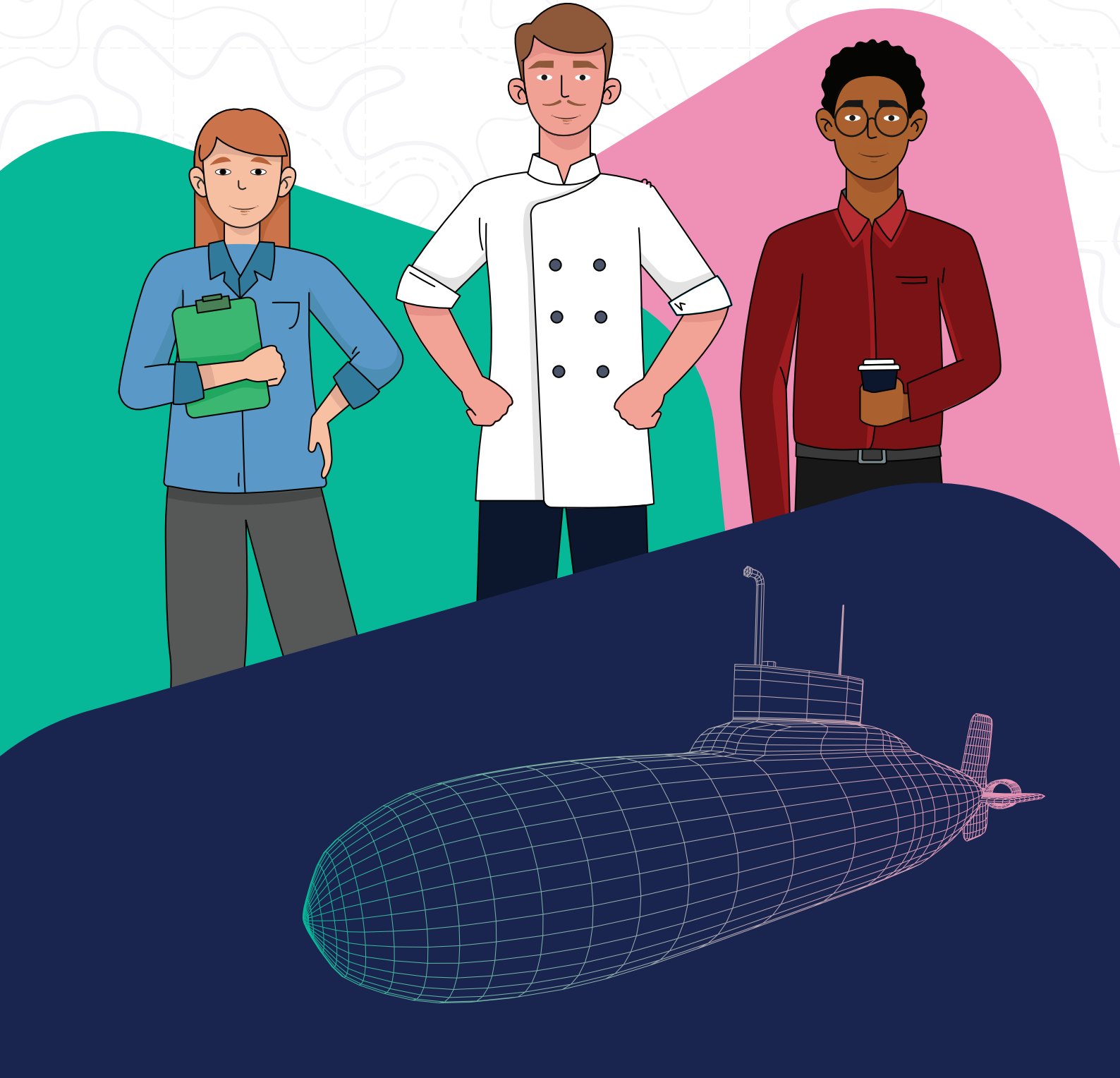
Eko

DIVE DEEPER INTO STEM

KS3 WORKBOOK

SUBMARINE SCIENCE



INTRODUCTION

EKO stands for Engagement, Knowledge, and Opportunities. All organisations who are part of the Defence Nuclear Enterprise (DNE) are interested in promoting and encouraging STEM to young people in educational establishments and communities.

The DNE help to build and keep submarines at sea. Part of their work also includes protecting the nation and keeping us all safe.

There are a wide range of apprenticeships and graduate opportunities to start your career in the DNE who support the building and maintenance of submarines. These include designers, project managers, software developers and engineers. The DNE also have careers for those who look after the crew whilst on board a submarine - including chefs and medical officers.

In this booklet, we have designed some fun activities that involve science, technology, engineering and maths (or STEM for short). They have all been designed to help you think about STEM and how useful it is for many different careers.

We include some words and phrases in this workbook that you might not have seen or used before. To check out what they mean, take a look at our glossary at the end of the workbook.

CONTENTS

CAREERS

Did you know? There are many jobs and careers that use science subjects you study at school.

These include: Biomedical Scientist, Marine Engineer, Catering Services, Communications and Information Specialist, Dental Officer, Engineering Technician, Logistics Officer, Cryptology Technician, Environmental Health Officer, Medical Assistant, Nursing Officer, Radiographer, Musician.

And there are many more! Sarah, Will and Kofi work for the Defence Nuclear Enterprise and they need your help with the activities in this workbook.

Let's find out a little bit more about what they do!

Sarah, Warfare Officer (Submariner) Working with SONAR

Sarah is a specialist in the use of sophisticated submarine SONAR equipment. SONAR stands for SOund Navigation And Ranging. It is a system that uses sound to detect objects in water.

"I work on a submarine and my job is to ensure that the submarine has power and the technology is working correctly. I have skills in engineering and the use of technology - which means I use some of the most advanced underwater equipment as part of my job."

Scan the QR code or click here to find out more about this career

Will, Catering Services (Chef) (Submariner)

Will prepares meals and cooks for his submarine's crew. He also delivers high end front of house service to visiting VIPs and royalty when the submarine is in port.

"I think I have the best job underwater. I keep all the crew healthy with great food and a lot of choices. My kitchen is run like any commercial restaurant and as a chef I have all the ingredients I need for our long journeys around the world."

Scan the QR code or click here to find out more about this career

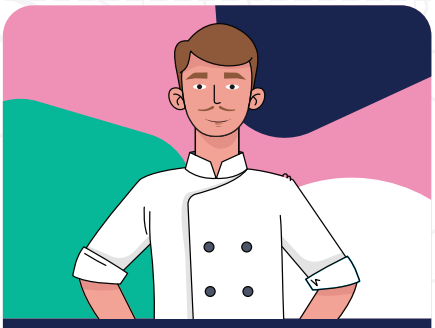
Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi spends most of his working day maintaining some of the most advanced technology ever developed. He really enjoys learning about how submarines work whilst working as an Apprentice.

"I'm really excited to be part of an Apprenticeship Scheme as it gives me the opportunity to work on some of the most advanced submarines in the world, working with specialist teams."

Scan the QR code or click here to find out more about this career

ENERGY FOR FOOD



Will, Catering Services (Chef) (Submariner)

Will knows that nuclear fission is the process of splitting uranium atoms, which releases energy. On a nuclear submarine, this energy heats water to create steam. The steam drives turbines that generate electricity. Will knows that this electricity powers the submarine's systems, including his kitchen for cooking meals for the crew. Any leftover, or residual electricity is stored in batteries so that when the submarine is deep underwater, Will can still prepare meals and feed the crew.

Can you help Will to work out the energy required to feed the crew in the examples below?

1 **If the submarine uses 500 kWh of electricity per day for cooking, how much energy will it need for a 30 day mission?**

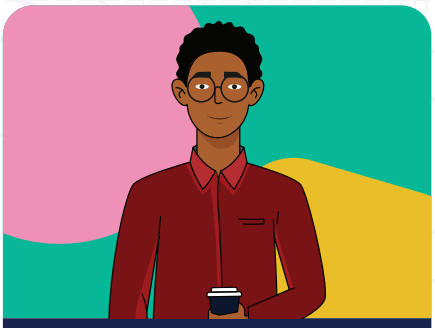
2 **If cooking a stew uses 23 kWh per day, how much energy will be used in 12 days?**

3 **A submarine uses 680 kWh of electricity per day to cook for 100 crew members. How much energy will be needed for 20 days if only 50 crew members are onboard?**

4 **The submarine uses 600 kWh each day for cooking in the first 15 days of its mission. The daily total increases by 25% on day 16. How much energy is needed on day 16?**

kWh stands for kilowatt hour, which is a unit of energy that measures how much electricity is used over time.

NAVIGATING WITH CODE



Kofi, Accelerated Apprentice Scheme (Submariner)

As an Apprentice engineer Kofi is learning all about how coding can help him carry out his job more effectively and efficiently. Today he's working on a programme to support the navigation system on his submarine. This system ensures the submarine moves safely in the water and avoids obstacles and other vessels. It does this by issuing commands or instructions that the submarine must follow.

Kofi has written a fill-the-gaps quiz for you so that you can think like a coder! From the list of words, choose the correct one so that the submarine can safely operate and avoid any obstacles.

The Code Explorer submarine is about to begin its _____ through the deep sea. However, its navigation system is _____ ! Some of the control commands have been scrambled, and unless they are fixed, the submarine might _____ a rock or get stuck in a trench.

The submarine captain must replace the _____ words with the correct movement commands. To move forward, the submarine must use the command _____ . If it needs to turn left, it should use _____ , and to turn right, the command should be _____ . When the submarine needs to go deeper into the ocean, it must use _____ , and to rise toward the surface, the command is _____ .

The captain carefully checks the _____ list to make sure all the commands are correct. If any mistakes are left in the code, the submarine might _____ into an obstacle. Once everything is fixed, the submarine safely reaches its destination.

Words:

move_forward
turn_left
dive
surface
command log
bump
broken
journey
turn_right
hit
incorrect

Additional activity: Do you want to know more about coding and develop your skills? Take a look at these free resources (scan the QR code or **click here**) and you can learn about Python one of the world's most popular programming languages to create digital art, interactive maps and models.

PERISCOPE WORDSEARCH

Sarah, Warfare Officer (Submariner) Working with SONAR

Sarah's work ensures the safety of the submarine as it travels across oceans. Her work with SONAR helps the submarine to navigating around obstacles Another useful navigation device is the periscope - a device that allows the crew inside a submarine to see above the water's surface whilst the submarine remains submerged. They've been around for hundreds of years and are still used on submarines today (although SONAR and video cameras are more accurate for seeing things above and beneath the sea surface).

Can you help Sarah find the 11 words related to periscopes in the wordsearch below?

V	R	E	F	L	E	C	T	I	O	N	R	S
O	F	P	T	L	P	I	V	J	Y	X	P	B
W	B	X	U	B	V	F	D	K	R	Y	E	R
T	S	S	T	E	A	L	T	H	N	T	R	N
B	E	R	E	S	C	O	V	J	Y	X	I	O
A	F	G	T	R	P	I	R	J	Y	X	S	I
E	E	X	N	A	V	I	G	A	T	E	C	T
C	M	S	I	R	P	A	S	M	N	T	O	C
A	I	J	F	X	C	A	T	G	T	L	P	A
F	R	G	T	L	P	I	V	I	Y	X	E	R
R	R	X	U	S	C	I	T	P	O	Y	H	F
U	O	F	L	X	C	D	I	G	N	N	P	E
S	R	G	T	L	A	N	G	L	E	L	P	R
T	E	B	E	C	A	F	R	U	S	R	I	K

Words to find:

Periscope
Prism
Mirror
Stealth
Observation
Reflection
Surface
Navigate
Angle
Refraction
Optics

Additional activity: Carry out some research to create a list of your own definitions of the words related to periscopes in this wordsearch. You might find some of these in the glossary or elsewhere in this booklet.

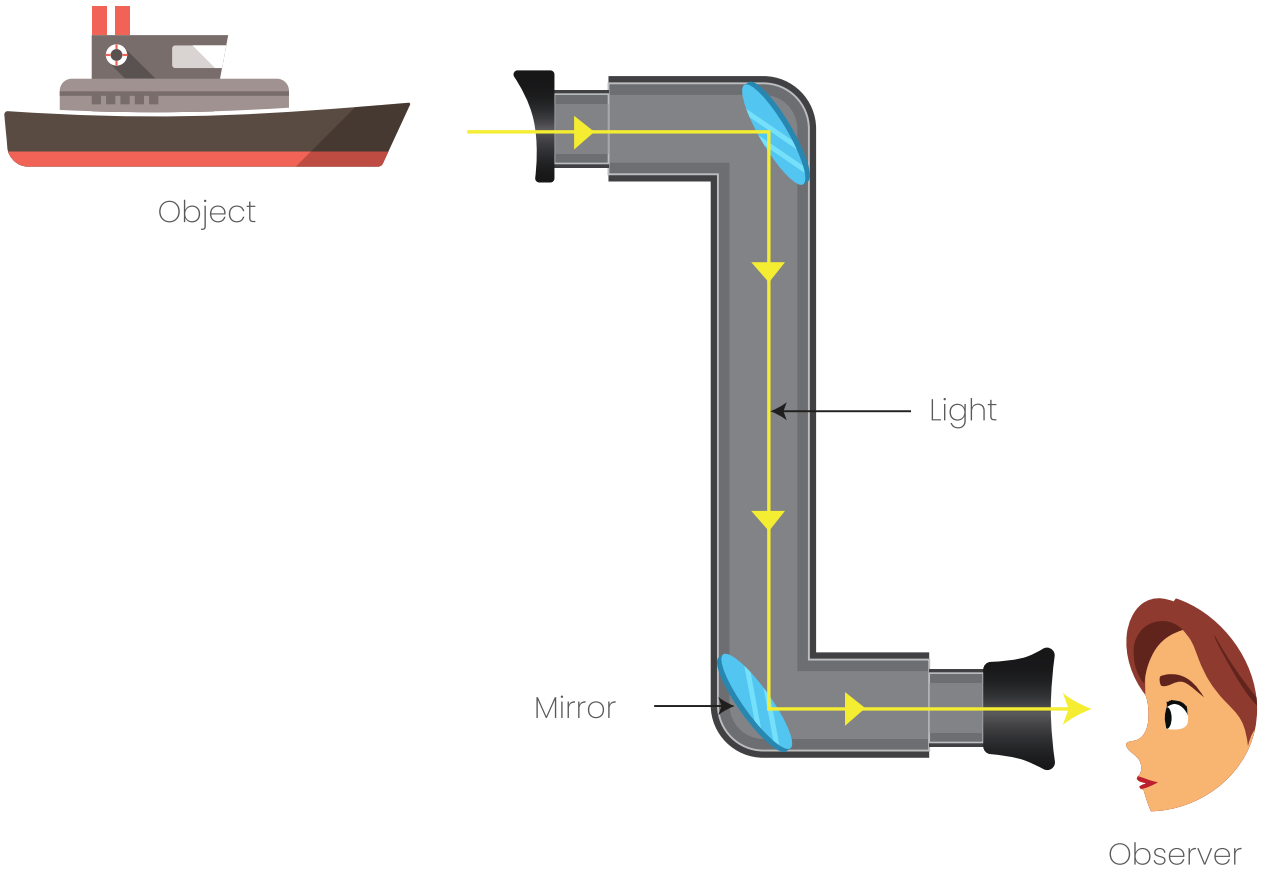
Periscopes serve a variety of purposes, such as observation, stealth, and aiding submarine navigation.

Observation: Allows spotting of ships, land, or obstacles without surfacing.

Stealth: Enables submarines to stay hidden underwater while collecting visual information.

Navigation & Safety: Assists in avoiding collisions and maintaining the correct course.

HOW PERISCOPES WORK



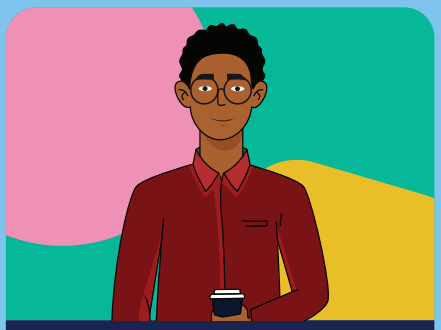
The basic design of a periscope consists of a long tube with mirrors or prisms placed at both ends. These mirrors or prisms are positioned at a 45-degree angle to reflect light from one end of the tube to the other.

Reflection of light: To understand how a periscope works, we need to know about reflection. Reflection happens when light bounces off a surface. In a periscope, when light from an object (such as a ship on the ocean) hits the top mirror or prism, it is reflected downwards into the tube. This light then travels down until it reaches the second mirror or prism, which reflects it again - this time towards the viewer's eyes. Since the mirrors are placed at 45-degree angles, they direct the light correctly so that the image appears the right way up for the viewer.

Plane mirrors vs. prisms: Early periscopes used plane mirrors, which are flat, shiny surfaces that reflect light. However, modern periscopes often use prisms, which are specially shaped pieces of glass that bend and reflect light more efficiently. Prisms allow periscopes to produce clearer and brighter images.

Scan the QR code or click here to learn more about how periscopes work

CALCULATING THE SPEED OF SOUND



Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi knows that sound waves travel at different speeds in different situations. Using appropriate calculations he knows that he can work out lots of things about the sound, including how far away it is.

Can you help Kofi calculate the following? We've provided some hints to help you.

a) The speed of sound in air is 343 m/s. If a sound wave takes 2 seconds to travel, how far does it go?

Hint: Distance = Speed x Time

b) If an explosion happens 1,029 meters away, how long will it take for the sound to reach you?

Hint: Distance = Speed x Time

c) If sound takes 0.5 seconds to travel 171.5 meters, what is its speed?

Hint: Speed = Distance ÷ Time

?

Did you know? Sound travels faster in water than in air because water particles are closer together than air particles. Sound is a mechanical wave, meaning it needs a medium (like air, water, or solids) to travel. The speed of sound depends on how quickly particles can pass vibrations to one another. In air, the particles are far apart, so it takes longer for vibrations to move from one particle to the next. In water, the particles are much closer together, allowing vibrations to transfer more quickly. As a result, sound travels about 4 times faster in water (1,480 m/s) than in air (343 m/s).

MEASURING DISTANCE WITH SONAR

Sarah, Warfare Officer (Submariner) Working with SONAR

Sarah has been carrying out some research work on SONAR. She knows that it stands for Sound Navigation and Ranging, was first developed during World War I by French physicist Paul Langévin. SONAR uses sound waves to detect underwater objects and measure distances. Initially used for submarine detection, it is now widely used in navigation, marine biology, and ocean exploration.

Sarah knows that sound waves travel 1500 m/s in water and that a sound wave has to travel to the object and return to the submarine to be detected.

Can you help Sarah calculate how far away these objects are from her submarine using SONAR readings?

1. **Sea floor:** 4 seconds

   Distance = _____

2. **Another Submarine:** 8 seconds

   Distance = _____

3. **Shipwreck:** 6.5 seconds

   Distance = _____

4. **Coral:** 7.6 seconds

   Distance = _____

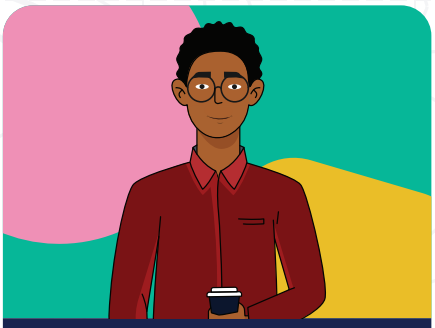
Equation:
Distance = Speed x Time

Remember that the SONAR device measures the time 'to' the object and 'from' the object - so you must divide by 2 in order to get the correct distance.

Scan the QR code or click here to learn about how SONAR works

Scan the QR code or click here to learn about the science behind sound navigation!

THE DOPPLER EFFECT



Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi knows that the Doppler Effect is the change in pitch of a sound when the source or listener moves. Sounds waves experience the Doppler Effect where the waves squash as the object emitting them moves closer to the observer, increasing the pitch of the sound. An example is the sound created by a police car siren as the car approaches you. As the police car moves away from you, the waves will stretch, decreasing the pitch.

Carry out some research into the Doppler Effect and test your knowledge by answering the questions below. (The QR codes and links below will help).

1 What is the Doppler Effect?

a) The change in the loudness of a sound as it travels.
b) The change in the pitch or frequency of a sound when the source moves relative to the listener.
c) The way light travels through space.

2 Which of the following is a good example of the Doppler Effect?

a) The sound of birds chirping.
b) The siren of an ambulance passing by you.
c) The ticking of a clock.

3 What happens to the sound waves and the source of the sound moves away from the listener?

a) The waves spread out, and the frequency decreases.
b) The waves get closer together, and the frequency increases.
c) The waves stop moving.

4 Which of the following uses the Doppler Effect in real life?

a) Measuring the speed of a car with a radar gun.
b) Listening to a song on the radio.
c) Watching television.

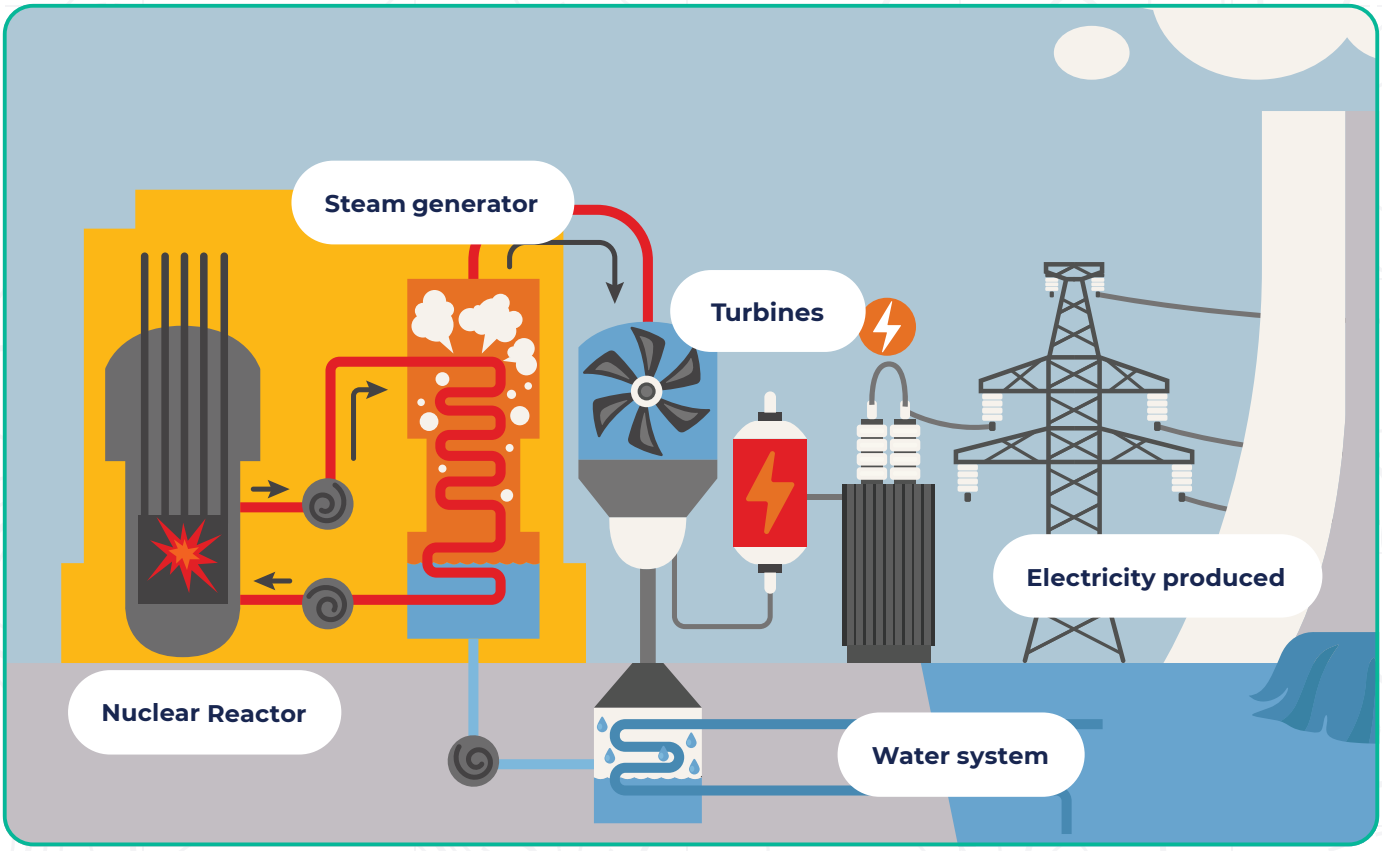
Named after Austrian scientist Christian Doppler (1842), the Doppler Effect explains why a car's siren sounds higher-pitched as it approaches and lower as it moves away. It's used in radar, astronomy, and weather forecasting.

Scan the QR code or click here to find out more about the Doppler Effect

Scan the QR code or click here to watch a short video about how the Doppler Effect works

GENERATING NUCLEAR POWER

Nuclear powered submarines generate energy in a similar way to nuclear power plants. Energy produced by nuclear power plants is used to provide electricity to our homes. Take a look at the image below of a nuclear power plant, it has many of the same components as a nuclear powered submarine.

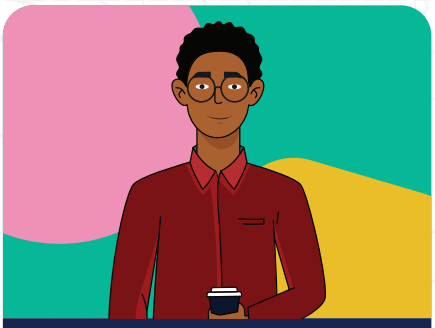


Did you know? The UK was home to the world's very first commercial nuclear power plant! Calder Hall, in Cumbria, opened in 1956. It was a ground breaking project, producing electricity for homes and businesses whilst also helping with national defence by creating materials for nuclear weapons. This pioneering power station put the UK on the map as a leader in nuclear technology and helped pave the way for how we use nuclear energy today. The site is now being carefully decommissioned, but its legacy as a key moment in science and energy history lives on!

Scan the QR code or click here to try your skills at running your own nuclear reactor!

Scan the QR code or click here to test your understanding of nuclear power and how it is produced

NUCLEAR POWERED SUBMARINES



Kofi, Accelerated Apprentice Scheme (Submariner)

One of Kofi's jobs is to understand how submarines work by harnessing nuclear power. He knows that they can stay underwater for months without refueling. They help with disaster response, monitoring ocean health, and protecting sea routes.

Kofi has been researching nuclear energy sources and would like you to help him identify the key components of a typical nuclear generator.

Can you match the term to the correct definition?

1. **The part of the system that uses heat to turn water into steam.**

   _____

2. **Where nuclear fission takes place, splitting uranium atoms.**

   _____

3. **Devices powered by steam that propel the submarine and generate electricity.**

   _____

4. **The part that moves the submarine forward, powered by the turbine.**

   _____

5. **The machine that converts turbine power into electricity for the submarine's systems.**

   _____

Key term:

Nuclear Reactor

Generator

Turbines

Propeller

Steam generator

EFFICIENCY OF NUCLEAR POWER

Sarah, Warfare Officer (Submariner) Working with SONAR

Sarah is interested in the benefits of nuclear powered submarines. She is particularly interested in how much power they generate and how far they can travel when compared to other submarines.

Can you help Sarah with her comparisons between a nuclear powered submarine and diesel-electric submarine below?

1 A nuclear submarine's reactor generates 300 megawatts (MW) of power, but only 30% of this is converted into useful electrical power for propulsion.

a) How much electrical power is actually available for propulsion?

b) If an alternative diesel-electric system only provides 65 MW for propulsion, how much more power does the nuclear reactor provide in comparison?

2 A conventional diesel-electric submarine requires 15,000 litres of diesel per day for propulsion. A nuclear powered submarine, however, can operate for up to 20 years without refuelling.

a) How much diesel would a conventional submarine need for one year of operation?

b) How much diesel would it need over 20 years?

A megawatt (MW) is a unit of power that measures how much energy is being used or produced. 1 megawatt = 1,000 kilowatts (kW) or 1,000,000 watts (W). One megawatt-hour is enough to drive an electric vehicle 3,600 miles. This is equivalent to driving from the UK to Spain and back, twice!

PERISCOPES - KEY TERMS

Sarah, Warfare Officer (Submariner) Working with SONAR

Sarah knows that the modern submarine periscope was invented in the 19th century by the British engineer, Sir Howard Grubb. It was originally used to allow sailors to see above the water while remaining submerged. Over time, periscopes were adapted for other uses, including in tanks and observation towers.

Can you help Sarah to match the key term, related to periscopes and their use, to the correct definition? We've completed the first one for you.

Definition: An optical device that lets you see over or around obstacles, often used in submarines.

a) Periscope ✓

Definition: A curved piece of glass or plastic that focuses or spreads light, sometimes used in modern periscopes.

b)

Definition: A reflective surface that bounces light, crucial for traditional periscope designs.

c)

Definition: The bouncing back of light from a surface, such as a mirror, used in periscopes to redirect light.

d)

Definition: The bending of light as it passes through different materials, like glass or waters.

e)

Definition: The straight path that light travels, allowing the viewer to see through the periscope.

f)

Definition: The area visible through the periscope, which can be limited depending on its design.

g)

Definition: The study of light and its behavior, including reflection and refraction, crucial for periscope operation.

h)

Definition: The angle at which light hits a surface, affecting how it reflects in a periscope.

i)

Key term:

Angle of incidence	Line of sight	~~Periscope~~
Field of view	Mirror	Reflection
Lens	Optics	Refraction

HISTORY OF PERISCOPES

The periscope is a fantastic invention that helps people see over walls, around corners, and even above water while staying hidden! But how did it develop from a simple optical trick to a crucial tool for submarines?

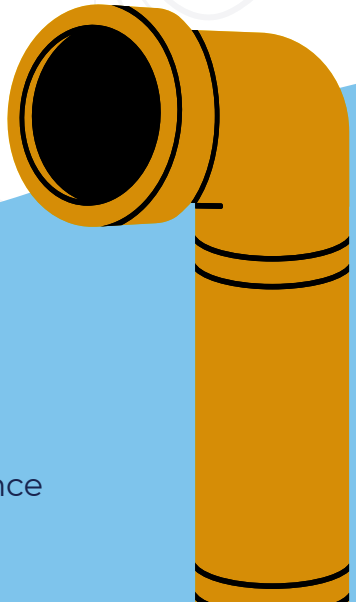
Early Periscopes
The idea of a periscope started in the 1600s when Johannes Hevelius, a Polish astronomer, experimented with mirrors to create a device that let people see over obstacles. His design used angled mirrors to reflect light so someone could look over a wall without climbing it. Other scientists, like Johannes Kepler and Christoph Scheiner, also explored how mirrors and lenses could bend light, leading to better telescopes and early periscopes.

Using periscopes for spying and observing the enemy
By the 19th century, inventors realised periscopes could be useful when spying on others. In 1845, German inventor Johann Friedrich Voigtländer created a more practical periscope design. Later, French scientist Jules Carpentier improved it, making it stronger and easier to use in trenches and other settings.

The submarine periscope
The biggest development leap came in the early 1900s with Howard Grubb, an optical engineer. He designed an advanced periscope for submarines, allowing captains to see above the water while staying safely hidden below. His periscope had better optics, clearer vision, and a more stable design, making it a key tool for naval warfare during World War I.

Thanks to these inventors, periscopes went from simple wall-peeking gadgets to lifesaving submarine technology!

Additional activity: Periscopes can see around corners ... and so can you by making your own out of cardboard and mirrors. You can scan the QR code or **click here** to follow some step-by-step instructions. It's a fun and easy way to learn about light, reflection, and optics while building your own working periscope.

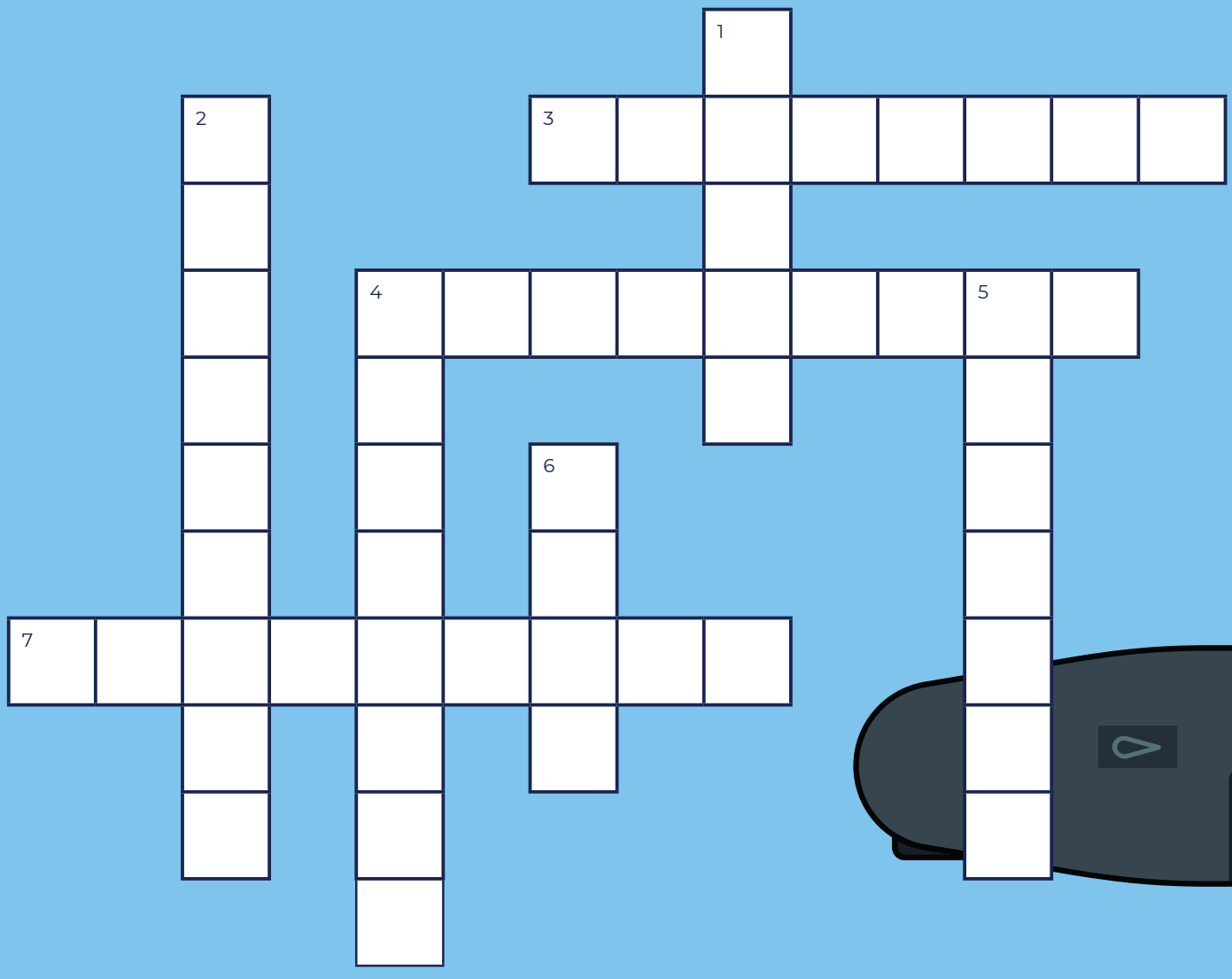


NUCLEAR SUBMARINE CROSSWORD

Sarah, Warfare Officer (Submariner) Working with SONAR

As a Warfare Officer, Sarah needs to understand the intricate systems that ensure the safe and efficient operation of a submarine. This includes understanding key concepts related to the operation of the vessel. She has decided to work on this crossword puzzle to test her knowledge and understanding.

Can you help her to identify the words from the clues on the next page? →



NUCLEAR SUBMARINE CROSSWORD

Down clues

1) A system that uses sound waves to detect objects underwater.

2) A device used to look above the water from the submarine.

4) The action of diving deep under the water.

5) The type of power often used by modern submarines.

6) The main body of a submarine.

Across clues

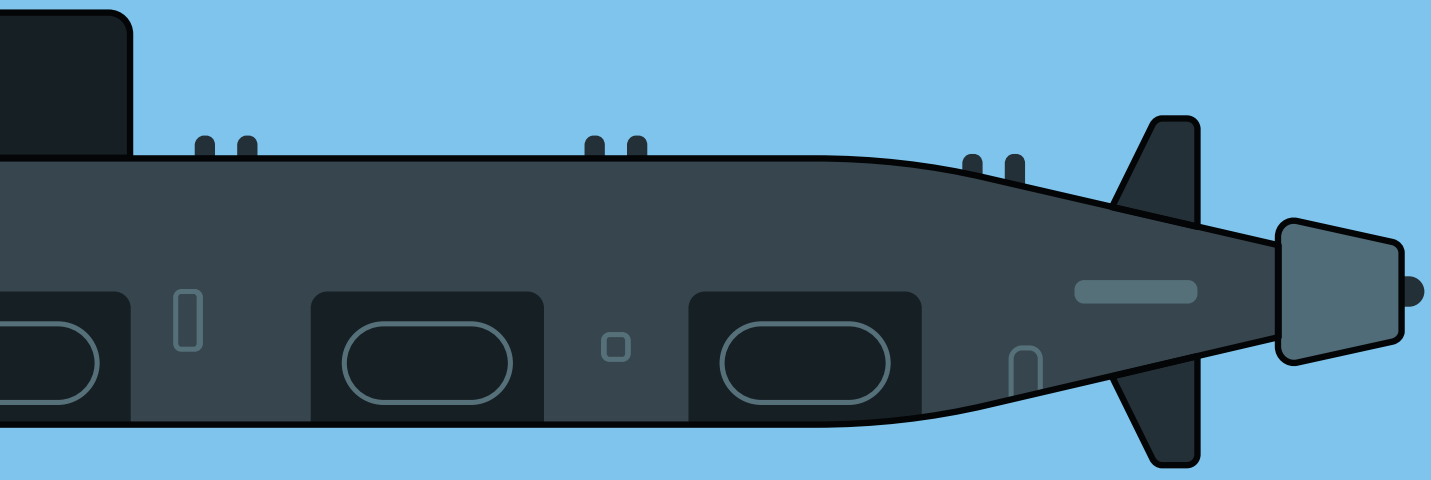
3) Submarines are designed to operate underwater by controlling this force.

4) Another name for an underwater vessel.

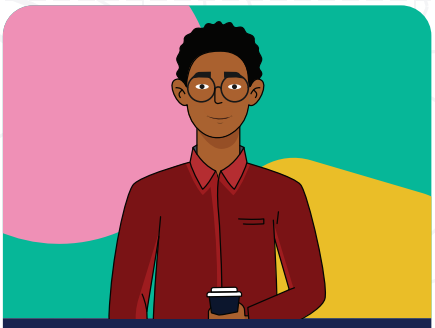
7) The part of a submarine that moves it forward.

Scan the QR code or click here to find out more about the science behind stealth submarines

Did you know? Nuclear propulsion revolutionised maritime exploration by providing a nearly unlimited energy source. Using nuclear reactors, it generates heat through nuclear fission to produce steam, which powers turbines for propulsion. This system allows ships and submarines to travel for years without refueling, making it highly efficient and ideal for long-term missions. First used in the USS Nautilus submarine in the 1950s, nuclear propulsion also powers some icebreakers and spacecraft, enabling them to operate in extreme conditions where traditional fuels are impractical.



ATOMIC TIME-KEEPING



Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi works with the crew to ensure that the submarine maintains its course and can travel safely when submerged.

While surfaced or near the surface, submarines use GPS signals for precise location tracking. GPS systems are dependent on atomic clocks aboard satellites, which provide highly accurate time stamps used to calculate position. Once submerged, submarines lose the ability to receive GPS signals. In this case, they rely on inertial navigation systems (INS), which track the submarine's position based on internal measurements of speed and direction. The accuracy of INS diminishes over time, but atomic clocks help mitigate this drift by providing a stable and precise time reference.

Can you help Kofi with the calculations below using the atomic clock on his submarine?

1 Calculate the distance

The submarine is traveling at a steady speed of **60 km/h**, and the atomic clock records a travel time of **3 hours**.

How far did the submarine travel?

_____ **km**

2 The error challenge

Kofi knows that there is a very slight error in the atomic clock. It deviates (or loses) 1 second every 100 million years!

How many seconds does the atomic clock deviate in 1 year?

_____ **seconds**

3 Comparing accuracy

Kofi has a wall clock in his office that deviates (or loses) 1 second per day.

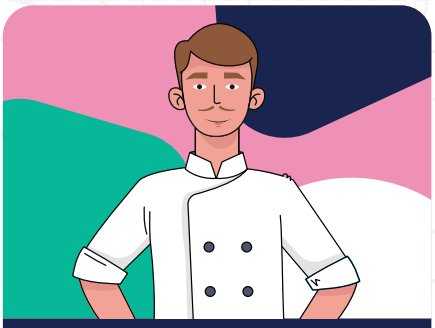
How many seconds does his office clock deviate in 1 year, and how many minutes is this?

_____ **seconds** _____ **minutes**

An atomic clock is a precise timekeeping device that uses atomic vibrations. In nuclear submarines, it helps track movement and calculate distance accurately, even when GPS is unavailable underwater.

Scan the QR code or click here to learn how submarines navigate

HISTORY OF THE SUBMARINE



Will, Catering Services (Chef) (Submariner)

The history of the submarine is a fascinating journey of human ingenuity and innovation. From humble beginnings as rudimentary wooden vessels powered by human effort, submarines have evolved into highly sophisticated machines capable of operating in the most extreme underwater environments. Initially conceived as tools of exploration and military advantage, early pioneers like Cornelis Drebbel and David Bushnell laid the foundation for modern submersible technology. Today, they stand as a testament to humanity's relentless pursuit of conquering the depths of the ocean. **Will has been making some notes of the key historical developments in submarines and submarine technology. Take a look at what he's discovered.**

1620: Dutch inventor Cornelis Drebbel designs and builds the first recorded submersible. It was a human-powered, wooden vessel covered in greased leather and was powered by oars that moved underwater.

1800: Nautilus, designed by Robert Fulton, becomes one of the first practical submarines, capable of staying submerged for hours using compressed air.

1888: Isaac Peral, a Spanish naval officer, builds the Peral, one of the first electric-powered submarines.

1896: Irish inventor John Philip Holland demonstrates the Holland VI, the first modern submarine powered by a combination of gasoline engines (on the surface) and electric motors (underwater).

1920s-1930s: Development of diesel-electric submarines and improved torpedo technology. Submarine designs become more sophisticated and capable of extended missions.

1954: The USS Nautilus (SSN-571) becomes the world's first nuclear powered submarine, capable of staying submerged for extended periods.

1980s: Stealth technology and quieter propulsion systems are developed, reducing the acoustic signatures of submarines.

1990s-Present: Introduction of air-independent propulsion (AIP) systems, allowing non-nuclear submarines to remain submerged for longer periods.

2000s: Advances in autonomous underwater vehicles (AUVs) and unmanned submarines for scientific, military, and commercial purposes.

2020s: Focus on hybrid and fully autonomous submarines, improved SONAR and stealth capabilities, and multi-role submarines for both military and scientific applications.

Scan the QR code or click here to find out more about the history of the modern submarine

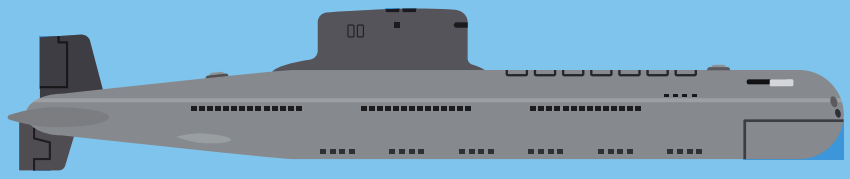
POWERING SUBMARINES

Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi is analyzing different types of energy sources for his work as an Apprentice in submarine technology.

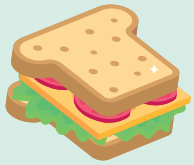
He has identified three main propulsion systems used in submarines: nuclear, diesel-electric, and air-independent propulsion (AIP). Each of these systems relies on different types of energy resources to power the submarine.

Can you carry out some research to help Kofi to identify two advantages and two disadvantages for each of the energy sources? To help with your research, we've included some QR codes/weblinks on the next page.

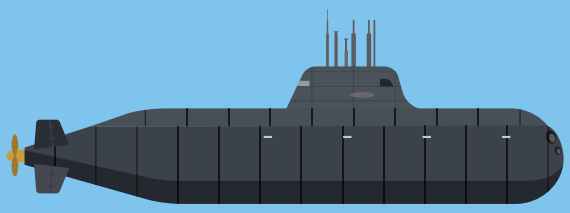


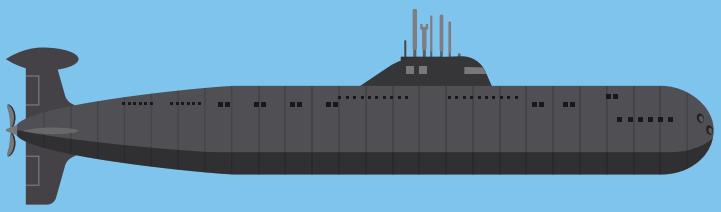
Nuclear Propulsion	
Advantages:	**Disadvantages:**

Nuclear powered submarines are amazing because they can stay underwater for months without needing to come up for air! This is because they use nuclear power instead of regular fuel, which gives them endless energy. The only reason they need to come to the surface is to get more food for the crew!



POWERING SUBMARINES





Diesel-Electric Propulsion

Advantages:

Disadvantages:

Air-Independent Propulsion

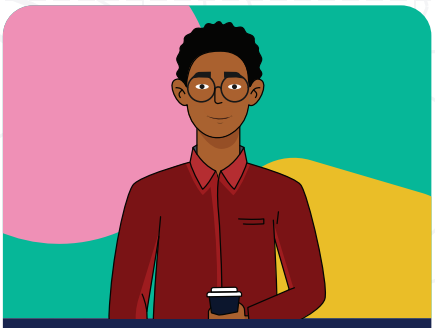
Advantages:

Disadvantages:

Scan the QR code or click here to learn about types of submarines

Scan the QR code or click here to compare different types of submarine

BUOYANCY



Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi is interested to learn more about how submarines dive and surface. He knows that this is linked to buoyancy. He decides to carry out some research work on this and has discovered that buoyancy is the upward force that makes objects float in a liquid or gas. It happens because the liquid or gas pushes upwards on the object. This force is called the buoyant force, and it works against the weight of the object. Whether something floats or sinks depends on its density compared to the liquid or gas it's in. Density is how much mass is packed into a certain space. If an object is less dense than the liquid, it will float. If it's more dense, it will sink.

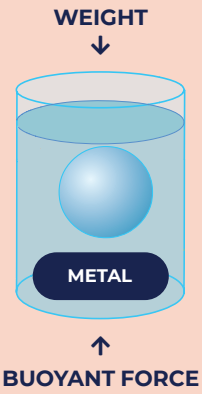
For example, a boat floats because it is designed to spread its weight over a large area, making it less dense than water. Submarines use buoyancy to move up and down in water. They have tanks that can be filled with air or water. When the tanks are filled with air, the submarine becomes less dense and floats. When they are filled with water, it becomes more dense and sinks. Buoyancy is an important principle used in many areas of science and engineering, from designing ships to understanding how hot air balloons rise into the sky. It explains why some objects float, while others sink!

Buoyancy of different objects

When the weight of an object is less than the buoyant force, the object will float in water.

When the weight of an object equals the buoyant force, the object will suspend in water.

When the weight of an object is greater than the buoyant force, the object will sink in water.



Did you know? Buoyancy is the upward force that helps objects float in a liquid or gas. It works because the liquid or gas pushes up on the object. An object floats if it is less dense than the liquid or gas and sinks if it is more dense. Buoyancy is what makes boats float and is also used by submarines to help them rise to the surface or dive underwater.

BUOYANT FORCE

Kofi wants to calculate his submarine's buoyancy force to help work out how to make the submarine surface or descend in the water. Understanding the submarine's buoyant force will enable to him and the crew to precisely dive, surface, and maintain specific depths underwater.

Can you help Kofi with his buoyant force calculations? The information he has includes the following: (a) submarine is partially submerged in water, and (b) the weight of the submarine is 120,000 N, and it displaces 125,000 N of water.

1 What is the buoyant force on the submarine?

Hint: The buoyant force is equal to the weight of the water displaced by the submarine.

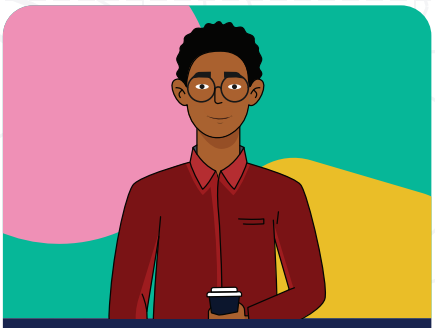
2 Is the submarine floating (surfacing) or sinking (descending)?

'N' or 'Newton' is the unit of force in physics. It is named after Sir Isaac Newton, who developed the laws of motion. A force is any push or pull, and the newton is used to measure how much force is being applied to an object. In real life, forces measured in newtons help explain everything from why objects fall to how rockets launch. In the buoyancy activity, N is used to measure forces like the weight of the submarine and the upward buoyant force.

3 How much more weight is needed to make the submarine sink (or descend)?

Did you know? Archimedes was a Greek mathematician, engineer, and scientist. He is famous for many discoveries, but one of his most important contributions was understanding buoyancy, which explains why objects float or sink in water. Legend says Archimedes discovered this principle while taking a bath. When he got into the tub, he noticed the water level rising. He realised that his body was pushing water out of the way, and the amount of water displaced was linked to the force pushing him up. Excited by his discovery, he shouted "Eureka!", which means "I've found it!" in Greek. This led to the Archimedes Principle, which states: "An object submerged in a fluid experience an upward force equal to the weight of the fluid it displaces." To find out more about Archimedes scan the QR code or **click here**.

CODING & ARTIFICIAL INTELLIGENCE



Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi knows that computer science and coding are essential to his submarine operations. Computer programmes and artificial intelligence (AI) automate certain tasks on submarines, so humans can focus on critical decisions and safety.

As part of his role on the submarine, Kofi uses computer science and coding in the following ways:

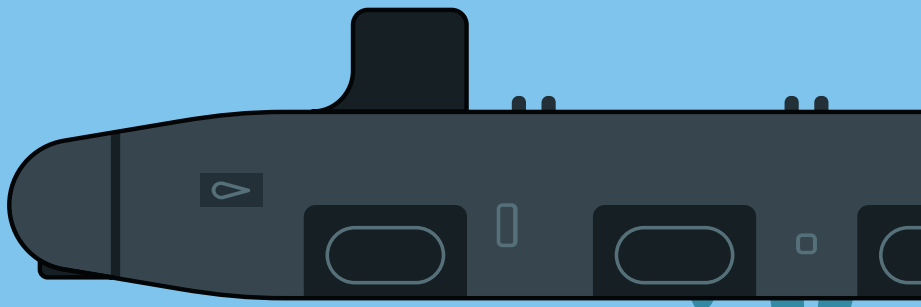
- **Navigation:** Programming controls GPS and SONAR to guide the submarine.
- **Communication:** Submarines use encrypted messages, written in code, to send and receive messages.
- **Defence systems:** Automated programmes detect and respond to threats.
- **Monitoring:** Sensors collect data on water pressure, temperature, and speed, analysed by computer software.

Can you help Kofi with this coding task? He needs you to help him to programme the submarine to dive to a specific depth and then to re-surface. To do this you need to put the instructions in order, from Step 1 to Step 7 on page 27 →

Additional activity: Test your skills by writing your own set of instructions for a submarine to complete a task, such as navigating to a location or avoiding an underwater obstacle. Key coding principles to consider include:

- **Sequencing:** The order of your instructions matters. Write them step by step.
- **Precision:** Be specific: The submarine doesn't understand vague instructions.
- **Loops:** If the submarine needs to perform the same action multiple times, use a loop.
- **Debugging:** Test your instructions mentally. Do they achieve the goal? Fix any errors.

Scan the QR code or click here to make your own codes using the computer programme 'Scratch'.



CODING & ARTIFICIAL INTELLIGENCE

Instructions (steps):

- Activate the pumps to release water from the ballast tank.
- Check the current depth.
- Monitor depth and stop when reaching 50 meters.
- Return to the surface.
- Slowly increase the ballast to take in water.
- Stay at 50 meters for 30 seconds.
- Turn on the ballast tank system.

Correct order of instructions (steps):

Step ❶ =

Step ❷ =

Step ❸ =

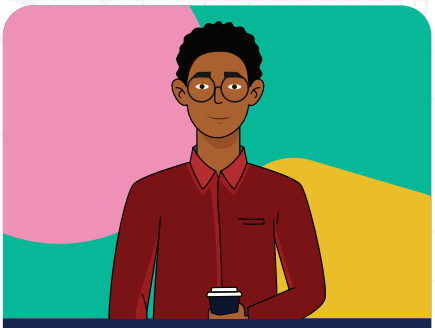
Step ❹ =

Step ❺ =

Step ❻ =

Step ❼ =

NUCLEAR PROPULSION



Kofi, Accelerated Apprentice Scheme (Submariner)

Kofi is an Accelerated Apprentice on a nuclear powered submarine. One of his tasks is to understand how the nuclear propulsion system works. He knows that uranium atoms are split inside the nuclear reactor (through nuclear fission), which generates heat. This heat turns water into steam, which then drives turbines. The turbines generate electricity, and the steam also powers the propeller to propel the submarine forward. This system allows submarines to remain underwater for long periods without needing to refuel, offering high energy efficiency. A nuclear reactor on a submarine is a complex piece of equipment, with many parts.

Can you conduct some research work to provide definitions of the following elements: Nuclear Reactor, Turbines, Steam Generator. Include the sources you've used.

1 Nuclear Reactor:

My source:

2 Turbines:

My source:

3 Steam Generator:

My source:

ANSWERS

P6 ENERGY FOR FOOD

1) 500 kwh per day x 30 days = 15,000 kwh.
2) 23 kwh per day x 12 days = 276 kwh.
3) 680 kwh = 100 crew. 50 crew = 680 kwh / 2 (340 kwh). 340 kwh x 20 days = 6800 kwh.
4) 600 kwh x 25% = 150 kwh extra required on day 16. 750 kwh in total required for day 16.

P7 NAVIGATING WITH CODE

journey
broken
hit
incorrect
move_forward
turn_left
turn_right
dive
surface
command log
bump

P8 PERISCOPE WORDSEARCH

V	R	E	F	L	E	C	T	I	O	N	R	S
O	F	P	T	L	P	I	V	J	Y	X	P	B
W	B	X	U	B	V	F	D	K	R	Y	E	R
T	S	S	T	E	A	L	T	H	N	T	R	N
B	E	R	E	S	C	O	V	J	Y	X	I	O
A	F	G	T	R	P	I	R	J	Y	X	S	I
E	E	X	N	A	V	I	G	A	T	E	C	T
C	M	S	I	R	P	A	S	M	N	T	O	C
A	I	J	F	X	C	A	T	G	T	L	P	A
F	R	G	T	L	P	I	V	I	Y	X	E	R
R	R	X	U	S	C	I	T	P	O	Y	H	F
U	O	F	L	X	C	D	I	G	N	N	P	E
S	R	G	T	L	A	N	G	L	E	L	P	R
T	E	B	E	C	A	F	R	U	S	R	I	K

P10 CALCULATING THE SPEED OF SOUND

a) 343 x 2 = 686 metres.
b) 1029 / 343 = 3 seconds.
c) 171.5 / 0.5 = 343 m/s

P11 MEASURING DISTANCE WITH SONAR

1) (1500 m/s x 4 seconds) / 2 = 3000 metres.
2) (1500 m/s x 8 seconds) / 2 = 6000 metres.
3) (1500 m/s x 6.5 seconds) / 2 = 4875 metres.
4) (1500 m/s x 7.6 seconds) / 2 = 5700 metres.

P12 THE DOPPLER EFFECT

1) (B) The change in the pitch or frequency of a sound when the source moves relative to the listener.
2) (B) The siren of an ambulance passing by you.
3) (A) The waves spread out, and the frequency decreases.
4) (A) Measuring the speed of a car with a radar gun.

P14 NUCLEAR POWERED SUBMARINES

1) Steam generator
2) Nuclear reactor
3) Turbines
4) Propeller
5) Generator

P15 EFFICIENCY OF NUCLEAR POWER

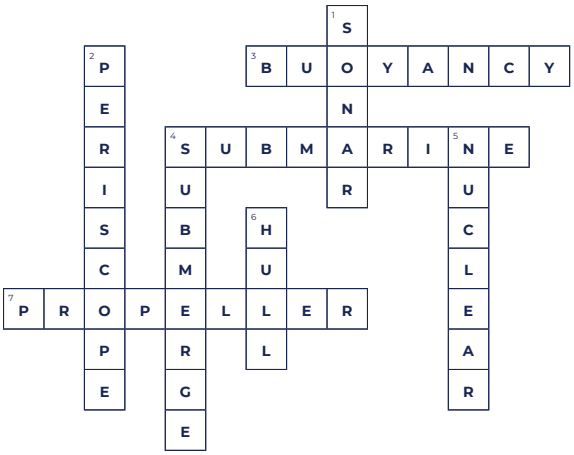
1) a) Useful electrical power = 250 MW × 30% = 90 MW.
1) b) Extra power compared to diesel-electric = 90 MW – 65 MW = 25 MW. The nuclear powered submarine has 30 MW more power available for propulsion.
2) a) Diesel per year = 15,000 litres × 365 days = 5,475,000 litres.
2) b) Diesel over 20 years = 5,475,000 litres × 20 = 109,500,000 litres (109.5 million litres!)

P16 PERISCOPE: KEY TERMS

a) Periscope
b) Lens
c) Mirror
d) Reflection
e) Refraction
f) Line of sight
g) Field of view
h) Optics
i) Angle of incidence

ANSWERS

P18 NUCLEAR SUBMARINE CROSSWORD



P20 ATOMIC TIME KEEPING

1) 60 km/h x 3 = 180.

2) 1 / 100,000,000 = 0.00000001 seconds/year.

3) 1 x 365 days = 365 seconds. 365 / 60 = 6.08 minutes.

P22 POWERING SUBMARINES

Nuclear powered:
Advantages include ability to remain submerged for long periods of time and their speed and efficiency.
Disadvantages include they are expensive to build and maintain and they create radioactive waste which must be stored correctly.

Diesel-electric:
Advantages include they are cheaper to build than nuclear powered submarines and they are reasonably quiet to operate.
Disadvantages include they need to resurface often to refuel and re-charge batteries and they are slower than nuclear powered submarines.

Air-independent:
Advantages include they can remain submerged much longer than diesel-electric submarines and they are very quiet – making them hard to detect.
Disadvantages include they are slower than nuclear submarines and they have limited power supplies and therefore cannot travel long distances without refuelling.

P25 BUOYANT FORCE

1) The buoyant force is the weight of the displaced water, which is 125,000 N.

2) The submarine's weight = 120,000 N. Since the buoyant force is greater, the submarine is floating.

3) To sink (descend), the submarine's weight must exceed the buoyant force. The current weight of the submarine is 120,000 N. To sink (descend) it's weight needs to be more than 125,000 N. Increasing its weight by 5,001 N will allow it to sink (descend).

P27 CODING & ARTIFICIAL INTELLIGENCE

1) Check the current depth.

2) Turn on the ballast tank system.

3) Slowly increase the ballast to take in water.

4) Monitor depth and stop when reaching 50 meters.

5) Stay at 50 meters for 30 seconds.

6) Activate the pumps to release water from the ballast tank.

7) Return to the surface.

P28 NUCLEAR PROPULSION

Nuclear reactor: A device that initiates and controls a sustained nuclear chain reaction to produce heat for power generation.
Turbines: Rotating machines that convert steam energy into mechanical energy to generate electricity or propulsion.
Steam generator: A heat exchanger that transfers thermal energy from the reactor coolant to water, producing steam to drive turbines.

GLOSSARY

Some key terms and words used in this workbook and short definitions of what they mean.

Air-Independent Propulsion (AIP): A technology that allows non-nuclear submarines to remain submerged longer without surfacing for air.

Angle of Incidence: The angle at which light hits a surface, affecting how it reflects in a periscope.

Apprentice: A person who works and studies to gain skills and knowledge in a specific job.

Archimedes' Principle: A scientific law stating that the buoyant force on an object is equal to the weight of the fluid it displaces.

Atom: The smallest particle of an element. They act as the 'building blocks' of everything. They are made from protons, neutrons, and electrons.

Atomic Clock: An extremely precise clock that uses atomic vibrations to maintain accurate time, essential for submarine navigation.

Ballast tanks: A compartment within a boat, ship, or submarine that holds water. It controls the buoyancy of the vessel.

Buoyancy: The upward force exerted by a fluid that allows objects to float or sink depending on their density.

Command Log: A recorded set of instructions used in submarine navigation and automated systems.

Cryptology: The science of encoding and decoding secret messages, crucial for submarine communications.

Density: The measure of how much mass is contained in a given volume, affecting whether an object floats or sinks.

Doppler Effect: The change in frequency or pitch of a wave as its source moves relative to an observer, commonly experienced with passing sirens.

Electric Generator: A device that converts mechanical energy into electrical energy, providing power to submarine systems.

Inertial Navigation System (INS): A system that tracks the movement of submarines underwater by measuring changes in speed and direction.

Kilowatt-hour (kWh): A unit of energy measurement used to calculate electricity consumption over time.

Navigation: The process of determining and controlling the movement of a submarine to ensure safe travel.

Nuclear Fission: The process of splitting uranium atoms to release energy, used in nuclear power generation.

Nuclear Reactor: A device in which controlled nuclear fission reactions generate heat for power production in submarines and power plants.

Optics: The study of light and its interactions with different materials, essential in periscopes and lenses.

Periscope: An optical device used in submarines to allow viewing above the water's surface while remaining submerged.

Power Efficiency: The percentage of generated power that is converted into useful work, such as propulsion in a submarine.

Propeller: A rotating device that pushes water backward to move a submarine forward.

Reflection: The bouncing of light or sound waves off a surface, used in SONAR and periscopes.

Refraction: The bending of light or sound waves when they pass from one medium to another, affecting visibility and SONAR signals.

Residual Electricity: The unused or stored electrical energy in a submarine's battery system.

SONAR (SOund Navigation And Ranging): A system that uses sound waves to detect, locate, and measure distances to objects underwater.

Sound Speed in Water: Sound travels at approximately 1,500 meters per second in water, much faster than in air.

Stealth Technology: Methods used to reduce a submarine's visibility to SONAR detection.

Steam Generator: A component that heats water into steam to power turbines in nuclear submarines.

Submarine Hull: The main body of a submarine, designed to withstand underwater pressure.

Turbine: A machine that converts steam energy into mechanical energy to generate electricity or propulsion.

Wave Frequency: The number of waves passing a point per second, determining the pitch of sounds.

Defence Nuclear Enterprise

There are many organisations who are part of the Defence Nuclear Enterprise (DNE). These include the following:

Eko

AWE NUCLEAR SECURITY TECHNOLOGIES

babcock™

Strategic Command

Defence Nuclear Organisation

Ministry of Defence

Submarine Delivery Agency

BAE SYSTEMS

ROLLS ROYCE

ROYAL NAVY