India had a solar energy capacity of **97.58 GW**. This means India's solar energy capacity is 55% of mean electricity demand.

**Question 13: Read this claim:**

**“India now generates 55% of its electricity from solar power!”**

**Which of the following is the most logical, scientific response to this claim?**

This claim is false. Solar energy capacity has been confused with solar energy production.

Yes, this is clearly possible. The information supports this claim.

The data take no account of the simple fact that solar power does not work at night. Therefore, this claim is highly misleading.

India can probably do that but only under optimum conditions, ie: during a sunny day.

**Question 14: Which of the following claims can be made based upon the information provided.**

Claim 1: The total solar capacity of the World is increasing very quickly (exponentially) with time.

Claim 2: China and India have installed the most solar energy generation systems.

Claim 3: The graph shows that the global total solar energy capacity approximately doubled between 2021 and 2024

Only Claim 1 is valid

All of these claims are valid.

Claim 3 and Claim 2 are valid

None of the claims are valid, they all make huge assumptions.

**For interest:**

As of 2024, China generates approximately 35–38% of its electricity from renewable sources.

China is rapidly expanding its renewable energy infrastructure and aims to reach 1,200 GW of solar and wind capacity by 2030, with a long-term goal of 80% non-fossil energy by 2060.

The UK Government has pledged to reach net zero greenhouse gas emissions from energy production by 2050.

**End of Section. Do not press submit, please just carry on to the next section!**

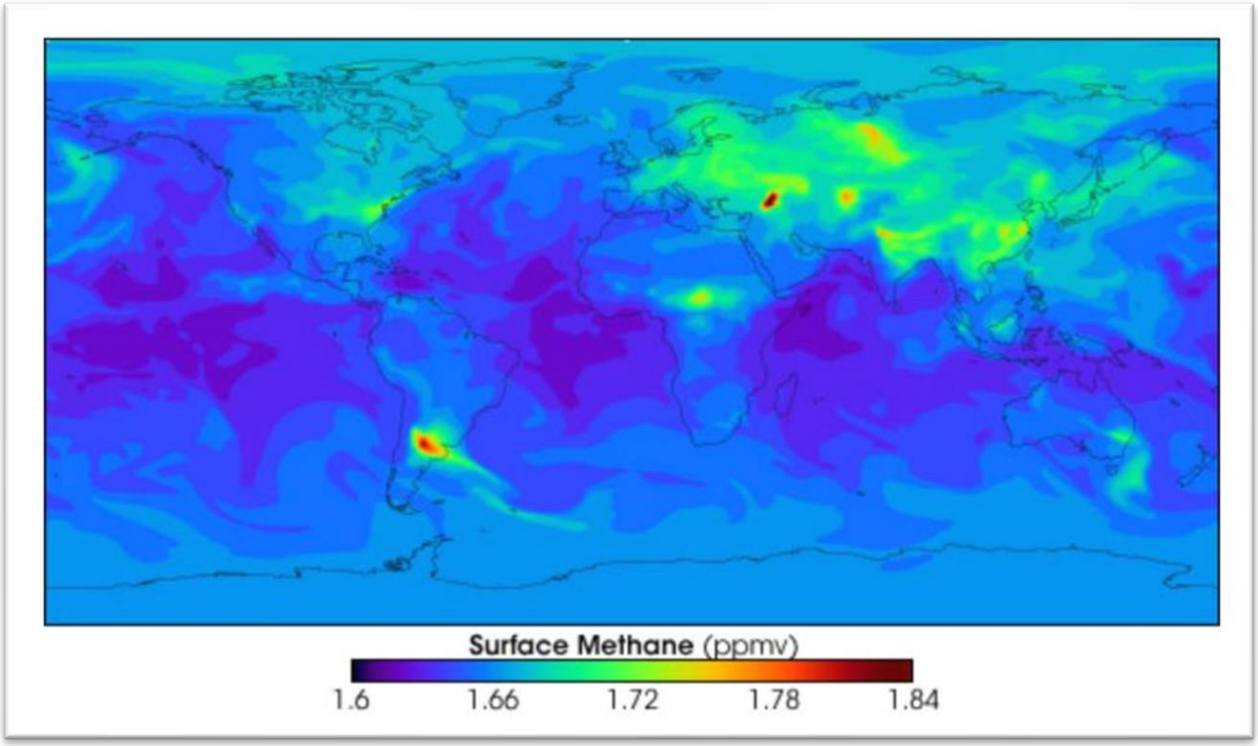
**Section 3/6**

One of the most important and effective ways to combat climate change is to reduce global **methane** emissions.

Methane forms when organic matter decomposes in oxygen-poor environments, such as marshes, rice fields, or the digestive systems of cattle. It can also escape during the extraction of fossil fuels.

Global methane emissions are a major concern because methane ($CH_4$) is a potent greenhouse gas—**over 25 times more effective than $CO_2$** at trapping heat in the atmosphere over a 100-year period.

NASA has used computer models to show how methane is distributed in our atmosphere both at the surface and higher up in the stratosphere (10 - 50 km up from the surface).

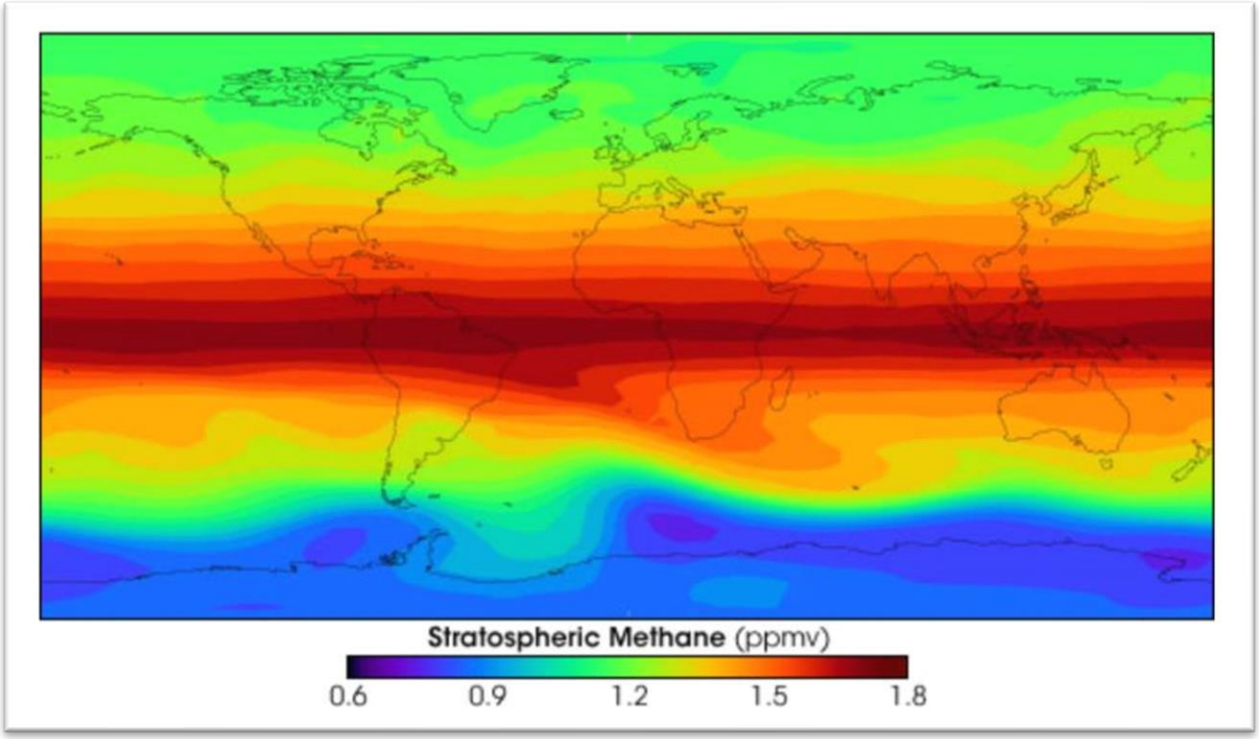



Source: NASA

The abbreviation ppmv means “Parts per Million by Volume”.  EG: 1ppmv means 1 litre of methane per 1 million litres of air.

To picture 1 ppmv, if you imagine 1 million litres of air (roughly the total volume inside a family home with 4 bedrooms), there would be 1 litre (the volume of a carton of orange juice) of methane mixed into that volume of air.

This map shows methane concentrations in the stratosphere, high up in the atmosphere.




Source: NASA

**Question 15: Using the two maps above, showing stratospheric and surface methane concentrations, where, according to NASA, are the lowest concentrations of atmospheric methane to be found?**

At the Earth's surface, in regions close the Equator

It is not possible to work this out from the information provided

Over North America at sea level

In regions close to the equator, high in the atmosphere in a layer called the Stratosphere

**Question 16: Using the two maps above, showing stratospheric and surface methane concentrations, where are the highest concentrations of atmospheric methane to be found?**

Close to the equator, at sea level.

Close to the equator in the Stratosphere (high up in the atmosphere).

It is not possible to work this out from the information provided.

In polar regions, around the North and South Poles.

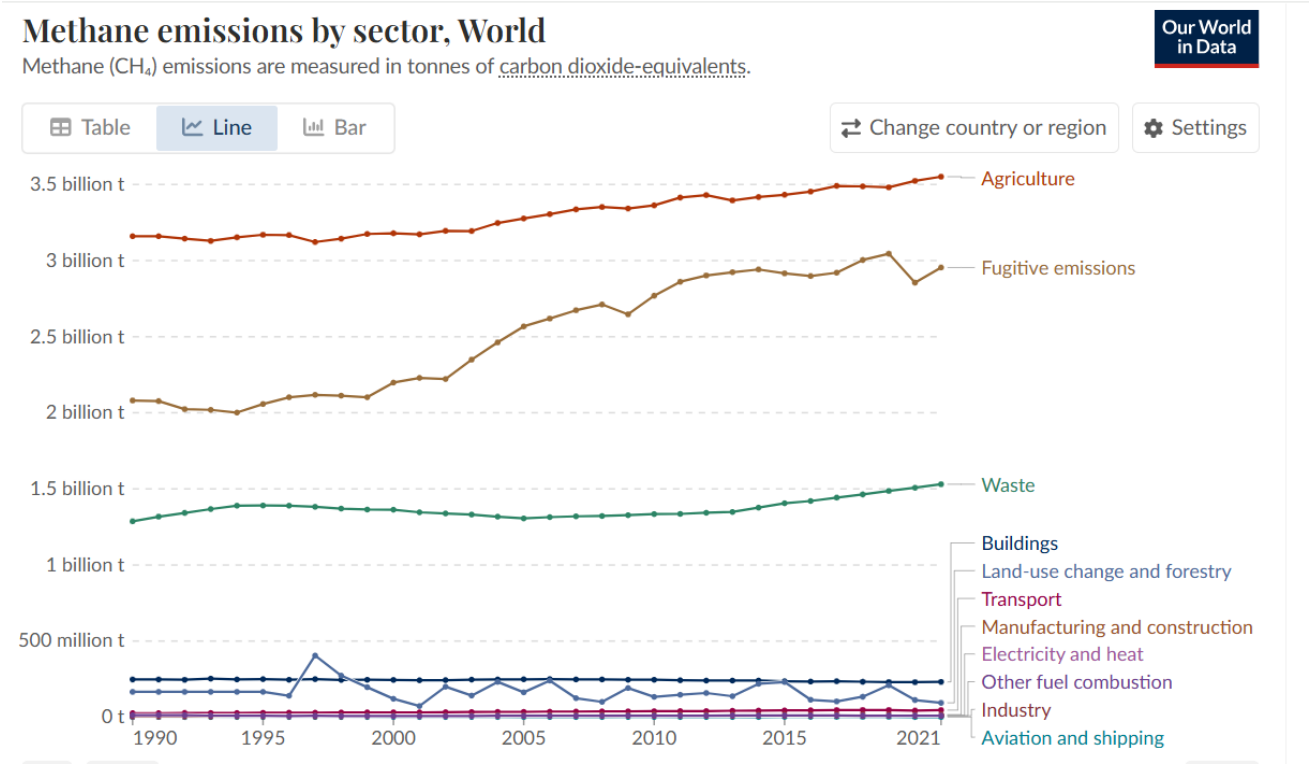
**Question 17:** The overall concentration of atmosphere carbon dioxide is 420 ppmv (parts per million by volume). The overall concentration of methane at is taken to be around 1.8 ppmv. Using this information, how many times more abundant is carbon dioxide in our atmosphere, compared to methane?

You cannot calculate this from the information provided

420 ÷ 1.8 = 233. So, carbon dioxide is roughly 230 times more abundant (by volume) in our atmosphere.

(1.8 ÷ 420) x 100 = 0.42%

[(420 – 1.8) ÷ 420] x 100 = 99.5%




This graph shows global methane emissions by sector:

**Agriculture** produces methane emissions by several processes, for example:

- **Enteric Fermentation** during the digestive process of ruminant animals (like cows, sheep, and goats) which is then exhaled or belched.
- When **animal manure** is stored or treated in systems that promote anaerobic conditions (like pits),
- **Flooded rice fields** create anaerobic conditions in the soil, ideal for methane-producing microbes

**Fugitive emissions** are caused by methane escaping into the atmosphere unintentionally. Fossil fuel extraction is by far the biggest cause of this.

"**Waste**" refers to methane emitted from landfill refuse sites (Waste management.)

"**Buildings**" can lead to methane productions from sources such as wastewater and sewage tanks.

**Question 18: According to the data presented on the graph above, which sector is responsible for the largest contribution to global methane emissions?**

Buildings

Waste

Fossil fuel extraction

Agriculture

**Question 19: Approximately, what quantity of methane was released into the atmosphere in 2021 due to "waste" management?**

Considered in terms of its ability to trap heat in the atmosphere, it is a mass equivalent to approximately 1.5 billion tonnes of carbon dioxide.

Approximately 1.5 billion tonnes

As a greenhouse gas, a mass equivalent to approximately 1.5 million tonnes of carbon dioxide.

It is not possible to answer this question using the information shown on the graph above.

Here is part of a table of physical data relating to methane:

| Property | Value | Unit | Value | Unit |
|---|---|---|---|---|
| Autoignition temperature | 810 | K | 537 | °C |
| Boiling Point | 111.51 | K | -161.6 | °C |
| Critical density | 10.139 | $mol/dm^3$ | 162.7 | $kg/m^3$ |
| Critical Pressure | 4.5992 | MPa=MN/m2 | 45.99 | bar |
| Critical Temperature | 190.56 | K | -82.59 | °C |
| Critical Volume | 98.63 | $cm^3/mol$ | 0.00615 | $m^3/kg$ |
| Density, gas | 41.0 | $mol/m^3$ | 0.657 | $kg/m^3$ |
| Density, gas at STP; 32°F/0°C 1 atm | 44.7 | $mol/m^3$ | 0.7168 | $kg/m^3$ |
| Density, liquid at -260 °F/-162°C | 26429 | $mol/m^3$ | 422.6 | $kg/m^3$ |
| Flammable, gas and liquid | yes | | | |
| Flash point | 85 | K | -188 | °C |
| Gas constant - R | 518.28 | J/kg K | 0.1440 | Wh/(kg K) |
| Gibbs free energy of formation | -51 | kJ/mol | -3179 | kJ/kg |
| Heat (latent) of vaporation | 8.19 | kJ/mol | 511 | kJ/kg |
| Specific heat, Cp | 35.8 | J/mol K | 2.232 | kJ/kg K |
| Specific Heat, Cv | 27.4 | J/mol K | 1.709 | kJ/kg K |
| Heat of combustion | -890.8 | kJ/mol | -55528 | kJ/kg |
| Heat(enthalpy) of formation | -75.00 | kJ/mol | -4675 | kJ/kg |
| log KOW (Octanol/Water Partition Coefficient) | 1.09 | | | |
| Melting point | 90.55 | K | -182.6 | °C |
| Molecular Weight | 16.042 | g/mol | | |
| Solubility in water | 0.022 | mg/ml | | |

*Source: Engineeringtoolbox.com*

**Question 20: Below what temperature would methane exist as a solid (at atmospheric pressure)?**

511 °C

-188 °C

-182.6 °C

This information is not shown on the table above

Some good news!

*Asparagopsis taxiformis* is a species of **red algae** with a wide distribution in **tropical to warm temperate waters**. It's gaining attention for its powerful ability to reduce methane emissions from ruminant livestock like cattle.

Asparagopsis taxiformis:

*Source: greenergrazing.com*

Scientists have found that adding a very small amount of these red algae, dried and in pellet form, to cattle feed can reduce enteric (from the gut) methane production by as much as 80%. This has been evaluated in scientific trials and has caused no issues to the health of cattle.

End of section. Do not press submit, just carry on to the next section.

## Section 4/6

This question is about nuclear power.

Nuclear power is very reliable, and, in operation, a nuclear power station does not emit carbon dioxide into the atmosphere.

There is a way to design nuclear reactors to make them, potentially, even safer than the type being used today. These are called **"molten salt reactors".**

These use a fuel (thorium) that is more abundant and safer than the fuel used in existing nuclear reactors.

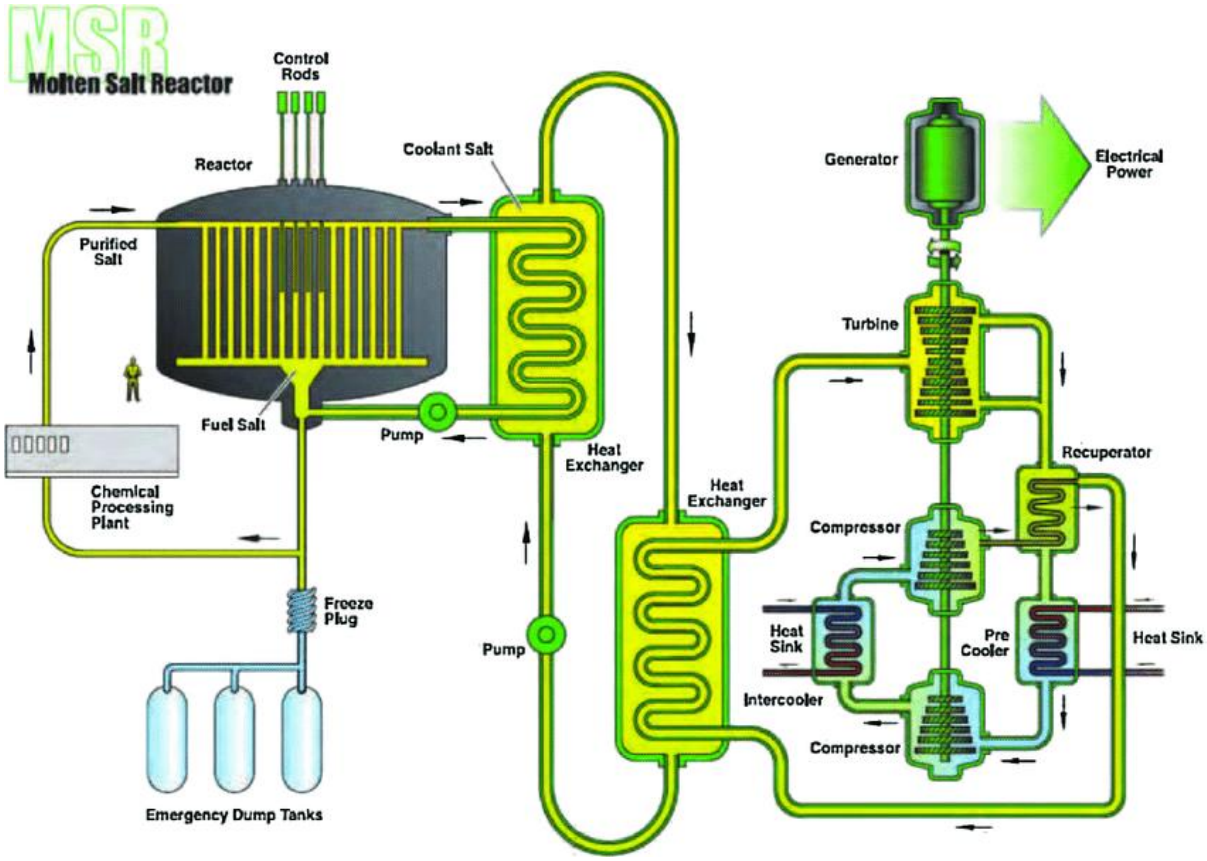
In a molten salt reactor, the fuel is added to a hot liquid (molten salt) that is flowing around inside the reactor. The rate of the nuclear reaction is controlled by adjusting the quantity of nuclear fuel added to the molten salt before it flows into the reactor.

If a molten salt reactor overheats, it will slow down and stop without any human intervention.

China has already built the world's first molten salt reactor in the Gobi Desert.


*Credit: interestingengineering.com*

This diagram shows how a molten salt reactor works.




*Source: researchgate.net*

**Question 21: What do you think might be happening inside the reactor?**

The nuclear fuel is added and it is being converted into safer compounds.

Salt can be added and purified as it flows through the reactor.

The nuclear (potential) energy of the fuel is converted directly into electricity.

The nuclear fuel, dissolved in a special blend of salts, is reacting and a large amount of heat is being released.

**Question 22: The "freeze plug" is a safety feature. If the reactor were to malfunction (go wrong) the temperature inside the reactor goes up. What do you think the freeze plug might do in this situation?**

The freeze plug would freeze the contents of the reactor, stopping the nuclear reaction happening inside.

Engineers would pull this plug out and the reaction happening inside the reactor would stop.

The freeze plug would melt, the molten contents of the reactor would drain into the emergency dump tanks, removing the fuel from the reactor and stopping the reactor completely.

It would do nothing at all in this situation.

A **heat exchanger** is a device that transfers heat from one fluid (liquid or gas) to another without the fluids mixing or coming into direct contact with each other.

**Question 23: How does this nuclear reactor generate electricity?**

The heat inside the reactor spins the pumps backwards and this has the effect of generating electricity.

The nuclear reactor creates electricity as a waste product, and the electrical current is carried away from the reactor with the molten salt.

The heat from inside the reactor is used to turn water into steam. This steam is used to turn a turbine (fan) which spins a generator to make electricity.

The molten salt is composed of charged particles called ions and when these flow through the heat exchangers, the flow of charged particles creates an electrical current.

**Background information:**

**Atoms** have a tiny nucleus (containing particles called protons and neutrons) orbited by fast moving electrons.

The element **uranium** can exist as uranium 233 (U-233). This means there is a total of 233 particles (protons and neutrons) in its nucleus. (92 protons and 141 neutrons, in this case.)

Whilst all uranium atoms have 92 protons, they may have different numbers of neutrons. Atoms of the same element that have different numbers of neutrons in their nuclei are called **isotopes**. This explains why uranium exists as uranium 233, uranium 235 and uranium 238.

**Nuclear fission** occurs when an atomic nucleus splits apart (usually after being hit by a fast-moving neutron). A vast amount of energy is released during this process.

An atom that can release energy by nuclear fission and can be used as a nuclear fuel is called "**fissile**".

An atom that is not fissile but can change into an atom that can do fission is called "**fertile**".

Here are four different **isotopes**. (U = uranium and Th = thorium.) You will need this information to answer the next question:

| | |
|---|---|
| Th-232 | **Fertile (turns into U-233)**. More than 3 times more abundant (plentiful) on Earth than uranium. Can be produced as a by-product from titanium mining. |
| U-233 | **Fissile**. |
| U-235 | **Fissile**. Used currently in nuclear power stations operating globally. Can be used make nuclear weapons. |
| U-238 | **Neither fissile nor fertile**. (Does emit alpha radiation, though.) |

**Question 24: Of the four radioisotopes listed above, which one would make the best nuclear fuel?**

Th-232. It is the most abundant (plentiful) of the isotopes listed and, inside the reactor, it changes into a fissile form of uranium (U-233) that is not used in weapons.

U-233. Is the best fuel to use because it is fissile but is not used to make weapons.

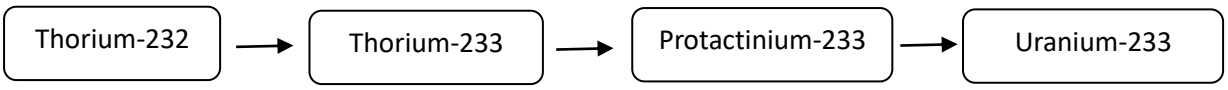
U-235. Is the best fuel to use because it is the fuel already used in nuclear reactors.

U-238. Is the best fuel to use because being neither fissile nor fertile, it is going to be very safe.

**This is the order in which nuclear reactions occur inside a molten salt reactor:**

1. **Thorium-232 (Th-232)** absorbs a neutron and becomes **thorium-233 (Th-233)**
2. **Th-233** undergoes a nuclear reaction and becomes **protactinium-233 (Pa-233)**
3. **Protactinium-233** undergoes a nuclear reaction and becomes **uranium-233 (U-233)**

**On a flow chart, this would be:**

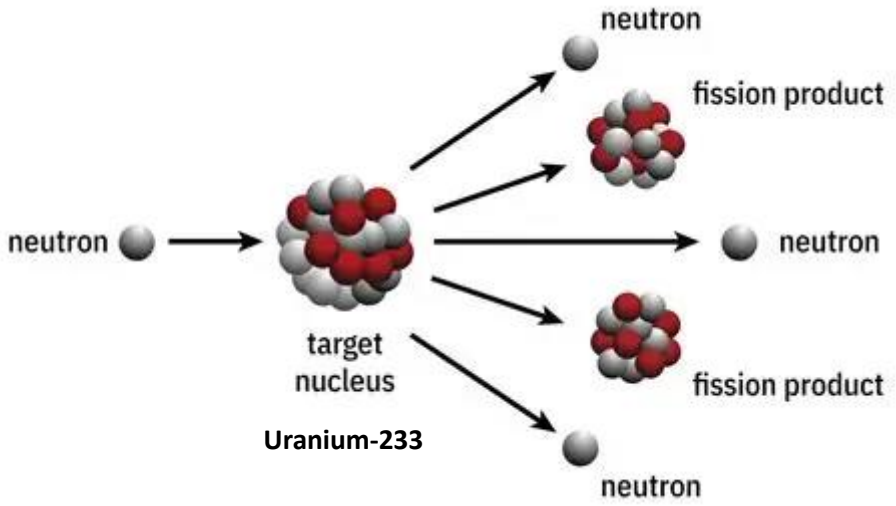



Once Uranium-233 has been formed, the nuclear fission reaction used to release a lot of heat can happen:

4. Uranium-233 absorbs a neutron, becomes unstable and its nucleus breaks apart (fission).
5. A huge amount of energy is released as heat. (This boils water, makes steam, turns a turbine and spins an electrical generator)
6. Uranium-233 changes into the elements strontium and xenon.

On average 2.48 neutrons are released per thermal fission (each time a U-233 nucleus "fissions" or splits up)

A diagram of uranium 233 undergoing nuclear fusion might look like this:




Source: researchgate.com

**Question 25: Which sentence best explains how heat is transformed from nuclear energy inside the reactor?**

233 Uranium atoms absorb neutrons and releases a lot of energy.

The nucleus of a Uranium atom with 233 particles in it, absorbs a neutron, becomes unstable and breaks apart, creating smaller atoms. A large amount of energy is released.

A neutron engulfs the uranium atom and a lot of heat is released.

A Uranium atom with 233 particles in its nucleus absorbs a particle called a neutron and turns into something called fission and other smaller atoms.

**Question 26: How can it be that, on average, 2.48 neutrons are released during the fission of uranium 233, when the diagram above clearly shows 3 neutrons being released?**

The diagram is wrong. It should show 2.48 neutrons being released.

It is incorrect. There is simply no way this can happen.

The number 2.48 means that during nuclear fission, atoms are broken up and a large amount of energy is released.

Sometimes the reaction releases 2 neutrons and sometimes it releases 3 neutrons. If you take the average (mean) number of neutrons released for millions of these reactions the answer is 2.48.

To start the whole process requires one neutron to collide with a thorium atom. The process generates an average of 2.48 neutrons per reaction. The extra neutrons can then be used to create more fuel than can be used up and so, this reactor is called a "breeder reactor".

A molten salt, thorium breeder reactor is potentially very safe, shutting down if it starts to overheat:

- If there was a fault inside the reactor, the rate of the nuclear reaction would increase and the temperature inside the reactor would rise.
- Neutrons produced in the reactor would now travel much faster (they have more energy).
- At high temperatures, the moderator (control rods) made from graphite become less able to absorb neutrons (mainly because the atoms in the control rods are vibrating more and this decreases the density of the material).
- To change into uranium, thorium has to absorb **low energy** neutrons (colliding with lower speeds).

**Question 27: A molten salt reactor cannot catch fire or explode. Which statement below is the best explanation of this?**

Higher temperatures mean control rods are less able to absorb neutrons and so they cannot turn into the fuel the reactor needs.

Hotter temperatures mean faster neutrons, but thorium 233 has to absorb slower / low energy neutrons to be changed into more fuel for the reactor. The fuel that has already been made soon runs out and the reaction stops.

At higher temperatures, the nuclear fuel in the reactor is used up very quickly and the reactor will stop without any human interaction.

At high temperatures, the control rods are less able to absorb neutrons. This situation leads to the nuclear reaction becoming faster and faster until it is uncontrollable.

*End of Section. Do not press "Submit" just carry on to the next section.*

## Section 5/6

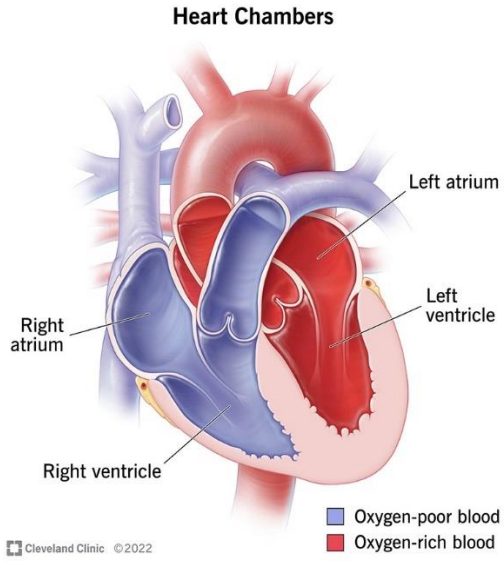
**This question is about the human heart and sleep.**

Electrical signals, carried to the heart by nerves, cause the muscles of the heart to contract, pumping blood around the body.

Firstly, the atria (chambers at the top of the heart) pump blood into the ventricles, which are at the bottom of the heart.

The ventricles contract and pump blood out of the heart to the lungs (from the right ventricle) and around the body (from the left ventricle).

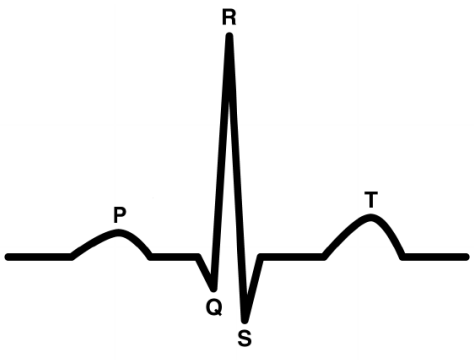
(Note on language: *atria* is the plural of *atrium*)




Doctors can use something called an electrocardiogram (ECG) to study the heart in a lot of detail. An ECG monitors the electrical activity of the heart. It is a non-invasive, painless process and is performed by sticking very sensitive electrodes onto the skin at different positions on the body.

> *(The first ECG was published in 1888 by Augustus Waller. Apparently, he used to give demonstrations of ECGs using his dog, Jimmy, who would patiently stand with his paws in jars of salty water whilst an ECG was recorded!)*

A typical ECG signal for a single healthy heartbeat looks like this:




**P**: atrial depolarisation (the contraction or beat of the atria)

"**QRS** complex": ventricular depolarisation (the contraction or beat of the ventricles)

T: ventricular repolarization (the ventricles are getting ready to beat again)

**Question 28**: what is a likely reason for there not being a signal on an ECG that corresponds to atrial repolarisation (the atria getting ready to beat again)?

The atria beat at exactly the same time as the ventricles

An atrial repolarisation signal is hidden by the large size of QRS complex

The atria do not need to repolarise

The atria repolarise automatically

**Question 29**: In which direction should an ECG trace be read, to show how the heart works in the in the correct order?

From left to right

From right to left

The ECG appears all at the same time because everything about a heartbeat happens at once.

There is no way to answer this question because we cannot see the trace being formed.

Look at this ECG of a normal, healthy human heart:

*Credit: ECGlibrary.com*

You are going to be asked to use the information below to work out the pulse rate of this patient:

**Heart Rate from an ECG**

Identify the QRS complex (this is generally the biggest wave); count the number of large squares between one QRS wave and the next; divide 300 by this number to determine the rate. This has been done for us in Table 2 below.

**Table 2: Some common heart rates as determined by analysis of the QRS complex**

| Number of large squares between QRS complexes | Heart rate (bpm) |
|---|---|
| 5 | 60 |
| 4 | 75 |
| 3 | 100 |
| 2 | 150 |

Source: Chapter 3, ***Cardiology Explained,*** *Euan A Ashley and Josef Niebauer*:

**Question 30**: using the ECG of the normal, healthy human heart above, choose the best estimate of the patient's pulse rate from these options:

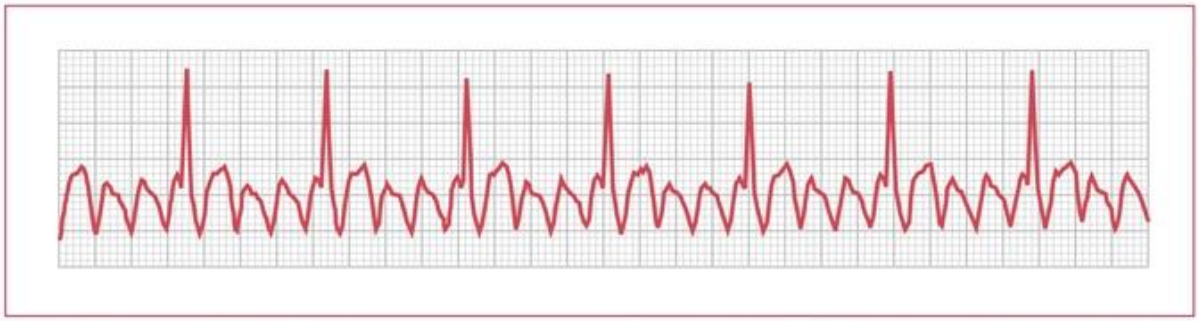
Exactly 62 bpm

100 bpm

Slightly under 50 bpm

Around 75 bpm

Look at this ECG trace of a patient with who has a problem with their heart:



*Credit:* ***Cardiology Explained,*** *Euan A Ashley and Josef Niebauer. London: Remedica, 2004.*

**Question 31: This shows there is a problem with the heart of this patient. What might it show?**

*Ventricular flutter*: the ventricles of the heart are beating more frequently than they should

The patient has an unusually high pulse rate – a condition called *tachycardia.*

*Atrial flutter*: the atria of the heart are beating more frequently than they should.

The patient has an extremely uneven pulse rate – a condition called *arrythmia*.

The human body has what is called the Autonomic Nervous System (ANS). The function of this is to control essential functions within the body which we do not have to think about consciously. These things include breathing rate, the digestion of food and, of course, heart rate.

The Autonomic Nervous System (ANS) has two branches:

- **Sympathetic nervous system**: "fight or flight"
- **Parasympathetic nervous system**: "rest and digest"

It is the parasympathetic nervous system that tells the heart rate to slow down when you are in a relaxed state. The electric signals controlling this are carried from the brain by the Vagus Nerve.

**When we exercise, our pulse rate increases**. Microsoft Copilot, a popular A.I. search engine was used to suggest four reasons why this might be the case. Here are the reasons that were given:

I. **Increased Oxygen Demand**
Muscles need more oxygen when you're active. To meet this demand, the heart pumps faster to deliver oxygen-rich blood more quickly to working muscles.

II. **Removal of Carbon Dioxide and Waste Products**
Exercise produces more carbon dioxide and metabolic waste. A faster heart rate helps transport these waste products away from muscles and to organs like the lungs and kidneys for removal.

III. **Sympathetic Nervous System Activation**
Physical activity stimulates the sympathetic nervous system (the "fight or flight" response), which releases adrenaline. This hormone increases heart rate to prepare the body for increased physical demands.

IV. **Maintaining Blood Pressure and Circulation**
As muscles contract and blood vessels dilate during exercise, the heart compensates by beating faster to maintain adequate blood pressure and ensure continuous circulation throughout the body.

**Question 32: The search engine warned us that "AI generated answers may be incorrect". We should always think about the answers we are given and be prepared to check them further. To the best of your knowledge, which, if any, of these suggestions are incorrect?**

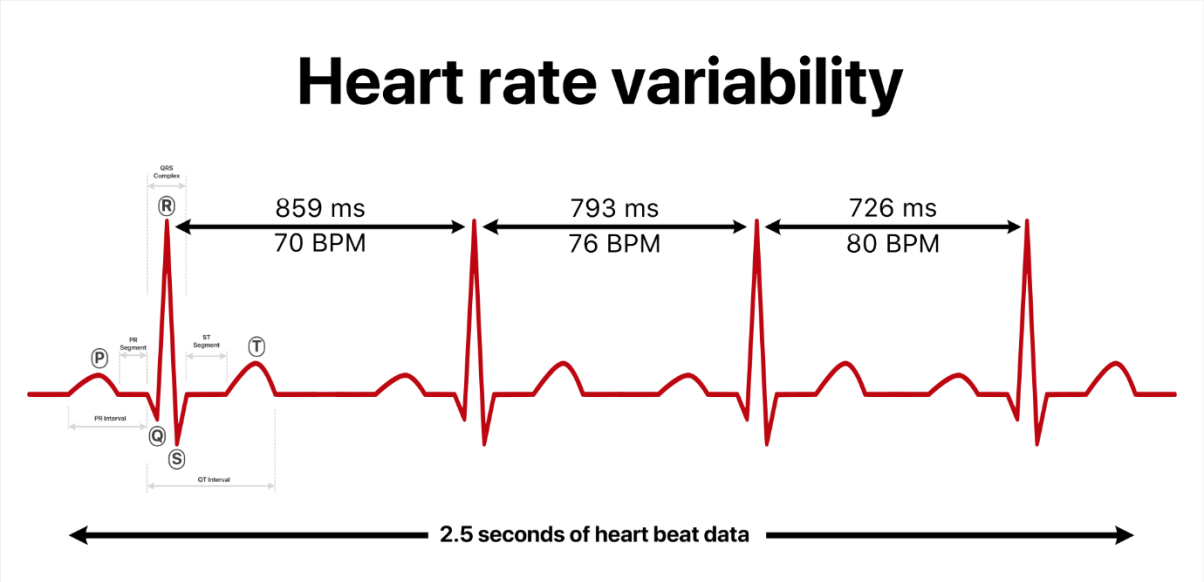
None of them. All of the four suggestions are sensible and explain why heart rate increases when we exercise.

Only Reason I, about increased oxygen demand, is correct.

Reason IV, about maintaining blood pressure and circulation, is most like to be incorrect.

Reason III about sympathetic nervous system activation, is incorrect – it does not really explain why the heart rate increases when we exercise.

Heartbeats do not occur at exactly the same time interval. In fact, if they did, the person would almost certainly be either extremely stressed or unwell.




*Source: wikipedia.org/wiki/Heart_rate_variability#/media/File:Heart_rate_variability_(HRV).svg*

This diagram, produced for Wikipedia, is a great image. It shows how the interval between successive heartbeats is not exactly the same.

(The letters ms stand for milliseconds and 1 ms = 0.001 second. BPM: beats per minute).

The diagram tells us that a time interval of 859 ms between two, adjacent heartbeats (two, adjacent R peaks) is equivalent to 70 bpm (beats per minute).

**Question 33: If we know that the time interval between two heartbeats is 859 ms, how can we calculate that the equivalent heart rate is 70 beats per minute (bpm)?**

You can't calculate this from the information provided.

859 ms = 0.859 seconds per beat. 1 ÷ 0.857 = 1.164 beats per second. 1.167 x 60 = 69.8 beats per minute which rounds up to 70 BPM.

It cannot be calculated directly, the pulse rate would have been collected using a separate heart rate monitor.

(0.859 x 2.5) ÷ 3 = 0.7158 Multiply by 100 to obtain 71.58. This rounds down to 70 BPM

The time interval between normal beats is taken as the time interval between successive, normal R peaks on an ECG trace. Scientists and doctors call this the ***NN interval*** (normal to normal).

**Question 34: what is the range of the NN intervals shown in the diagram above?**

80 – 70 = 10 BPM

895 – 726 = 169 ms

859 – 726 = 133 BPM

859 – 726 = 133 ms

Scientists have long known that **when we are relaxed, our heart rate is not perfectly regular**. This is called Heart Rate Variability. (HRV).

- HRV is a measure of the variation in time between heartbeats.
- A **higher HRV** generally indicates better cardiovascular fitness and resilience.
- A **lower HRV** may suggest stress, fatigue, or underlying health issues.

Some smartwatches can tell the wearer how stressed, or maybe even unwell, they are. This is done by a smartwatch monitoring the wearer's pulse rate and noticing when their heart rate variability decreases. HRV is also used by smartwatches to monitor sleep because the different stages of sleep are associated with different levels of heart rate variability.

End of Section. Please do not press submit, just continue with the next section.

**Section 6/6**

This is an astronomy question about “interstellar comets”.

**Interstellar** means **between the stars**. In astronomy, it refers to anything that exists or occurs **in the space between stars, within a galaxy**, rather than being part of a single star system.

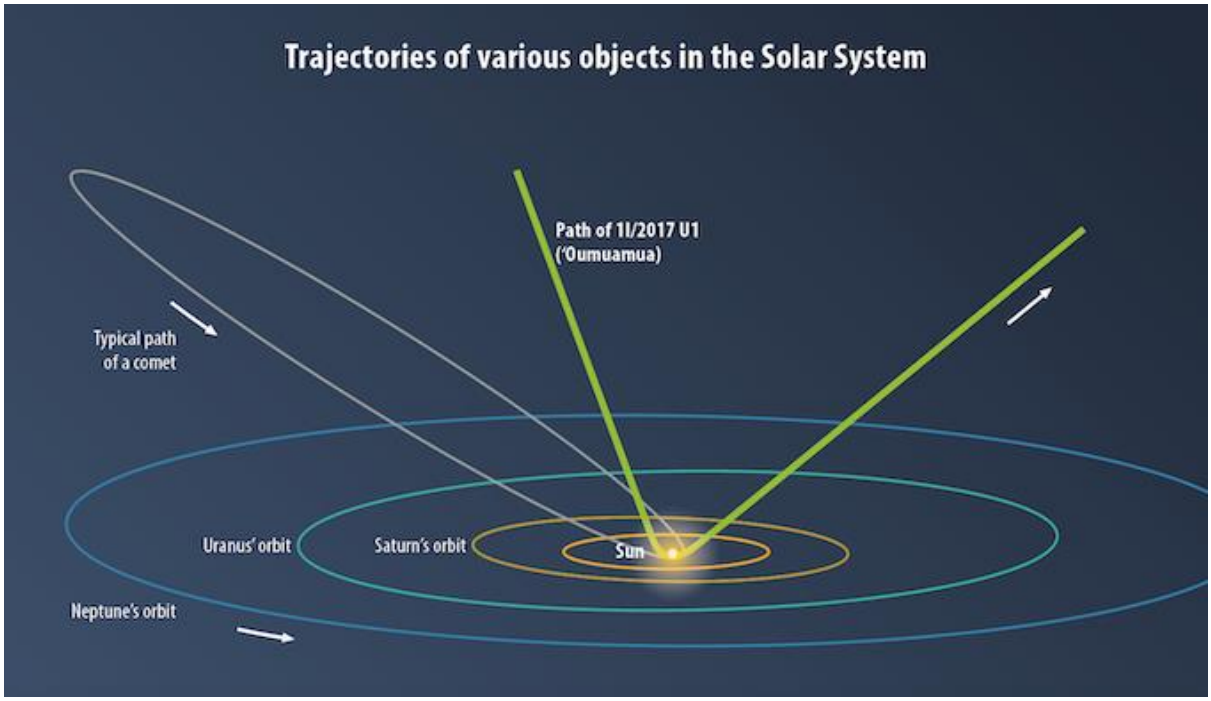
A comet is a large object made of ice and dust that orbits the Sun. However, “interstellar comets” come from beyond our solar system and these have been observed for the first time only recently.

Technological advances such as better image detectors in telescopes, automated scanning of the night sky and powerful data processing have made it possible to detect very faint, fast-moving objects against the background of stars.

Three interstellar comets have been discovered so far. They are called Oumuamua, Borisov and Atlas 3I (“three i”).

***An artist’s impression of ’Oumuamua as it voyaged through the Solar System. Image: NASA/ESA/J. Olmsted and F. Summers (STScI).***

The orbits of comets are interesting - they happen on a different plane (level) to the rest of the planetary motion happening around the Sun (called the “ecliptic plane”. This is shown in the next diagram:




Credit: AstronomyNow.com

What you can see on this diagram above is how Oumuamua came from beyond our solar system, curved round our Sun and returned to interstellar space!

Here is a table of information about the three interstellar comets which have been discovered so far:

| **Name of Comet** | Borisov | Oumuamua | ATLAS (3I) |
|---|---|---|---|
| Discovery | August 2019<br>MARGO telescope, Crimea | October 2017<br>Pan-STARRS telescope, Hawaii | July 2025<br>Asteroid Terrestrial Impact Last Alert System, Chile |
| Orbital Eccentricity | 3.36 | ≈ 1.20 | ≈ 6.14 |
| Closest approach to Earth | 285 million km<br>28 Dec 2019 | 24 million km<br>14 Oct 2017 | 270 million km<br>19 Dec 2025 |
| Orbital tilt relative to the solar plane | 95.4 degrees | 122.74 degrees | 177.11 degrees |
| Hyperbolic Excess Velocity | 32.3 km/s | 26.3 km/s | 58 km/s |
| Unusual Properties | Pristine coma | Reddish, dry surface, no coma | Coma developed far from the Sun |
| Dimensions | 0.4 – 0.5 km | 100 – 1000 metres long (cigar or splinter shaped) | 0.3 – 5.6 km |
| Likely age (billions of years) | 3.8 | 1.0 | 9.6 |
| Relative Brightness (apparent magnitude) | (During 2025): approx. 18.1 | Approx. 19.7 | Approx. 14.8 |

Sources: NASA, TheSkyLive, ScienceAlert.com, Arxiv.org

Glossary and Notes:

The unit **km/s**: kilometres per second

**Coma**: the glowing cloud of gas and dust that surrounds the nucleus of a comet when it gets close enough to the Sun for its ices to sublimate (turn directly from solid to gas).

**Orbital eccentricity**: a measure of how much an orbit deviates from being a perfect circle. It's a dimensionless number that describes the shape of an orbit:

- **0** → Perfect circle.
- **Between 0 and 1** → Elliptical orbit around the Sun. (Another word for *ellipse* is *oval*)
- **Exactly 1** → Parabolic trajectory (escape orbit).
- **Greater than 1** → Hyperbolic trajectory (unbound by the Sun's gravity, interstellar object).

**Hyperbolic excess velocity:** the speed an object has after escaping the gravitational influence of the Sun, measured relative to the Sun at an infinite distance.

An **orbital plane** is the imaginary, flat, two-dimensional surface that contains the path of an orbiting object around a central body (like the Sun).

**Orbital tilt relative to the solar plane**: the angle between an object's orbital plane and the ecliptic plane (the plane in which Earth and most planets orbit the Sun).

- The **ecliptic plane** is the reference plane for the Solar System.
- The tilt is called **orbital inclination** and is measured in degrees:
    - **0°** → Orbit lies exactly in the ecliptic plane.
    - **90°** → Orbit is perpendicular to the ecliptic plane.
    - **>90°** → Orbit is **retrograde**, meaning the object moves opposite to the planets' direction.

**Apparent Brightness:** see later notes, but the bigger the number, the less bright the object appears.

**Question 35: Which of the three interstellar comets can be considered to be unbound by the Sun's gravity (ie: are not part of our Solar System? (Hint: use "orbital eccentricity" to answer this.)**

Oumuamua only.

Borisov and Oumuamua

All three of them.

None of them.

**Question 36: Which was the first interstellar comet to be discovered?**

Borisov

ATLAS (3I)

Oumuamua

This information is not shown on the table.

**Question 37: Which of the three comets in the table moves fastest through Space?**

ATLAS (3I)

Oumuamua

Borisov

This information is not provided on the table.

This is the same table of data, repeated so that you don't have to scroll back up so far to answer the next three questions:

| **Name of Comet** | Borisov | Oumuamua | ATLAS (3I) |
|---|---|---|---|
| Discovery | August 2019<br>MARGO telescope, Crimea | October 2017<br>Pan-STARRS telescope, Hawaii | July 2025<br>Asteroid Terrestrial Impact Last Alert System, Chile |
| Orbital Eccentricity | 3.36 | ≈ 1.20 | ≈ 6.14 |
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| Unusual Properties | Pristine coma | Reddish, dry surface, no coma | Coma developed far from the Sun |
| Dimensions | 0.4 – 0.5 km | 100 – 1000 metres long (cigar or splinter shaped) | 0.3 – 5.6 km |
| Likely age (billions of years) | 3.8 | 1.0 | 9.6 |
| Relative Brightness (apparent magnitude) | (During 2025): approx. 18.1 | Approx. 19.7 | Approx. 14.8 |

**Question 38: Which of the three interstellar comets do you think is most likely to be of deep interstellar origin? (Hint: astronomers think "very fast and very old" suggests this.)**

Oumuamua

Borisov

This information is not provided on the table.

ATLAS (3I)

**Question 39**: **Astronomers have published these comments about one of the comets in the table:**

> "One theory suggests [name of comet] is a **nitrogen-rich shard** from the surface of a Pluto-like exoplanet (a planet outside of our solar system).
>
> If true, its composition would be very different from Solar System comets, explaining the **lack of typical cometary emissions**."
>
> *(Source: dailygalaxy.com)*

**Which of the three comets do you think is being referred to in the comments above?**

Borisov

Oumuamua

ATLAS (3I)

It is not possible to make this deduction from the information shown on the table.

**Question 40: Which of the three interstellar comets is likely to be the largest?** *(This question asks for your judgement. The objects are so small and so distant that their sizes can only be given within a range of values. Use the skills you have learned in maths for rounding numbers and thinking about ranges of values.)*

Oumuamua

Borisov

This information is not provided on the table.

ATLAS (3I)

This is the same table of data, repeated so that you don't have to scroll back up so far to answer the next three questions:

| **Name of Comet** | Borisov | Oumuamua | ATLAS (3I) |
|---|---|---|---|
| Discovery | August 2019<br>MARGO telescope, Crimea | October 2017<br>Pan-STARRS telescope, Hawaii | July 2025<br>Asteroid Terrestrial Impact Last Alert System, Chile |
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| Likely age (billions of years) | 3.8 | 1.0 | 9.6 |
| Relative Brightness (apparent magnitude) | (During 2025): approx. 18.1 | Approx. 19.7 | Approx. 14.8 |

**Question 41: Which of the three interstellar comets has come closest to Earth?**

Borisov

ATLAS (3I)

It is not possible to make this deduction from the information shown on the table.

Oumuamua

**Question 42: Which of the three interstellar comets has an orbital tilt that is closest to the ecliptic plane of our solar system? (Hint: there are 180 degrees in a straight line…)**

Oumuamua

Borisov

ATLAS (3I)

This information is not provided on the table.

The next two questions are about the **apparent brightness of the comets**. The numbers in Relative Brightness or apparent magnitude refer to how bright an object appears from Earth, and the scale is **logarithmic and inverted**:

**How It Works**

- **Lower numbers (including negative numbers) = brighter objects**.
- **Higher numbers = fainter objects**.
- Each step of **5 magnitudes** corresponds to a brightness change of **100 times**.

**Examples**

- **Sun**: −26.7 (extremely bright).
- **Full Moon**: −12.7.
- **Bright stars**: ~0 to +1.
- **'Oumuamua**: ~19.7 → very faint, needs large telescopes.

Here is the same table of data repeated so you don't have to scroll so far back to find the information you need:

| **Name of Comet** | Borisov | Oumuamua | ATLAS (3I) |
|---|---|---|---|
| Discovery | August 2019<br>MARGO telescope, Crimea | October 2017<br>Pan-STARRS telescope, Hawaii | July 2025<br>Asteroid Terrestrial Impact Last Alert System, Chile |
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| Dimensions | 0.4 – 0.5 km | 100 – 1000 metres long (cigar or splinter shaped) | 0.3 – 5.6 km |
| Likely age (billions of years) | 3.8 | 1.0 | 9.6 |
| Relative Brightness (apparent magnitude) | (During 2025): approx. 18.1 | Approx. 19.7 | Approx. 14.8 |

**Question 43: Which of the interstellar comets is the brightest, according to information on the table?**

ATLAS (3I)

Oumuamua

Borisov

There is no way to work this out from the information provided.

**Question 44: If you round the numbers for Relative Brightness to 2 significant figures, which comet is roughly 100 times less bright than ATLAS (3I)?**

ATLAS (3I)

Oumuamua

Borisov

You cannot answer this question from the information provided in the table

**Question 45: Using the information in the table of information above, which of the comets would have been hardest to study due to its small size, lack of cometary coma and dark surface?**

Oumuamua

ATLAS (3I)

Borisov

Oumuamua or Borisov are possible answers

---

In case you are interested, the reasons for the names of the three interstellar comets are as follows:

**Oumuamua** is Hawaiian for "messenger from afar"

**(3I)** means it was the third interstellar comet to be discovered and it was found by the ATLAS telescope in Chile. ATLAS is derived from its full name, the Asteroid Terrestrial Impact Last Alert System.

**Borisov** is named after the amateur Ukrainian astronomer, Gennadiy Borosov who discovered it. He is actually a telescope maker and an engineer who maintains the telescopes at the Crimean Astronomical Observatory, astronomy is his hobby.

# End of Questions!

**Please check you are happy with your answers before you press “submit”.**

**When you press “submit” you will have completed the science challenge and your answers will be saved automatically.**