CLASS ZERO EMISSION

CLIMATE CHANGE EXPERIMENTS

INTERNATIONAL POLAR FOUNDATION

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INTERNATIONAL POLAR FOUNDATION

FOREWORD

This experiment booklet is designed for sixth form students. It allows students to work independently, learning through experiments about the key role the Polar Regions play in the Earth's climate system.

Given the broad nature of climate change issues, the experiments are interdisciplinary and provide a cross curricular learning experience linking to a range of subjects including biology, geography, citizenship, physics and chemistry. In addition, they offer the opportunity for to students to acquire research skills.

These experiments have already been extensively tested in Class Zero Emission workshops, organized by the International Polar Foundation.

The experiments are based on five themes, which are interlinked as illustrated in the flow chart. Each theme is introduced by a background information sheet, followed by a description of the experiment and a worksheet for students to complete. Models answers for the worksheet are available.

THEME	EXPERIMENT	AIMS
SEA LEVEL RISE	WHEN THE ICE MELTS	ESTABLISH WHETHER LAND ICE, SEA ICE OR BOTH CONTRIBUTE TO SEA LEVEL RISE
	WHEN WATER GETS WARMER	DETERMINE WHETHER THE WARMING OF THE OCEANS CONTRIBUTES TO SEA LEVEL RISE
ALBEDO	ALBEDO AND TEMPERATURE	ESTABLISH THE EFFECT OF ALBEDO ON TEMPERATURE
	ALBEDO AND LIGHT	DIRECT MEASUREMENT OF THE ALBEDO OF DIFFERENT MATERIALS
THERMOHALINE CIRCULATION	DENSITY DIFFERENCES	EVALUATE THE EFFECT OF TEMPERATURE AND SALINITY ON THE DENSITY OF WATER
	MOVEMENT OF WATER MASSES	OBSERVE THE MOVEMENTS OF WATER MASSES AS A FUNCTION OF THEIR DENSITY AND SALINITY
OCEAN ACIDIFICATION	CAN WE MAKE IT MORE ACIDIC?	DETERMINE THE INFLUENCE OF CO_2 ABSORPTION ON THE PH OF WATER. DETERMINE IF THE PROCESS OF ACIDIFICATION IS MORE IMPORTANT IN THE POLAR REGIONS
	THE SAD FATE OF SEA SHELLS	OBSERVE THE IMPACT OF A LOW PH ON THE SHELLS OF MARINE ORGANISMS MADE OF CALCIUM
PALAEOCLIMATOLOGY	RECORDS FROM THE PAST	ESTIMATE THE TEMPERATURE IN THE PAST, THROUGH THE ANALYSIS OF DIATOM SPECIES IN A SEDIMENT CORE

ADDITIONAL INFORMATIONS

You can find additional information on the educational website, www.educapoles.org

Teaching dossiers:

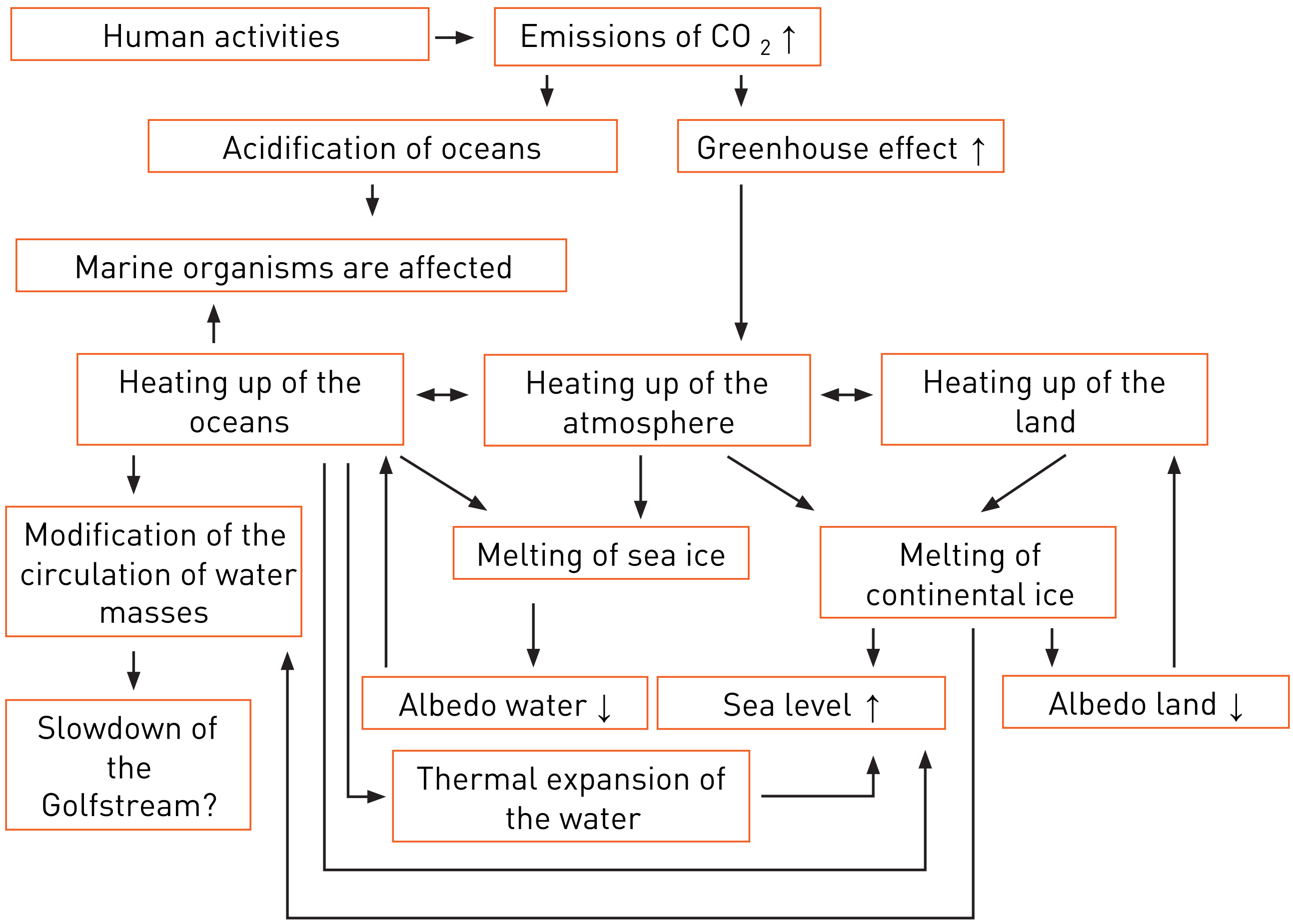
Climate change: What is it?
Climate Change: Consequences for the Planet and the Polar Regions

multimedia:

Humankind: Culprit and Victim of Climate Change Today
The Polar Regions: The First Areas of the Planet to Be Affected by Climate Change

There are also links to other sites, where you can find more information on polar regions and climate change.

CLIMATE CHANGE : LINKS BETWEEN THE EXPERIMENTS



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THEME 1

SEA LEVEL RISE
GENERAL INFORMATION

Sea level rise is often reported in relation to the intensification of the greenhouse effect. Measurements taken around the globe indicate that sea level has risen by 10 to 20cm during the 20th century and researchers predict that the increase in sea level during the 21st century will be even greater. The two major processes contributing to rising sea levels are illustrated by conducting experiments.

Before conducting the experiments, it is useful to distinguish between two types of ice: continental or land ice and sea ice and to understand thermal expansion.

Continental/land ice

Continental or land ice is formed by snow that piles up over several hundreds of thousands of years. This snow is transformed into ice under the pressure of its own weight. Glaciers, ice sheets and ice caps are examples of continental ice. Glaciers can be found in many locations around the world, but ice sheets only occur in Antarctica and Greenland. These two expanses of ice (over 50,000km2) are the largest in the world and are around 2-4km thick, which is a lot of ice!

Ice shelves are glaciers or ice sheets which extend across areas of ocean and are therefore floating. Ice bergs are formed when parts of an ice shelf break off and float freely in the ocean.

Sea ice

Sea ice is formed when the ocean freezes over. This sea ice is around 1.5-2 meters thick. If sea ice becomes permanent, as is the case for some of the ice in the Arctic, snow builds up to make the sea ice thicker.

left: Continental ice (ice sheet) (© International Polar Foundation – René Robert).

right: Sea ice (© International Polar Foundation – Alain Hubert).

ARCHIMEDES' PRINCIPLE

Buoyancy (Fu) is the upward force exerted on an object immersed in a fluid.

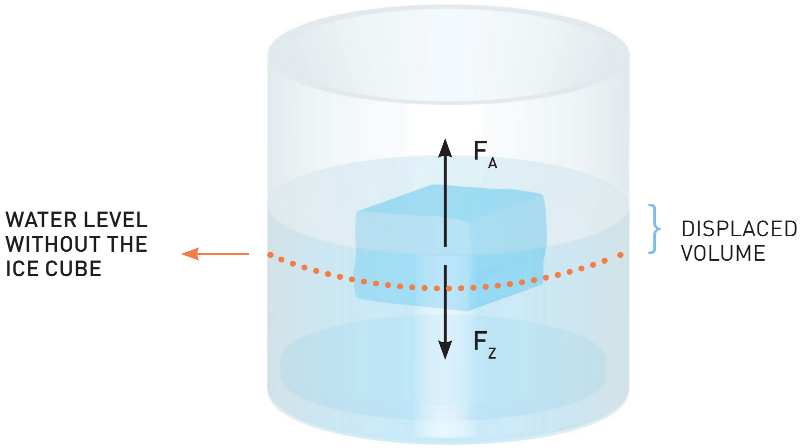


Illustration of Archimedes' Principle.

According to Archimedes' Principle, an object will float if the weight of the liquid displaced ($F_u = m_{ld} \cdot g$) equals the weight of the object ($F_g = m_{object} \cdot g$).

Where:

m_{ld} = mass of liquid displaced

m_{object} = mass of object

g = acceleration due to gravity

$\rightarrow F_u = F_g$

$\rightarrow m_{ld} \cdot g = m_{object} \cdot g$

$\rightarrow m_{ld} = m_{object}$

THERMAL EXPANSION

Thermal expansion occurs when matter changes volume (DV) in response to a change in temperature (DT). This occurs because as molecules become more mobile at higher temperatures, they take up more space, which increases the volume of an object. Thermal expansion is expressed as follows:

$\rightarrow \Delta V = \alpha \,.\, \Delta T \,.\, V$

Where:

V = the volume of the material

ΔV = the change in volume

ΔT = the change in temperature

α = the coefficient of thermal expansion

EXPERIMENT 1.1
WHEN THE ICE MELTS
DESCRIPTION

RESEARCH QUESTION

Does the melting of sea ice or continental/land ice, or both, cause sea levels to rise?

MATERIALS

- 2 plastic containers
- Water
- 10 small ice cubes
- Tape / post-its
- Stones
- Labels: sea ice and land ice

GET TO WORK!

Formulate your scientific hypothesis (see research question above) and fill it in on the worksheet.

Container 1

- Place the stone(s) on one side of the container
- Place five ice cubes on top of the stones.
- Fill the container with water so that the stones are not entirely covered.
- Mark the water level with a piece of tape/post-it. Be accurate!
- Which type of ice does this container represent? Place the correct label next to the container.

Container 2

- Place the stone(s) on one side of the container.
- Place five ice cubes in the container, not on the stone(s).
- Fill the container with water until the ice cubes float.
- Mark the level with a piece of tape/post-it. Be accurate!
- Which type of ice does this container represent? Place the correct label next to the container.

When the ice cubes have melted, write your observations on the worksheet. Analyze your findings by answering the questions and draw your conclusions and summarize the experiment. Prepare your team of scientists for a presentation in front of the group.

EXPERIMENT 1.1 WHEN THE ICE MELTS

WORKSHEET

HYPOTHESIS

RESULTS

What happens to the water levels in each of the containers?

ANALYSIS

What does this tell you about the influence of melting ice on sea level? Which type of ice contributes to sea level rise? Do they both contribute?

How can you explain this difference?
For the sea ice, what is the weight of the volume of displaced water?

How do the forces that interact on sea ice relate to each other? Draw a diagram below to illustrate. (Hint: Archimedes' principle).

What happens when the sea ice melts?

CONCLUSIONS

Is your hypothesis correct? If not, explain why.

IMPLICATIONS

Can you estimate by how much sea level would rise if the Greenland and Antarctic ice sheets melted completely if:

The Greenland ice cap weighs $25{,}6 \times 10^{17}$ kg

The Antarctic ice sheets weigh $22{,}9 \times 10^{18}$ kg

The total surface of the world's oceans is 361×10^{6} km^{2} (= S)

The density of water is 1000 kg / m^{3}

The change in the volume of sea water due to sea level rise, if the surface area of sea water stays the same, is expressed as follows:

$\Delta H = \Delta V / S$

Answer the following questions together with the group who did the "When water gets warmer" experiment.

Sea levels rise because of the warming climate. Can you name the two processes that contribute to this rise?

Who will be affected most by sea level rise?

EXPERIMENT 1.1 WHEN THE ICE MELTS

WORKSHEET - ANSWERS

HYPOTHESIS

Melting continental/land ice will contribute to sea level rise, melting sea ice will not.

RESULTS

The water level rises in the container where the ice cubes were on top of the stones, but the level doesn't change in the container where the ice was floating in the water.

ANALYSIS

Melting continental/land ice will contribute to sea level rise, melting sea ice will not.

The melting of a glacier or ice sheet results in additional water being added to the ocean, causing a rise in sea level. The melting sea ice does not change sea level, as the water is already floating in the ocean.

The weight of the sea ice is equivalent to the weight of the volume of displaced water.

$F_U = F_g$

When sea ice melts, the displaced water is replaced by melted ice (water), which means that the volume of the water in the ocean does not change.

IMPLICATIONS

$\Delta H = \Delta V / S$

Melting of Greenland Ice Sheet:

$\Delta V = 25.6 \times 10^{17} / 1000 = 25.6 \times 10^{14} m^3$

$\Delta H = 25.6 \times 10^{14} / 361 \times 10^{12} = 7.1 m$

Melting of Antarctic ice sheets:

$\Delta V = 22.9 \times 10^{18} / 1000 = 22.9 \times 10^{15} m^3$

$\Delta H = 22.9 \times 10^{15} / 361 \times 10^{12} = 63.4 m$

$\Delta H_{total} = 7.1 m + 63.4 m = 70.5 m$

The two main causes of sea level rise are the melting of continental/land ice and thermal expansion of water

The people who will be most affected by sea level rise are those people who live at the coast, in low-lying cities or towns. e.g. Bangladesh, islands in the Pacific (Tuvalu)

EXPERIMENT 1.2
WHEN WATER GETS WARMER
DESCRIPTION SHEET

RESEARCH QUESTION

How does temperature influence sea level?

MATERIALS

- 2 containers
- Water
- 10 ice cubes
- kettle
- test tube with a hermetically sealed tube fitted through the top

GET TO WORK !

Try to work out whether an increase in water temperature will cause the water level to rise. Formulate your scientific hypothesis and fill it in on the worksheet.

- Bring the water to the boil in the kettle.
- Carefully, fill one container to ¾ full with hot water.
- Half fill the other container with cold water and add five ice cubes.
- Place the test tube vertically in the container with hot water for a couple of minutes, and see what happens.
- Place the test tube in the container with cold water, and see what happens.
- You can repeat the last steps several times.

Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 1.2
WHEN WATER GETS WARMER
WORKSHEET

HYPOTHESIS

RESULTS

What happens to the water level in the small tube when the test tube is put into warm water?

What happens when you put it into cold water?

ANALYSIS

What phenomenon can be used to explain your observations?

CONCLUSIONS

Is your hypothesis correct? Explain.

IMPLICATIONS

Will sea levels rise due to the current changes in our climate?

Between 1993 and 2003, the surface waters of the oceans (layer thickness = 700m) warmed by 0.08 °C.

Sea water has a coefficient of thermal expansion of 2.6×10^{-4} / °C.

The volume of sea water (V) can be expressed as follows:

$V = H \cdot S$

Where:

H = thickness of the water layer

S = surface of the water layer

A change in the volume of sea water due to sea level rise, where there is no change in the surface area, is expressed as follows:

$\Delta V = \Delta H \cdot S$

Knowing also that:

$\Delta V = \alpha \cdot \Delta T \cdot V$

Where :

α = coefficient of thermal expansion

ΔT = change in temperature

V = volume

Calculate the sea level rise resulting from the thermal expansion of sea water between 1993 and 2003 (mm/year):

Measurements have shown that sea levels have risen 3.1mm per year between 1993 and 2003. Which of the following has made the most significant contribution?

- The melting of continental ice
- The thermal expansion of sea water
- Neither of them, they are equally important

EXPERIMENT 1.2
WHEN WATER GETS WARMER
WORKSHEET – ANSWERS

HYPOTHESIS

An increase in temperature will result in sea level rise.

RESULTS

The water level rises in the small tube when the test tube is placed in the measuring cup with hot water, and falls when it is placed in the measuring cup with cold water.

ANALYSIS

Thermal expansion. Thermal expansion is the increase in volume when a substance is subjected to higher temperatures. This happens because molecules become more mobile at high temperatures, which means that they take up more space, and therefore volume. In other words, volume changes when temperature changes.

IMPLICATIONS

Sea levels will rise due to the current changes in our climate, as the land and the atmosphere are warming up and the heat is being transferred to the ocean. As the ocean warms, the volume of sea water increases leading to sea level rise.

Sea level rise due to thermal expansion of the ocean between 1993 and 2003 can be calculated as follows:

$\Delta V = \Delta H \,.\, S$

$\Delta V = \alpha \,.\, \Delta T \,.\, V$

$\Delta H \,.\, S = \alpha \,.\, \Delta T \,.\, H \,.\, S$

$\Delta H = \alpha \,.\, \Delta T \,.\, H = 2{,}6 \,.\, 10^{-4}/°C \,.\, 0{,}08\ °C \,.\, 700\ m$

$\Delta H = 0{,}015\ m/10\ years$

$\Delta H = 15mm/10\ years$

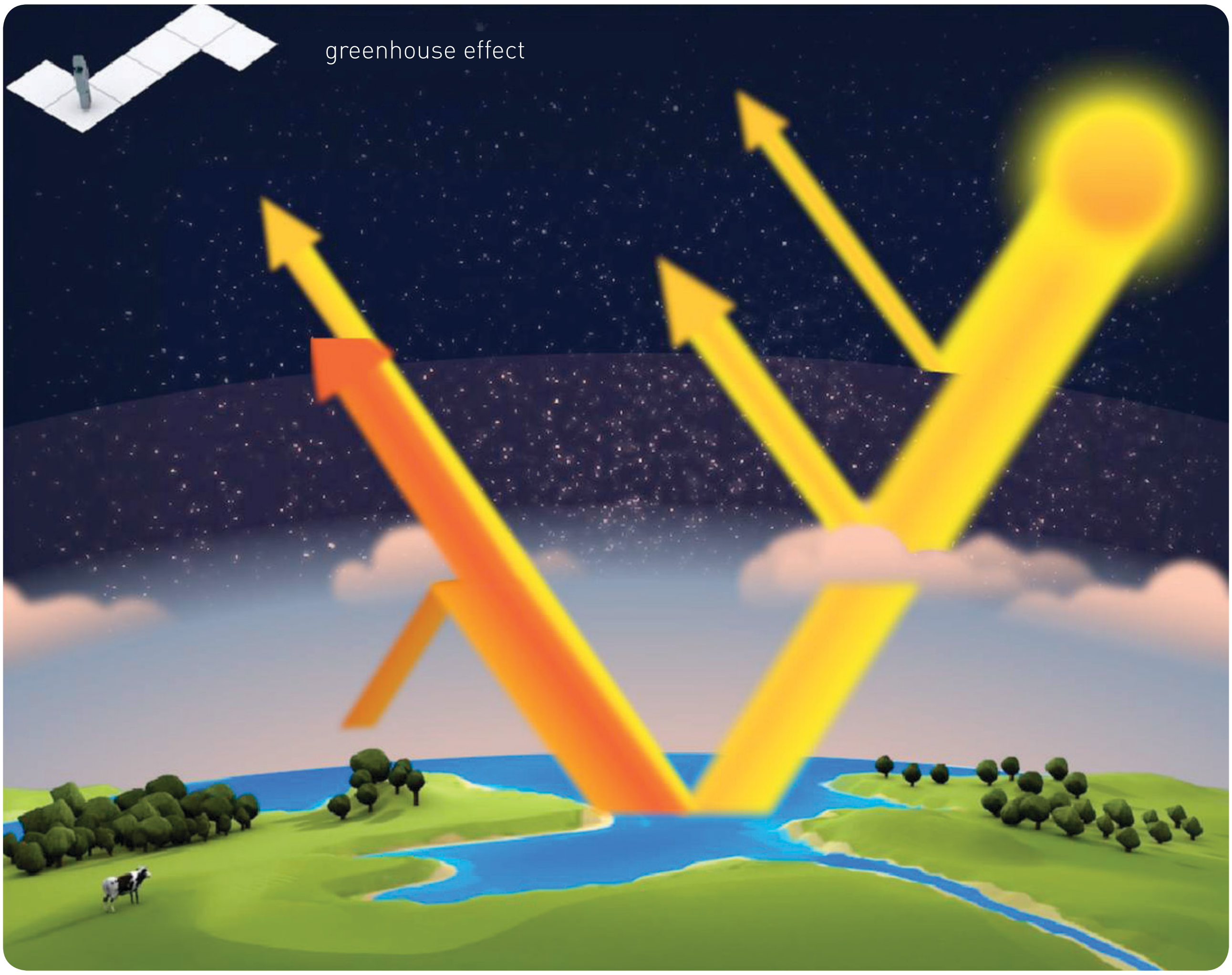
$\Delta H = 1.5\ mm\ per\ year$

Sea level rose by 1.5 mm per year between 1993 and 2003.

Observations of sea level indicate an increase of 3.1 mm / year between 1993 and 2003. This indicates that the contribution of melting of continental ice and thermal expansion of the oceans is of the same order of magnitude.

THEME 2
ALBEDO
BACKGROUND INFORMATION

When solar radiation reaches the Earth, part of the energy is absorbed by the surface, while the rest of the energy is reflected back into space.



The Greenhouse Effect (© International Polar Foundation)

Albedo (=A) is the percentage of incoming sunlight that is reflected, rather than absorbed by a surface.

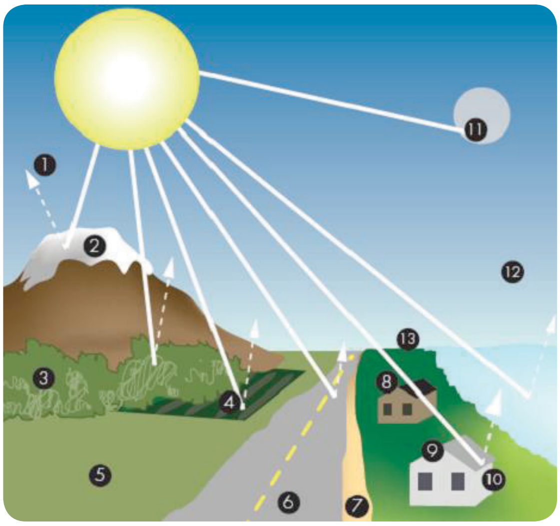
A = (total reflected radiation / incoming radiation) * 100

An albedo of 100% will therefore reflect all incident light.

An albedo of 0% will absorb all incident light.

Albedo depends on the colour and texture of the irradiated surface. A surface with a high albedo has a high reflecting capacity. Clean snow has a high albedo as it reflects a high percentage of the incoming light energy.

Darker surfaces have a low albedo as they absorb more energy than they can reflect. Figure 2.2 gives some examples of albedo for different surfaces.



01. ALBEDO (% REFLECTED)
02. FRESH SNOW : 80 – 95 %
03. FOREST : 10 – 20 %
04. CORN FIELDS : 10 – 25 %
05. GRASS : 25 – 30 %
06. ASPHALT ROAD : 5 – 10 %
07. CONCRETE : 17 – 27 %
08. DARK ROOF : 8 – 18 %
09. LIGHT COLOURED ROOF : 35 – 50 %
10. BRICKS, STONE : 20 – 40 %
11. THE MOON : 6 – 8 %
12. WATER : 10 – 60 % (STRONGLY DEPENDENT ON THE POSITION OF THE SUN)
13. THE EARTH (AVERAGE) : 35 %

Values of albedo for different surfaces. © International Polar Foundation

Averaged over the duration of a year, the incoming energy from the sun is highest at the equator and lowest at the poles. In addition, the poles reflect more energy because of the light coloured reflective snow and ice surfaces, compared to lower latitudes, where the surface absorbs more energy.

Winds spread air masses all over the Earth. If the atmosphere did not move any energy from the tropics to the poles, the tropics would overheat and the poles would be even colder than they are now.

This is one reason why the Polar Regions are important for the regulation of the Earth's climate. Because of climate change, snow and ice now form later in the autumn and melt earlier in the spring. Melting snow and ice uncover the darker land and water surfaces, which absorb more energy.

This leads to further warming of the Earth's surface, which causes more snow and ice to melt, resulting in more warming, etc. This reduction in albedo is called a positive feedback in global warming as it causes temperatures to rise even further.

This feedback phenomenon has been taking place for centuries: the ice sheets, ice caps, glaciers and snow cover expanded during the ice ages, which caused the Earth to cool even further. However, when the Earth became warmer again, the ice and snow cover gradually melted, resulting in less energy being reflected, which causes the Earth to warm more.

EXPERIMENT 2.1
ALBEDO AND TEMPERATURE

DESCRIPTION SHEET

RESEARCH QUESTION

Which plate will warm up the fastest: a white or black one?

MATERIALS

- Insulated metal plates (black and white)
- 2 thermometers (placed directly behind the metal plates)
- Source of warm light
- Stopwatch

GET TO WORK !

- Which surface do you think will be the fastest to warm up? Formulate your scientific hypothesis and fill it in on the worksheet.
- Measure the background temperatures and write them down in the table on your worksheet.
- Switch on the lights and start the stopwatch.
- Measure the temperature of each plate every 30 seconds and write it down on the table.
- Switch off the lights after 2.5 minutes.
- Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 2.1
ALBEDO AND TEMPERATURE
WORKSHEET

HYPOTHESIS

RESULTS

TIME (SECONDS)	TEMPERATURE OF THE WHITE SURFACE (°C)	TEMPERATURE OF THE BLACK SURFACE (°C)
0 (BACKGROUND)		
30		
60		
90		
120		
150		

ANALYSIS

CONCLUSION

Is your hypothesis correct?

IMPLICATIONS

High power incandescent light bulbs cause a faster and more intense warming than low energy light bulbs. Why?

Can you carry out this experiment with a compact fluorescent lamp (CFL)? Explain.

Compare your experiment with the "Albedo and Light" experiment (part 2). What is the main difference?

EXPERIMENT 2.1
ALBEDO AND TEMPERATURE
WORKSHEET - ANSWERS

HYPOTHESIS

The black plate absorbs energy more quickly than the white plate. The black plate will therefore heat up to a higher temperature and will heat up more quickly than the white plate.

RESULTS

Example results - these may vary depending on the equipment used.

TIME (SECONDS)	TEMPERATURE OF THE WHITE SURFACE (°C)	TEMPERATURE OF THE BLACK SURFACE (°C)
0 (BACKGROUND)	18.6	18.7
30	19.0	19.4
60	19.6	21.7
90	20.1	23.1
120	20.7	24.2
150	21.0	25.2

ANALYSIS

The light (which represents the Sun) is absorbed by the plates as thermal energy. The temperature rise is faster and greater for the black plate than the white plate, because the white surface reflects more of the light.

IMPLICATIONS

Incandescent light bulbs are small heating systems that consume a lot of energy to produce light. The speed and the intensity at which the plates warm depends on the power (Watts) of the light bulb: the higher the power of the light bulb, the faster the plates will heat up.

This experiment would be difficult to carry out with CFL bulbs as they do not give out much heat. With a 20W E27 CFL, the black plate only heats up to 21 to 22°C in 25 minutes. CFLs need 75% less energy than traditional incandescent light bulbs and they produce more visible light and less heat with the same electricity consumption. They are therefore a much more efficient form of lighting.

This experiment illustrates an indirect measurement of albedo using temperature, whereas the second experiment is a direct measurement of albedo using a light meter.

EXPERIMENT 2.2
ALBEDO AND LIGHT
DESCRIPTION SHEET

RESEARCH QUESTIONS

Does the colour of a surface affect the albedo? Does the texture of a surface affect the albedo?

MATERIALS

- Seven plastic boxes with a different surface (colour/texture) in the bottom
- Source of light (natural or artificial light)
- Light meter (measures the amount of light received / reflected from the different surfaces)
- Calculator

GET TO WORK !

- Formulate your hypothesis and enter it in the worksheet. Do this before starting the experiment! Think about what type of surface has the highest albedo (ie reflects the most light).
- Check how to work the light meter. Ask for help if necessary.
- Assign a role to each student around the table:
    - one person holds the sensor in the same position throughout the experiment, with their elbow on the table and wrist on the edge of the plastic box.
    - one person slides the boxes containing the various samples on the table, under the sensor for each measurement (two measurements per sample – incident and reflected light)
    - one person notes down the measurements from the light meter.

- Repeat for each sample
- Calculate the albedo of each surface.
- Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 2.2
ALBEDO AND LIGHT
WORKSHEET

HYPOTHESIS

RESULTS

SAMPLE (SEE SIDE OF EACH BOX)	INCIDENT RADIATION (LUX)	REFLECTED RADIATION (LUX)	ALBEDO (%)	ALBEDO RANKING *
A: SHINY WHITE PAPER (SNOW, ICE)				
B: BLUE PAPER (OCEAN)				
C: BLUE PAPER (OCEAN) + PIECES WHITE PAPER (ICE BERGS)				
D: GREEN PLASTIC MAT (CONIFEROUS FOREST)				
E: SANDPAPER (CONCRETE)				
F: BLACK PLASTIC (TARMAC, DARK ROCKS)				
G: BLACK CRUMPLED PLASTIC (DARK ROCKS WITH RELIEF)				

* Final column : rank albedo from lowest to highest

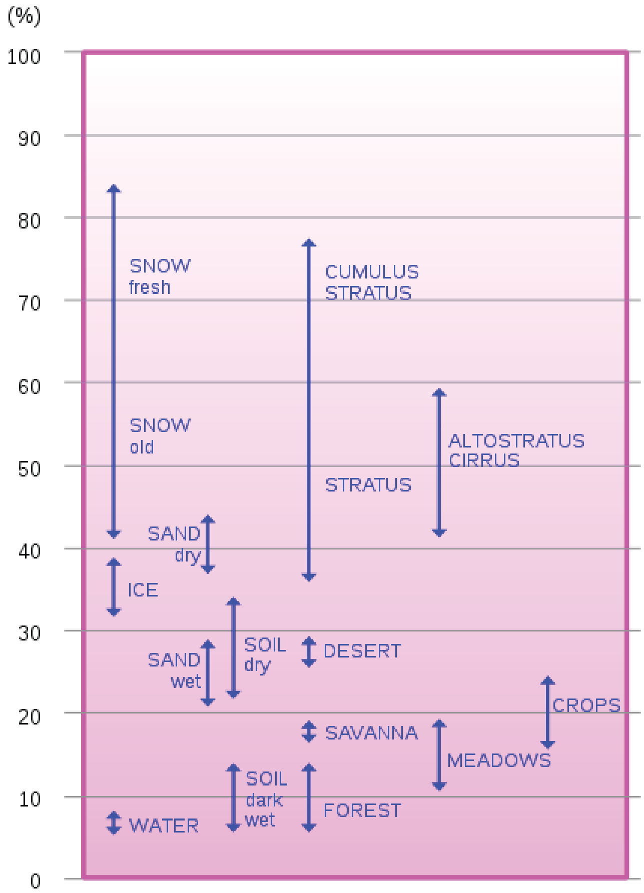
ANALYSIS

Which materials / textures / colours have the lowest albedo? Which has the highest albedo? Look at the last column of your table.

How does colour influence albedo ?

How does texture influence albedo ? (compare samples F and G

Compare your values with those in the graph below. How do you explain the differences observed?



Albedo values for different materials and clouds.

CONCLUSIONS

Is your hypothesis correct? If not, re-write this according to the outcome.

IMPLICATIONS

How can clouds influence the albedo of the Earth?

....

How will the albedo of the earth change if sea ice melts in the Arctic?

EXPERIMENT 2.2
ALBEDO AND LIGHT
WORKSHEET - ANSWERS

HYPOTHESIS

Light surfaces and smooth surfaces have the highest albedo.

RESULTS

Note : The values below are approximate - they may vary depending on the light source and experiment conditions.

SAMPLE (SEE SIDE OF EACH BOX)	INCOMING RADIATION (LUX)	REFLECTED RADIATION (LUX)	ALBEDO (%)	ALBEDO RANKING*
A : SHINY WHITE PAPER (SNOW, ICE)	220	152	69	7
B : BLUE PAPER (OCEAN)	225	93	41	5
C : BLUE PAPER WITH PIECES OF WHITE PAPER (ICE ON THE OCEAN)	231	123	53	6
D : GREEN PLASTIC MAT (CONIFEROUS FOREST)	226	57	25	3
E : SANDPAPER (CONCRETE)	224	78	35	4
F : BLACK FLAT PLASTIC (TARMAC, DARK ROCKS)	230	56	24	2
G : BLACK CRUMPLED PLASTIC (WITH RELIEF, DARK ROCKS)	227	22	10	1

* last column – rank albedo from lowest to highest

ANALYSIS

The lowest albedo = black folded plastic (dark terrain with relief, rocks), is the surface which absorbs more light.

The highest albedo = salt (snow and ice), is the surface that reflects more light.

The lighter the colour, the higher the albedo.

The smoother the texture, the higher the albedo.

Differences between the experiment results and the values in Figure 2.4 are because the experiment uses representative samples and not the real materials (ie. shiny paper for snow/ice; plastic mat for trees etc.). Also, the measurements depend on the accuracy of the person taking the readings and the light meter.

IMPLICATIONS

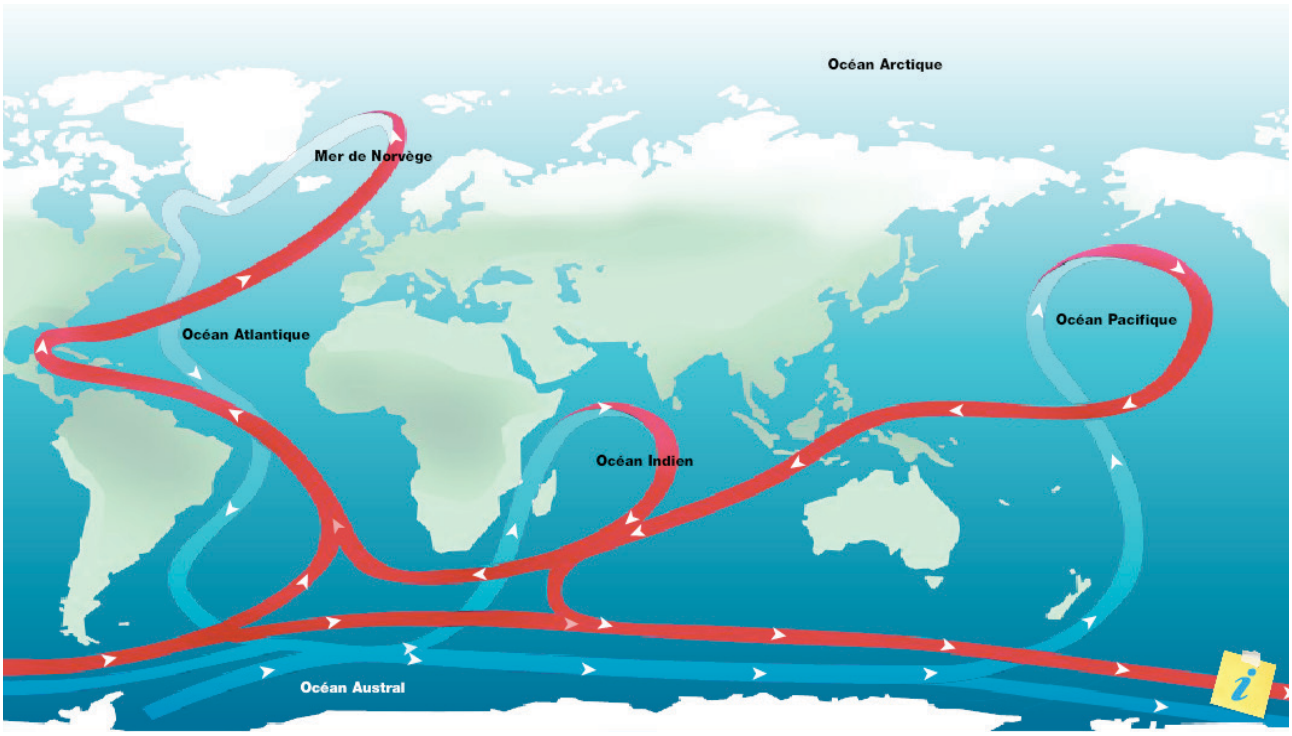
Clouds are different thicknesses, colours and textures: a cloud that is more diffuse and thin will have a low albedo (cirrus, high level clouds - like wispy angel hair). In addition, these clouds will allow more sunlight to pass to the surface of the Earth. Most clouds are thick and white (cumulus, the most recognizable cloud, shaped like a sheep), and have a high albedo. The high reflectivity of these clouds will therefore prevent a portion of sunlight reaching the Earth's surface. They have a cooling effect on the atmosphere.

With global warming, the ice (white) melts and leaves room for water (liquid form, blue). This surface has a lower albedo and will, therefore, increase the absorption of light energy by the ocean, and thus accelerate the melting ice.

This would affect the albedo of the area. These two biomes have different colours and textures (taiga is darker than tundra and has more depth), and therefore different albedos: Taiga has a lower albedo than the tundra and therefore absorbs more incoming light. An increase in taiga would therefore cause more warming.

THEME 3
THERMOHALINE CIRCULATION
BACKGROUND INFORMATION

Thermohaline circulation is the movement of water masses in the oceans. It is affected by two important factors: water density and wind. Water density is affected by temperature and salinity.



Thermohaline ocean circulation.

The density of a substance is the mass of the substance in a certain volume. ie.

$\rho = m / V$

Where :

ρ = density (kg/m^3)

m = mass (kg)

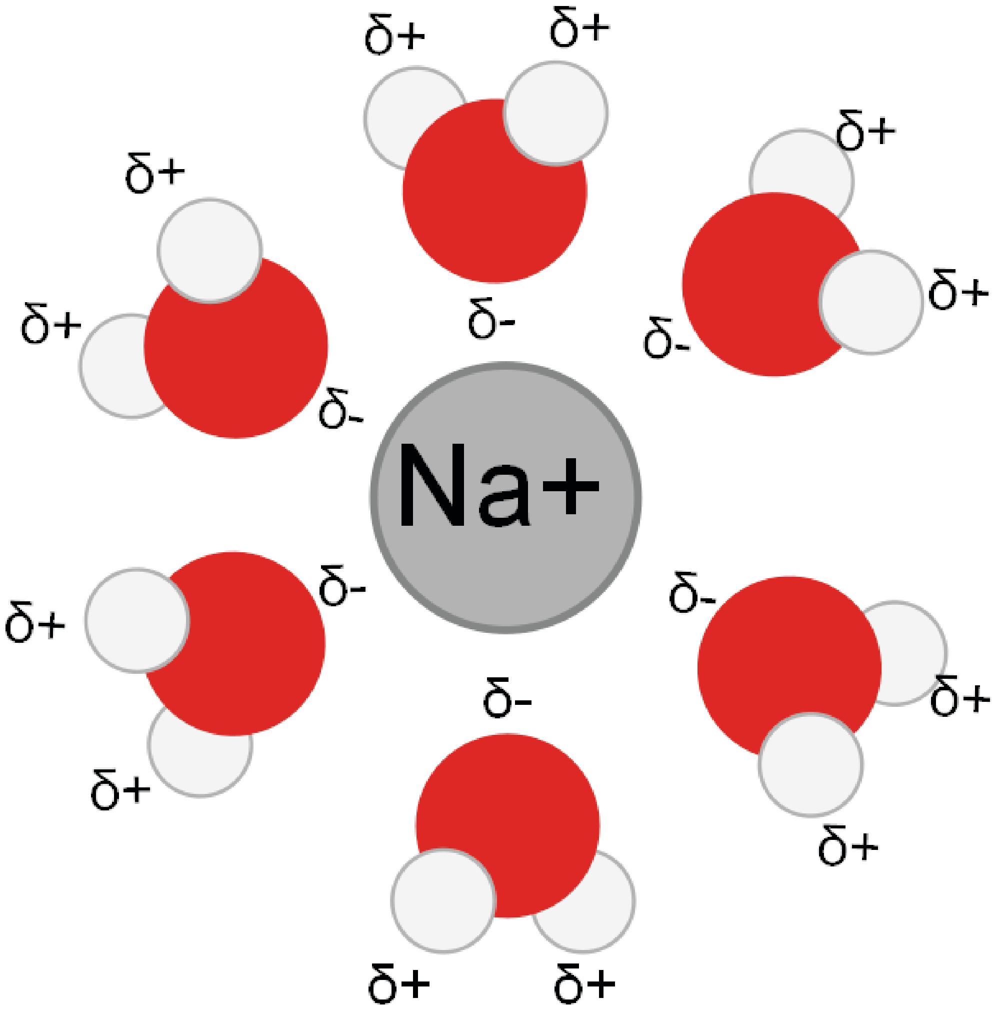
V = volume (m^3)

When a certain volume is very heavy, we say it has a high density (e.g. concrete). If a certain volume is very light, we say that its density is low (e.g. air).

We usually present the density of a substance at a specific temperature and pressure because if these change, the density will change. In ocean currents, both temperature and salinity affect density.

The salinity is expressed in g/kg (grams of salt per kilogram of water) or in psu (practical salinity unit, where

1 psu is equivalent to 1g salt per kg of water). When we add salt to water, the molecules dissolve into ions. Molecules of salt can no longer be formed as they are surrounded by water molecules.



Sodium ion succounded by water molecules

EXPERIMENT 3.1 DENSITY DIFFERENCES

DESCRIPTION SHEET

RESEARCH QUESTIONS

Does temperature affect the density of water?

Does salinity affect the density of water?

MATERIALS

- Hydrometer
- Graduated cylinder
- Water
- Kettle
- Salt
- Spoon
- Funnel

GET TO WORK!

- Think about whether temperature and salinity will have an effect on the density of water. Formulate your scientific hypothesis and fill it in on the worksheet.
- Fill the graduated cylinder with cold water.
- Place the hydrometer carefully in the water, it will float.
- Wait until the meter is stable, then measure the density and write it down on the worksheet. Use the 'specific gravity' scale.
- Take out half of the water.
- Fill the graduated cylinder with warm water.
- Give it a good stir.
- Measure the density of the water and write it down on the worksheet.
- Add 15g of salt (= 4 teaspoons) to the water. Use the funnel to do this. Give it a good stir so that the salt dissolves well in the water.
- Measure the density and write it down on the worksheet.
- Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 3.1 DENSITY DIFFÉRENCES

WORKSHEET

HYPOTHESIS

(1) Does the temperature of the water affect its density?

(2) Does the amount of salt in the water affect its density?

RESULTS

Complete the table.

	DENSITY (G/DM³)
COLD WATER – NO SALT	
WARM WATER – NO SALT	
WARM WATER – SALT	

ANALYSIS

From the table, what can you deduce about the influence of temperature on the density of the water (1)? What about the effect of salt (2)?

(1)

(2)

CONCLUSIONS

Is your hypothesis right? If not, explain why.

EXPERIMENT 3.1
DENSITY DIFFERENCES
WORKSHEET – ANSWERS

HYPOTHESIS

(1) The lower the water temperature, the higher the density of the water.

(2) The more salt in the water, the higher the density.

RESULTS

Note : the values below are indicative.

	DENSITY (G/DM³)
COLD WATER – NO SALT	1000
WARM WATER – NO SALT	990
WARM WATER – SALT	1040

ANALYSIS

(1) When the temperature of the water increases, the density decreases

(2) When salt is added to water, the density increases.

The water cools in the Polar Regions, sinks, and starts moving towards the equator. At the equator, the water heats up and rises to the surface, then returns to the Poles.

EXPERIMENT 3.2
MOVEMENT OF WATER MASSES
DESCRIPTION SHEET

RESEARCH QUESTIONS

How does water in the oceans circulate? What happens when two water masses with different densities meet? What is the effect of salinity?

MATERIALS

- Water tank
- Water
- Cold packs
- Halogen or incandescent lamp
- Blue ice cube made of salt water and blue food dye
- Red ice cube made of fresh water and red food dye
- Red and blue pens for completing worksheet

GET TO WORK!

- Think about what would happen when two water masses with different densities meet. Formulate your scientific hypothesis and fill it in on the worksheet.
- Fill the water tank ¾ full with water.
- Put the ice packs in the water tank, at the end with the retainer bars.
- Put the lamp at the opposite end of the water tank to warm it.
- Now wait for the water to cool at one end, and to warm up at the other end.
- After 15 minutes, put the blue ice cube in the water tank, next to the cold pack.
- See what happens to the circulation of water in the tank.
- Then put the red ice cube against the cold pack and see what happens.
- Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 3.2
MOVEMENT OF WATER MASSES
WORKSHEET

HYPOTHESIS

What happens when two water masses of different densities meet in the ocean? Which one will sink? Which one will rise?

RESULTS

In this experiment, you simulate the circulation of water in the oceans. Make a drawing of the water movement in the water tank (represented by the box below).

(1) Indicate the hot and cold side, respectively, with an H and C.

(2) Illustrate the movement of the salt water (blue ice cube) in fresh water. Use a blue pen.

(3) Illustrate the movement of fresh water (red cube) in fresh water. Use a red pen.

ANALYSIS

What two factors influence the water movement illustrated above?

(1)

(2)

Describe how water circulates between the poles and the equator on the basis of the circulation you simulated.

CONCLUSIONS

Is your hypothesis correct? If not, rewrite it.

IMPLICATIONS

Why is the circulation of ocean water masses called "thermohaline circulation"?

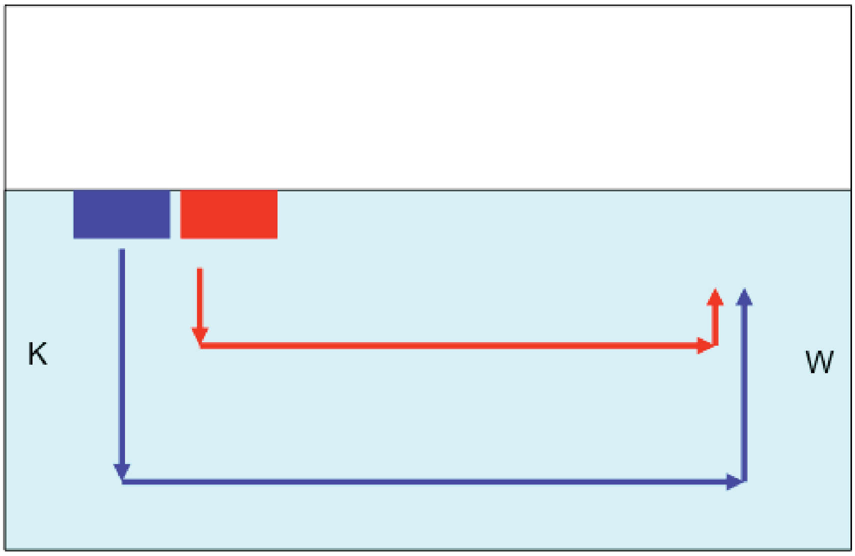
Why does ocean water sink in the Polar Regions? Give two reasons.

EXPERIMENT 3.2
MOVEMENT OF WATER MASSES
WORKSHEET – ANSWERS

HYPOTHESIS

The water mass with the highest density will sink.

RESULTS



ANALYSIS

Differences in water density cause the movement of water masses.

(1) The water density changes with the temperature of the water

(2) The water density changes with the amount of salt in the water

The water cools in the Polar Regions, sinks to the bottom of the ocean and moves along the sea bed all the way to the equator. At the equator, the water is warmed up and rises to the surface and then moves towards the poles again.

IMPLICATIONS

"Thermo" means the temperature, while "haline" means the salinity. Both have an impact on the density of the water, and therefore on the rising and sinking of the water masses.

Influence of temperature: colder temperature at the poles, therefore greater density which makes the water sink.

Influence of salinity: When sea ice forms, salt is expelled and this creates denser water under the sea ice. This water then sinks. This happens because salt is difficult to dissolve in ice as it cannot integrate within the ice crystal structure.

THEME 4
OCEAN ACIDIFICATION
BACKGROUND INFORMATION

Approximately 70% of the surface of the Earth is covered in water, which is why oceans play a crucial role in climate mechanisms. Oceans also play an important role in the carbon cycle. Because carbon dioxide (CO_2) is soluble in water, there is exchange between the atmosphere and the ocean surface until they reach a balance.

Until recently, the oceans were a source of CO_2. This situation has changed and has been reversed: because of human activities CO_2 concentrations in the atmosphere have increased so sharply that the oceans are now absorbing huge amounts of CO_2.

The absorption of CO_2 changes the acidity of the upper layers of the oceans. The acidity of a liquid is measured in pH, as defined by the following:

$pH = - \log_{10} [H^+]$,

where $[H^+]$ = is the concentration of hydrogen ions in the water (mol/l)

=> The higher the H+ concentration, the lower the pH, and the more acid a solution is.

A solution with pH greater than 7 is known as basic; less than 7, it is acidic.

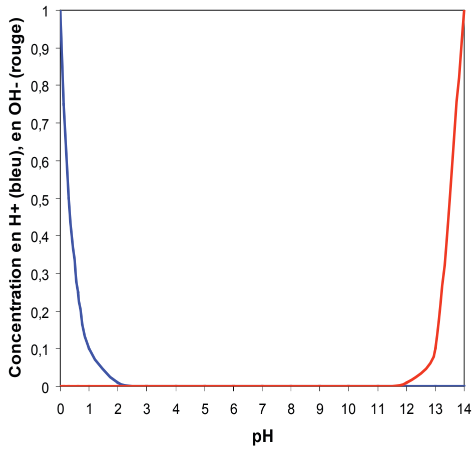
Here are some examples:

VINEGAR	PH = 3,5
MILK	PH = 6,5
LIMESTONE	PH= 8,2
AMMONIA	PH = 11,8

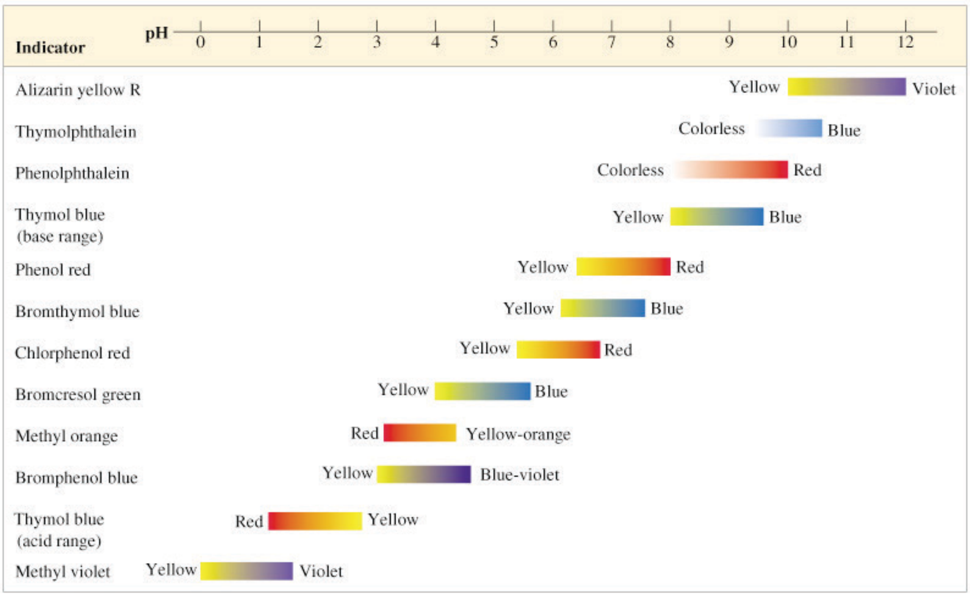
To get a rough estimate of the pH, scientists use pH paper. Because of the acid in a solution, the paper changes colour. By comparing the colour with the pH scale, we can estimate the pH. For a more accurate measurement of the pH, scientists use a pH-meter.

A pH indicator can be used to indicate when pH exceeds a certain threshold. A pH indicator is a chemical substance which changes colour depending on the pH. The pH zone in which the colour changes is called the pH transition range. The following graphs show some examples of indicators and their transition ranges, as well as the colours for their acidic and basic forms. A detailed overview for bromothymol blue is al so shown.

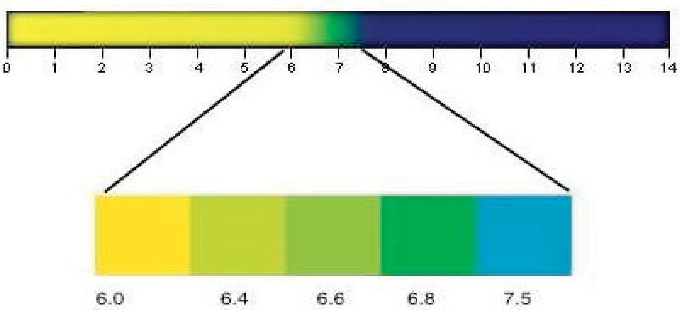
The absorption of CO_2 by the ocean poses a threat for marine organisms with a calcium carbonate ($CaCO_3$) skeleton or shell (e.g. mussels, cockles, sea stars, corals...).



pH in function of the concentration of H^+



pH indicators and their corresponding transition range, as well as the colours for the acidic and basic forms.



Bromothymol blue indicator colour range

EXPERIMENT 4.1
CAN WE MAKE IT MORE ACIDIC?
DESCRIPTION SHEET

RESEARCH QUESTIONS

What is the effect of CO_2 absorption on the pH of water?

What is the effect of the temperature of the water on the absorption of CO_2?

MATERIALS

- 2 conical flasks
- water
- ice cubes
- straws
- bromothymol blue (pH-indicator)
- 2 pairs of safety glasses
- measuring cup
- stopwatch

GET TO WORK !

- Do you think that the absorption of CO_2 will increase or reduce the pH of the water? Formulate your scientific hypothesis and fill it in on the worksheet.
- Do you think that the temperature of the water has an affect on the absorption of CO_2? Formulate a second hypothesis and fill it in on the worksheet.
- Fill flask 1 with 80ml of water, and flask 2 with 40ml of water.
- Put on your safety glasses.
- Add 10 drops of bromothymol blue to each flask and mix well.
- Add ice cubes to flask 2 until it is at the level of 80ml.
- Determine the colour and the pH of Flask 1 using the bromothymol blue colour scale and fill in the worksheet. This is your reference sample.
- Blow in each of the flasks for 2 minutes with a straw. You do not have to blow continually, you can take breaks.
- Immediately determine the colour and the pH of the liquid in each flask and fill in the worksheet.

Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 4.1 CAN WE MAKE IT MORE ACIDIC?

WORKSHEET

HYPOTHESIS

(1) ....

(2) ....

RESULTS

Complete the table; write down the colour and acidity in each flask. Determine the pH.

	COLOUR	PH GIVEN BY BROMOTHYMOL BLUE
REFERENCE FLASK		
FLASK WITHOUT ICE CUBES, 2 MINS BLOWING		
FLASK WITH ICE CUBES, 2 MINS BLOWING		

ANALYSIS

What happens to the colour when someone blows into the flask?

....

Does the water become more acidic when someone blows into the flask?

....

What causes the change in pH and colour? Hint: which gas are you blowing into the flask?

....

....

When you blow into the water, the following equilibrium reaction occurs:

$CO_{2\,(aq)} + H_2O_{(l)} \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^{-}{}_{(aq)} + H^+_{(aq)} \leftrightarrow CO_3^{2-}{}_{(aq)} + 2\,H^+_{(aq)}$

Which side will the equilibrium move towards when CO_2 concentrations rise?

....

....

What happens to the acidity level? Hint: check the pH formula.

Which flask contains the most acidic solution?

Why? Hint: solubility of gases

CONCLUSIONS

Are both your hypotheses correct? If not, explain.

IMPLICATIONS

Will increasing emissions of CO_2 lead to a more or less acidic ocean in the next century? Explain.

Which oceans will the first to be affected by acidification? The oceans around the equator or, those at the poles? Explain.

Will increased levels of CO_2 in the atmosphere have an impact on marine organisms? Discuss with the students who carried out the "The Sad Fate of Sea Shells" experiment. Explain.

If two scientists carried out the experiment and put their results on a graph (pH versus time), would their graphs be the same? Why?

EXPERIMENT 4.1
CAN WE MAKE IT MORE ACIDIC?
WORKSHEET - ANSWERS

HYPOTHESIS

When you blow into the water, you add CO_2 ; the water therefore becomes more acidic (lower pH).

The effect of water acidification is greater at colder temperatures (with ice).

RESULTS

	COLOUR	PH GIVEN BY BROMOTHYMOL BLUE
REFERENCE FLASK	BLUE	7.5
FLASK WITHOUT ICE CUBES, 2 MINS BLOWING	GREEN	6.8
FLASK WITH ICE CUBES, 2 MINS BLOWING	LIGHT GREEN / YELLOW	6.4

ANALYSIS

When you blow into the flask, the colour turns green (Flask 1) or light green/yellow (Flask 2).

Yes, the solution becomes more acidic when you blow into it.

CO_2 blown into the jar dissolves in the water, and causes the colour change (and therefore pH).

The equilbrium moves to the right when you blow into the water.

The acidity increases (the pH lowers) when you blow into the water.

The flask with the ice cubes becomes the most acidic.

A gas dissolves more easily in cold water than in warm water. The solubility is inversely proportional to the temperature. This means that more CO_2 is dissolved in the water with the ice cubes, giving a lower pH.

IMPLICATIONS

The oceans are likely to become more acidic over this century due to emissions of CO_2 in the atmosphere.

The first oceans to experience the effects of acidification will be the polar oceans as they are colder than those at the equator.

The increase of CO_2 in the atmosphere will cause ocean acidification. This acidification reduces the capacity of calcarious organisms to build their shells by affecting the calcification process.

If two scientists carried out this experiment, they would not get exactly the same result, as they wouldn't blow exactly the same amount of CO_2 into the water.

EXPERIMENT 4.2
THE SAD FATE OF SEA SHELLS
DESCRIPTION SHEET

RESEARCH QUESTION

What is the impact of a low pH in water on the shells of marine organisms which are made from calcium?

MATERIALS

Part 1:

- sample vials
- shells
- vinegar

Part 2:

- vials marked "BEFORE" (for shells without vinegar)
- vials marked "AFTER" (for shells that have been soaked in vinegar for a few days)
- Magnifying glass

GET TO WORK!

- Try to work out whether low pH levels in the water will damage the shells. Formulate your scientific hypothesis and fill it in on the worksheet.

Part 1:

- Put the shells in a vial.
- Pour vinegar over the shells until they are entirely covered. What can you see? Fill in the worksheet.

Part 2:

- Compare the reference shells to the shells that have spent a few days in the vinegar. You can carefully take the shells out of the vials, but make sure that you replace them in the right one. What can you see? Fill in the worksheet.
- Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 4.1
THE SAD FATE OF SEASHELLS
WORKSHEET

HYPOTHESIS

RESULTS

Part 1: What do you observe when you pour vinegar over the shells?

Part 2: What differences do you notice when you compare the reference shells with those that have been soaked in vinegar for a couple of days?

Part 2: Is there any difference between the various types of shells?

ANALYSIS

What are shells made of?

The ions Ca^{2+} and CO_3^{2-} are involved in the formation of calcium carbonate. Can you write the corresponding equation. Provide the phase for each part (aqueous (aq), liquid (l), solid (s), gas(g)).

What is vinegar? Is it an acidic or a basic solution? What does it release: H^+ or OH^-?

When you pour vinegar over the shells, the following reaction takes place (vinegar is a mixture of acetic acid, CH_3COOH, and water):

$CaCO_{3\ (s)} + 2\ H^{+}_{(aq)} \leftrightarrow Ca^{2+}_{(aq)} + CO_{2\ (g)} + H_2O_{(l)}$

What happens to the calcium carbonate when you pour vinegar over it? What effect does it have on the thickness of the shell?

What causes the effervescence?

If you heated the vinegar before pouring it over the shells, you would notice increased bubbling, how could you explain this? (Hint: the solubility of gasses).

CONCLUSIONS

Is you hypothesis correct? If not, explain.

IMPLICATIONS

Are organisms with a calcium skeleton or shell threatened by acidification of the oceans?

Why would polar organisms be the first to be impacted by ocean acidification? Discuss with the students who conducted the "Can We Make It More Acidic?" experiment.

Why do kettles often have to be descaled? Which kitchen product can you use to do this?

Limestone historic buildings and statues often look gray. Why? What damages the stone?

EXPERIMENT 4.2
THE SAD FATE OF SEA SHELLS
WORKSHEET – ANSWERS

HYPOTHESIS

Lower pH levels will damage the shells.

RESULTS

Part 1: The shells start effervescing (giving off bubbles) when vinegar is poured over them.

Part 2: The shells that were soaked in vinegar have lost their shine, they are damaged.

Part 2: There is some calcium deposit on the bottom of the glass containing the cockle and the small sea shell. The shell of the razor shell has clearly become more fragile.

ANALYSIS

The shells are made of Calcium Carbonate ($CaCO_3$).

The following equation describes the formation/decomposition of calcium carbonate:

$Ca^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)} \leftrightarrow CaCO_{3\,(s)}$

Vinegar is an acidic solution which releases H^+ ions.

The calcium carbonate reacts with the vinegar to produce Ca^{2+} and CO_2 . The exposed parts of the shell are broken down and the shell become thinner and more fragile.

The release of CO_2 causes the effervescence.

Gases dissolve better in cold liquids than warm liquids. When warm vinegar is added the solution is able to dissolve less CO_2, which means that more CO_2 is released to the atmosphere.

IMPLICATIONS

Calcareous organisms are vulnerable to the acidification of the oceans as their skeleton or shell is more likely to dissolve in an acidic solution.

$CaCO_{3\,(s)} + CO_{2\,(g)} + H_2O_{(l)} \leftrightarrow Ca^{2+}_{(aq)} + 2HCO_3^{-}{}_{(aq)}$

The organisms in the Polar Regions are the first to be affected by ocean acidification as the cold water increases the solubility of CO_2 leading to a decrease in the pH of the water. This acidity in the water leads to shell damage.

The minerals in tap water cause the calcium deposit formed when water is boiled. You can use vinegar to remove this.

Historic buildings and statues made from limestone can become grey due to acid rain.

THEME 5
PALAEOCLIMATOLOGY
BACKGROUND INFORMATION

Current climate change is having worldwide consequences. To help make climate forecasts for the future, it is useful to study past climate. The study of changes in past climate over the history of the Earth and the mechanisms that are causing climate change is called palaeoclimatology.

Palaeoclimatologists often work with proxies, which provide information about past climate. Tree rings and fossils are examples of proxies.

The floors of oceans and lakes are covered with layers of sediments, which contain the remains of animals and plants (fossils) that lived at the time of their formation. One type of fossil from lake or ocean sediments often used by palaeoclimatologists is diatoms.

Diatoms are mono-cellular algae that have a strong skeleton. When diatoms die, the skeleton sinks to the sea floor where it can be preserved for millions of years under the right circumstances. The diatoms are then covered by younger layers of sediments and diatoms. Each diatom species has a different skeleton. The difference in the skeleton is used by scientists to identify the various fossil types of diatom.

In addition to this, every species grows optimally at a certain temperature called the optimal temperature (To), which is why the presence of certain species can provide clues about the climate at the time when the species were still alive. For example, when temperatures rise, the composition of the diatom species will be dominated by the ones that are better adapted to warm conditions.

Scientists can determine the temperature at the time of formation of the diatoms, which is called the balanced average temperature (Tm), by applying the following formula:

$$T_m = [(n_{S1} \,.\, T_{o,\,S1}) + (n_{S2} \,.\, T_{o,\,S2}) + (n_{S3} \,.\, T_{o,\,S3}) + (n_{S4} \,.\, T_{o,\,S4})] \,/\, (n_{S1} + n_{S2} + n_{S3} + n_{S4})$$

T_m = balanced average temperature (°C)

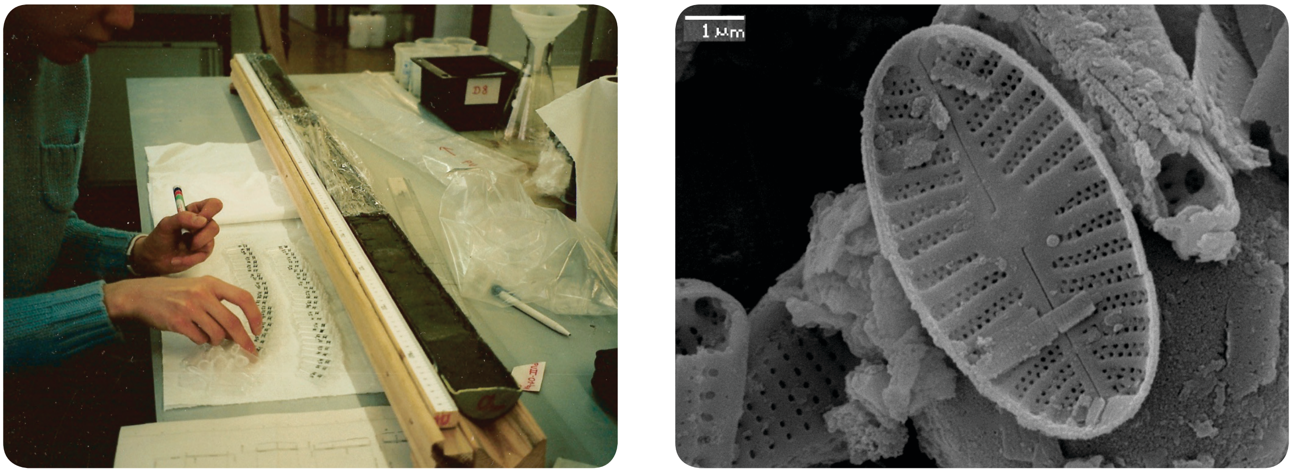
S_n = type of diatom

$T_{o,Sn}$ = optimal temperature of the type of diatom (°C)

n_{Sn} = total number of diatoms of a certain type

To study the diatom composition of lake sediments at various depths, palaeoclimatologists use a special drill to retrieve sediment cores. The deeper they drill, the further back in time the scientists can go. Back in their laboratories, the scientists take sub-samples from the sediment core, which are then analyzed under the microscope to determine the diatom composition.

Retrieving a core from lake sediments. (UGent).



Diatom analysis of a sediment core. a. Taking subsamples. b. Diatoms as they appear on the microscope (UGent).

EXPERIMENT 5
RECORDS OF THE PAST
DESCRIPTION SHEET

RESEARCH QUESTION

Can past climate be reconstructed by analyzing the types of diatoms from a sediment core?

MATERIALS

- Calculator
- Four colour pens
- 10 Petri dishes that correspond to sediment samples from different parts of a sediment core. The depth and age are indicated on each Petri dish.

SAMPLE NUMBER	AGE (YEAR BP*)	DEPTH (CM)
1	1000	5
2	2000	10
3	3000	15
4	4000	20
5	5000	25
6	6000	30
7	7000	35
8	8000	40
9	9000	45
10	10,000	50

** BP year = year before present, is a time scale which is used by palaeoclimatologists. «Before present" is misleading, because "present" means the year 1950. 100 years BP therefore means 100 years before 1950, in other words, 1850.*

Each Petri dish contains 12 pink, green, yellow and purple beads. Each colour represents a specific type of diatom that survives best in certain temperatures (= optimal temperature, To).

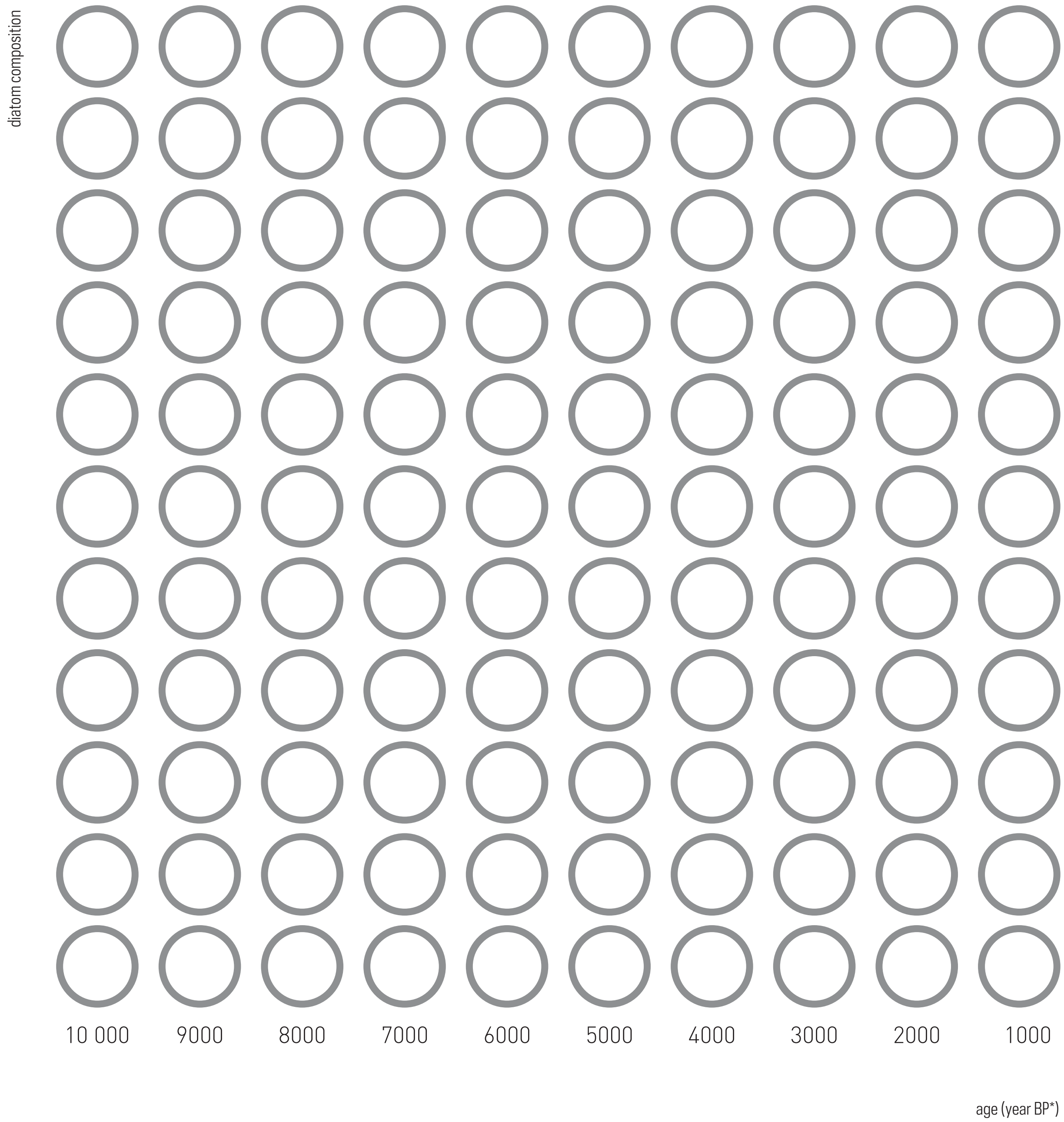
DIATOM SPECIES	T_0 (°C)
PINK	20
YELLOW	15
GREEN	10
PURPLE	5

GET TO WORK!

- Try to work out whether diatoms are a good proxy for climate reconstruction. Formulate your hypothesis and fill it in on the worksheet.
- Reconstruct the sediment core by piling up the Petri dishes. The Petri dish at the bottom represents the deepest sediment sample, the one at the top the shallowest. The deeper you go, the older the samples are so the Petri dish at the bottom is the oldest sediment sample and the one at the top is the youngest.
- Colour the diagram on the worksheet according to the diatom composition in each Petri dish. To do this, count the number of beads of each colour in each Petri dish and colour the circles accordingly, starting from the bottom of the graph. First colour in pink, then yellow, then green, and finally colour in purple.
- Draw a line above the top set of pink dots; this will give you a line with the age on the X-axis and the number of diatoms per type on the Y-axis.
- Calculate the balanced average temperature (Tm) for depths at 1000 years BP, 4000 years BP and 7000 years BP with the attached table.
- Complete the worksheet, analyse your results and prepare your team of scientists for a presentation in front of the whole group.

EXPERIMENT 5
RECORDS OF THE PAST
WORKSHEET

HYPOTHESIS



RESULTS

How does climate change over time in this experiment? In other words, describe the curve.

Fill in the tables.

	↑	MAXIMUM	↓	MINIMUM	↑	MAXIMUM
AGE (YEARS BP)						
WARM OR COLD CLIMATE						

AGE (YEARS BP)	$N_{PINK} \cdot T_{0,PINK}$	$N_{YELLOW} \cdot T_{0,YELLOW}$	$N_{GREEN} \cdot T_{0,GREEN}$	$N_{PURPLE} \cdot TO_{,PURPLE}$	N_{TOTAL}	T_M (°C)
1000						
4000						
7000						

Compare the balanced average temperatures of the two warmest periods. Which one was the warmest?

ANALYSIS

The curves for the two periods show the same maximum while the balanced average temperatures for these periods differ, how can you explain that?

CONCLUSIONS

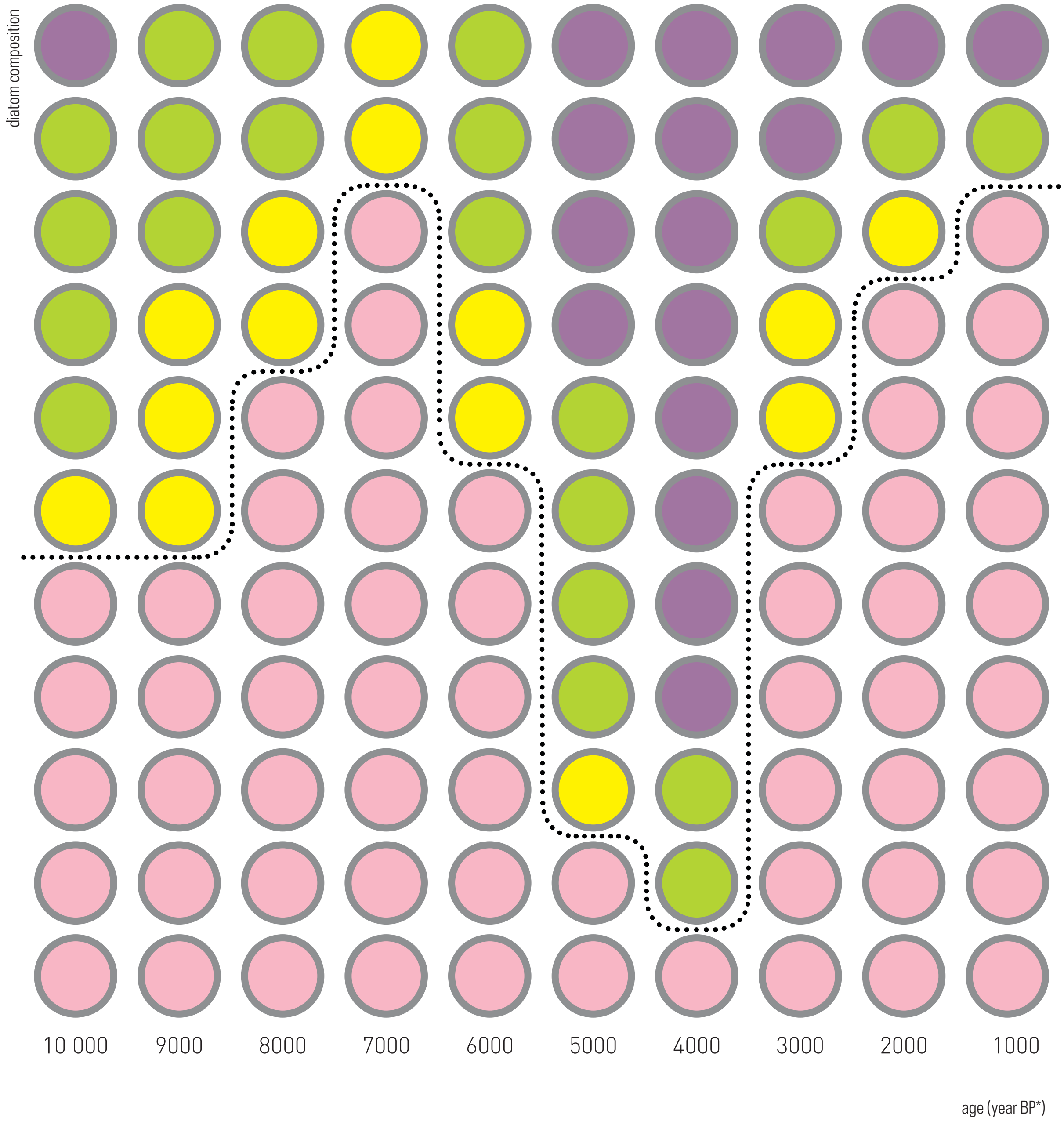
Is the hypothesis correct? If not, justify.

IMPLICATIONS

In the Polar Regions, palaeoclimatologists drill into the ice to retrieve ice cores. They use the same basic principles to reconstruct the climate. Which proxies in ice do they study in order to do this?

Where could scientists drill an ice core to go back furthest in time? The Greenland ice sheet or the Antarctic ice sheet?

EXPERIMENT 5
RECORDS OF THE PAST
WORKSHEET – ANSWERS



HYPOTHESIS

Diatoms are a good proxy for reconstructing climate.

RESULTS

First there was a warm period, followed by a colder one, and finally the climate warmed up again.

	↑	MAXIMUM	↓	MINIMUM	↑	MAXIMUM
AGE (YEAR BP)		7000		4000		1000
CLIMATE WARM OR COLD		WARM		COLD		WARM

AGE (YEARS BP)	$N_{PINK} \cdot T_{0,PINK}$	$N_{YELLOW} \cdot T_{0,YELLOW}$	$N_{GREEN} \cdot T_{0,GREEN}$	$N_{PURPLE} \cdot TO_{,PURPLE}$	N_{TOTAL}	T_M (°C)
1000	200	0	10	5	12	17,9
4000	40	0	20	40	12	8,3
7000	200	30	0	0	12	19,2

Comparing the balanced average temperatures of the two warmest periods, 7000 years BP was the warmest.

ANALYSIS

The balanced average temperature takes the various species of diatoms present in each sample into account, while the curve only represents the variation in pink diatom species. The curve does not provide any information on the exact temperature, but it does tell us whether a period was warm or not.

IMPLICATIONS

Gases, dissolved ions and dust contained in the ice cores serve as proxies. They can be analysed to provide information about the climate at the time the ice was formed.

The Antarctic ice sheet would give a longer record of past climate, as it is thicker than the Greenland ice sheet (a maximum of 5km, compared to a maximum of 3.2km).