Teachers Teaching with Technology™

T³ EUROPE

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Understanding climate change means complex thinking about a large number of variables and establishing connections between them.

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Sustainable Development Goal 13 Climate Action

2019 was the second warmest year on record and the end of the warmest decade (2010- 2019) ever recorded.

Carbon dioxide (CO_2) levels and other greenhouse gases in the atmosphere rose to new records in 2019.

Climate change is affecting every country on every continent. It is disrupting national economies and affecting lives. Weather patterns are changing, sea levels are rising, and weather events are becoming more extreme. Human activity which affects the climate in ways which are enhancing the “greenhouse effect” are clearly unsustainable and action is needed to promote more sustainable approaches to those activities which are currently releasing excess CO_2 and other greenhouse gases.

Although greenhouse gas emissions are projected to drop about 6 per cent in 2020 due to travel bans and economic slowdowns resulting from the COVID-19 pandemic, this improvement is only temporary. Climate change is not on pause. Once the global economy begins to recover from the pandemic, emissions are expected to return to higher levels.

Saving lives and livelihoods requires urgent action to address both the pandemic and the climate emergency.

The Paris Agreement, adopted in 2015, aims to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels. The agreement also aims to strengthen the ability of countries to deal with the impacts of climate change, through appropriate financial flows, a new technology framework and an enhanced capacity building framework.

Predicting the global rise in temperature as a result of manmade changes to the atmosphere is enormously difficult. Humankind is making many changes, for example the addition of CO_2 from the burning of fossil fuels, methane from farming livestock and the addition of water vapour as a result of warming and also from the burning of fossil fuels. Taking just CO_2 as an example, this suite of experiments allows students to explore some of the many consequences of adding CO_2 to the atmosphere. The consequences are interconnected and students are able to understand that constructing a model to predict global temperature rise is very complicated. **Any actions by governments around the world to make life more sustainable rely on such models and so it is very important that predictions are as accurate as possible.**

About the Experiments

The Greenhouse Effect, acidification of the oceans, melting of the ice at the poles, ... these events are reported time and again in the media. The movement "Friday for future" has particularly involved students in the discussions and calls on politicians and economists to act.

Action on climate change should be based on well-founded discussions using good data and evidence. Students should be able to make statements about individual phenomena involved in climate change.

But the question arises whether it is sufficient to consider all these phenomena separately or whether there is a need to think in a more complex way? Why is it so difficult to make concrete predictions about possible climate changes in 10, 20 or 50 years? Why is it so hard to develop climate models?

This material, which is aimed particularly at students in grades 8 – 10 (13-16 years old), uses carbon dioxide as an example to show the diversity of the processes to be considered in relation to climate change (global warming). Students should gain an insight into the need for the more complex consideration of different factors.

The material is designed in such a way that it can be used in project-oriented lessons. The students could work in different groups and summarize the individual results in an overview. The evaluation of this overview offers a variety of discussion approaches and should serve as a stimulus for further considerations.

All proposed experiments can also be used individually or in different combinations in regular lessons. The use of digital tools for the acquisition, presentation and evaluation of measurement data opens up new experimental approaches in this context. In particular, the use of the carbon dioxide sensor allows the possibility for recording measurement data that were previously difficult to access. When selecting the experiments care was taken that only a few, especially harmless and inexpensive chemicals are used.

When compiling the „further information“ material for the pupils, existing previous knowledge was taken into account. Extensive scientific presentations were avoided. Despite simplifications, essential statements about the laws under consideration should be made available to the students. No claim is made as to completeness of the material. This is not possible due to the complexity of the phenomena considered and the taking into account of the intended use of the material.

Special notes on the equipment and materials needed.

- In all proposed experiments, carbon dioxide is provided by the reaction of the components of an effervescent tablet with water in a gas generator. Alternatively, the reaction of a carbonate with an acid solution in the gas generator can be used. The use of a carbon dioxide gas bottle is also possible. It should be noted that the introduction of the gas into the aqueous solution must be very slow.
- A bio-chamber was used to perform the experiments to investigate the solubility of carbon dioxide at different water temperatures (experiment A) and different salinity (experiment B). Alternatively, a pneumatic tub or other vessel, which can be sealed with a foil or other materials, can be used. The bio-chamber used in the experiments has a volume of V = 2.5 l. The graphs shown in the sample solutions refer to the use of the described bio-chamber. It is essential to ensure that the carbon dioxide sensor does not come into contact with the water.
- The duration of the project depends, among other things, on the number of experiments performed by the student groups. For experiments A and B, about 30 minutes each, for experiments C, D and E about 20 minutes each.

Student sheets and Teacher Sheets

- There is a summary of the equipment and chemicals needed for each of the five experiments at the beginning.
- There is an overview sheet which prompts students to think about the questions involved. This is followed by a sheet for the teacher with suggestions filled in.
- Each experiment is described in a student sheet which contains the necessary instructions and questions.
- This is followed by an evaluation sheet, the teacher sheet which contains examples of the results which might be expected with suggested answers to questions.
- Finally there is a section of further information to which the student and the teacher are referred in the questions.

Equipment and chemicals needed for each of the five experiments.

Experiment A Solubility of CO_2 in "cold" and "warm" tap water

- Gas generator or an alternative to carbon dioxide supply
- Bio chamber or alternative vessel with cover
- Carbon Dioxide Sensor
- Thermometer
- Heating plate for heating approx. 500 ml tap water - effervescent tablets, alternatively chemicals for carbon dioxide evolution or carbon dioxide gas bottle.
- Tap water

Experiment B Solubility of CO_2 in tap and salt water

- Gas generator or an alternative to carbon dioxide supply
- Bio chamber or alternative vessel with cover
- Carbon Dioxide Sensor
- Balance (accuracy m = 1 g) - Effervescent tablets, alternatively chemicals for carbon dioxide evolution or carbon dioxide gas bottle
- Tap water
- Common salt (approx. 50 g per test)

Experiment C Change in electrical conductivity when CO_2 is injected into distilled water

- Gas generator or an alternative to carbon dioxide supply
- two beakers (V = 200 ml)
- Conductivity sensor
- Drinking straw or a corresponding alternative for "blowing" air into water - Effervescent tablets alternatively chemicals for carbon dioxide evolution or carbon dioxide gas bottle.
- Distilled Water

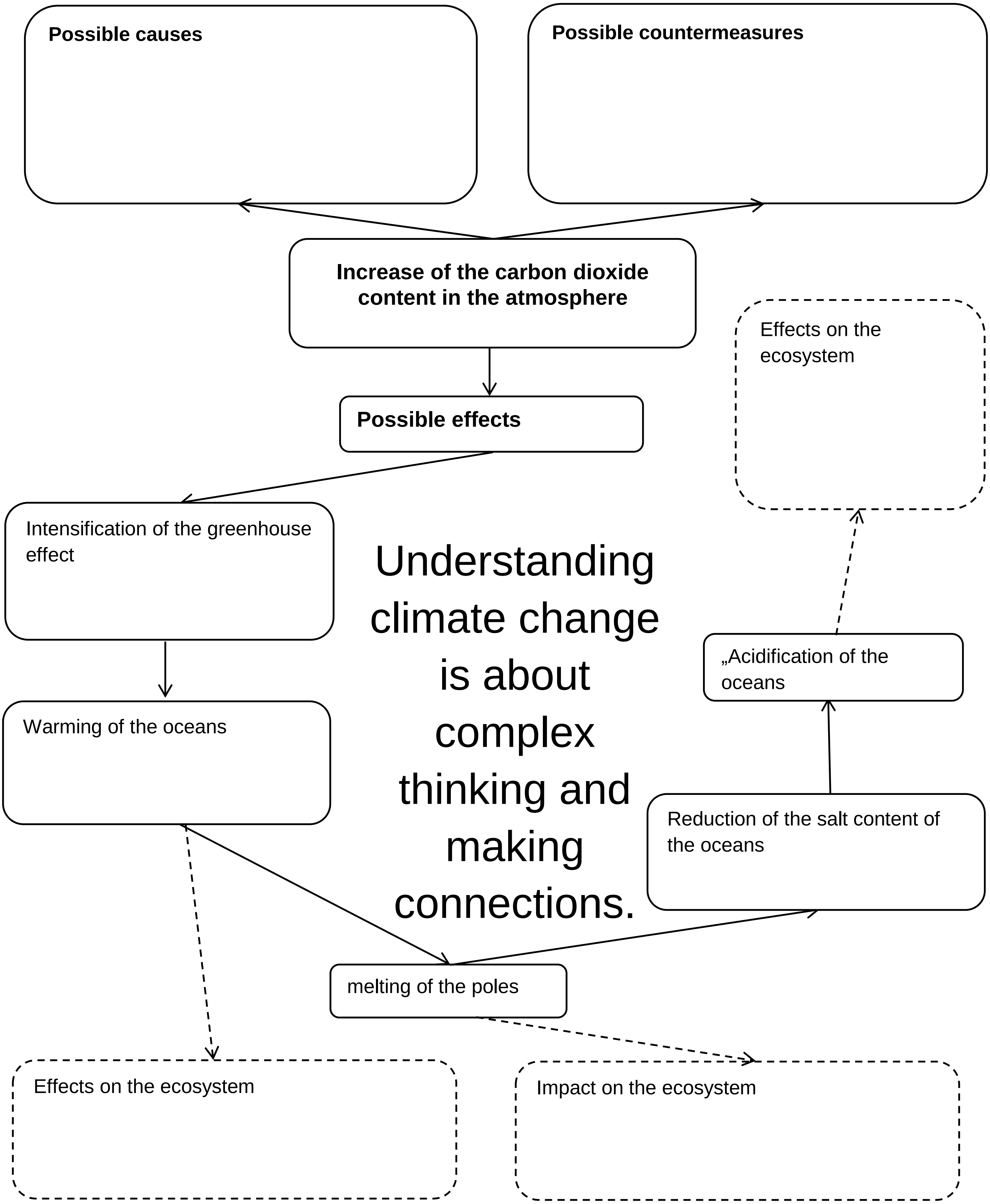
Experiment D Investigate the effect of CO_2 on global warming.

- Gas generator or an alternative to carbon dioxide supply
- Two beakers (V = 250 ml)
- Black paper to lay out the beaker bases
- Desk or heat lamp
- (60 Watt) - Effervescent tablets
- Alternatively chemicals for carbon dioxide evolution or carbon dioxide gas bottle.

Experiment E Investigate the change in pH when CO_2 is introduced into tap water.

- Gas generator or an alternative to carbon dioxide supply
- Two beakers (V = 150 ml)
- pH sensor
- Magnetic stirrer - Effervescent tablets alternatively chemicals for carbon dioxide evolution or carbon dioxide gas bottle
- Tap water
- Mineral water with fizz

Carbon dioxide and climate change



Complete the overview. Use the information sources provided and your test results regarding the properties of carbon dioxide.

Carbon dioxide and climate change: Compiled by pupils

Possible causes, e.g.

- Industrial fumes
- Drainage of bogs
- Deforestation

Possible countermeasures, e.g.

- Use of renewable energies
- Afforestation
- "Saving" carbon dioxide through innovation

Increase of the carbon dioxide in the atmosphere

Possible effects

- Intensification of the greenhouse effect
- Increase in average temperature on earth

- Warming of the oceans
- Solubility of carbon dioxide decreases
- Increase of the carbon dioxide content in the

Melting of the poles

Effects on the ecosystem, e.g.

- Species extinction (e.g. corals)
- New adaptation of living beings to the changed conditions is necessary

Effects on the ecosystem, e.g.

- sea level rise
- Destruction of habitat

- reducing the salinity of the oceans
- Solubility of carbon dioxide

"Acidification of the seas"

- Effects on the ecosystem, e.g.
- Species extinction (e.g. corals)
- New adaptation of living beings to the environment is

Understanding climate change is about complex thinking and making connections.

Complete the overview. Use the information sources provided and your test results regarding the properties of carbon dioxide.

Buffer station

Solve the following tasks when you have finished conducting and evaluating the experiments.

1 The change in carbon dioxide content was recorded over several years at the measuring station on MAUNA LOA in Hawaii.

https://www.esrl.noaa.gov/gmd/ccgg/trends/

1.1 Interpret the graphical representation.

1.2 Based on the graph, provide explanations for the changes in carbon dioxide content in the atmosphere.

↓

2 The combustion of methane and other fossil fuels produces large quantities of carbon dioxide.

Carbon dioxide is a colourless and odourless gas. It is heavier than air and has a suffocating effect. It does not support combustion and flames are extinguished at volume concentrations of 8-10% carbon dioxide in the air.

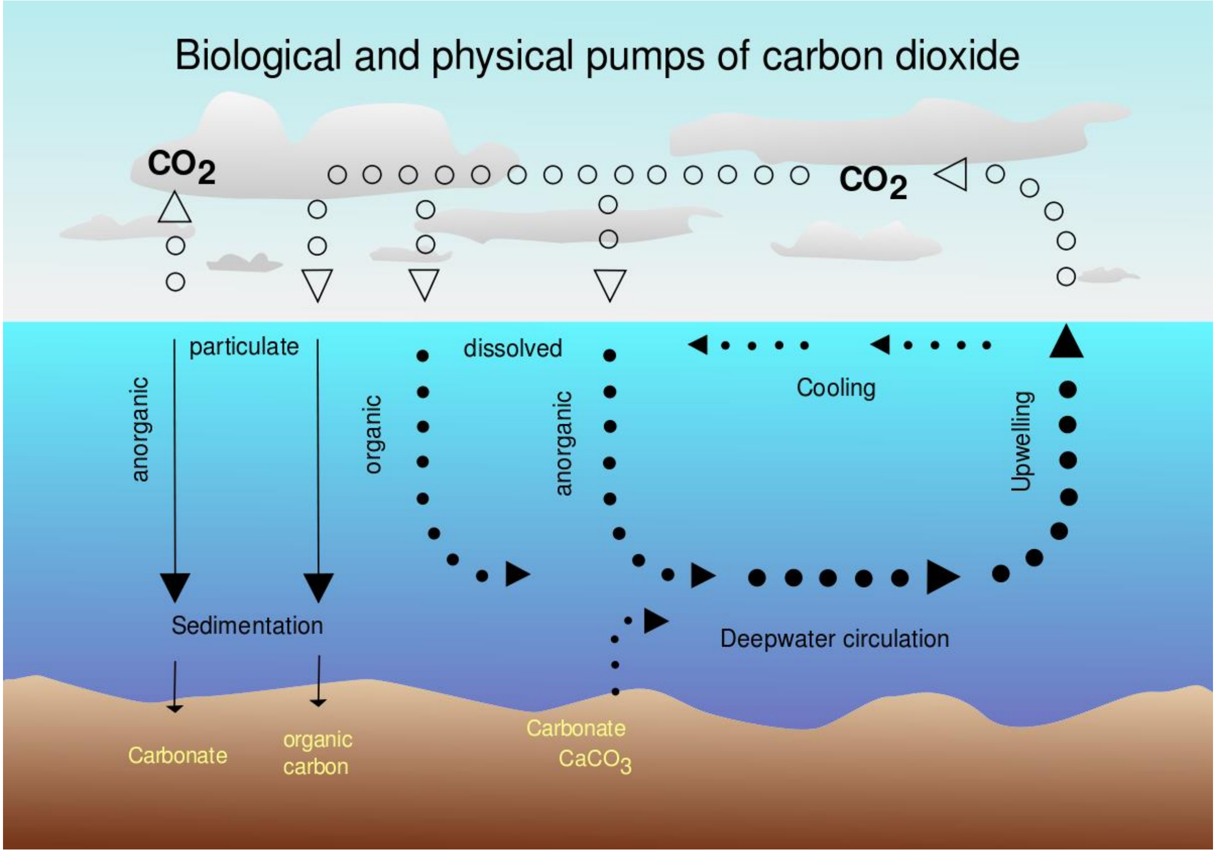
Carbon dioxide, an important greenhouse gas, is a natural part of the air, where it occurs in very low concentrations.

CCS stands for Carbon Capture and Storage, the underground storage of carbon dioxide, which was previously extracted from the Flue gases from coal-fired power plants. The procedure should help to reduce the CO_2 *content in the atmosphere and thus to counteract the advancing climate change.*

However, environmentalists fear that the high pressure required will make it difficult to prevent the CO_2 *from leaking into ground waters and so getting back into the atmosphere.*

Explain two possible consequences of extensive and uncontrolled release of carbon dioxide from underground storage sites. Include selected properties of the gas in your presentation.

Experiment A
Solubility of CO_2 in "cold" and "warm" tap water

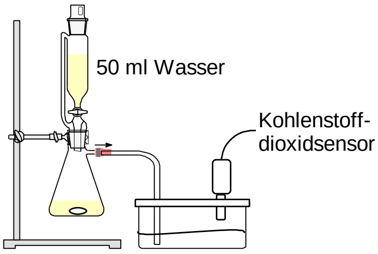


The solubility of carbon dioxide in tap water as a function of temperature.

1 The carbon dioxide required for the test can be obtained, for example, from an effervescent tablet containing, among other things, solid citric acid (H_3Ci) and sodium carbonate by adding water.
For the reaction of citric acid solution with sodium carbonate, develop the reaction equation in ion notation.

2 Perform the experiments described below.
Sketch or print the recorded graphs.

Experiment A1
Place an effervescent tablet in the Erlenmeyer flask with a lateral attachment. Fill the **dropping funnel with approx. 50 ml water.**
Pour 500 ml tap water into the measuring chamber. Determine the temperature of the water. Set up the test apparatus as described in shown in the adjacent sketch. Make sure that



- the drain pipe is immersed in the water,
- the CO_2 sensor does not come into contact with the water and
- the chamber is tightly closed so that no carbon dioxide can escape.

Prepare the computer with connected CO_2 sensor for data acquisition in such a way that a measurement value is recorded every 10 seconds for a period of 600 seconds. Start the data acquisition. After approx. 30 seconds, open the tap on the dropping funnel so that water is directed drop by drop to the effervescent tablet and carbon dioxide is slowly introduced into the water.
Save the recorded data at the end of the measurement.

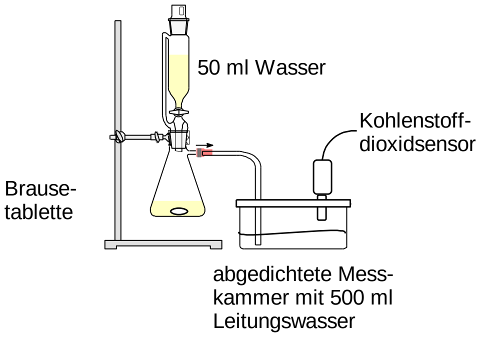
Experiment A2
Heat 500 ml tap water to approx. 60 °C. In the meantime, prepare the experimentation arrangement so that experiment A1 can be repeated under the same conditions. If necessary, dry the Erlenmeyer flask with lateral attachment slightly. Repeat experiment A1 with the heated tap water. Ensure that the introduction of carbon dioxide into the water is at a comparable speed (number of gas bubbles per time) to experiment A1.

3.1 Interpret the graphical representation.

3.2 From the experiment conducted, derive a statement about the solubility of carbon dioxide at different water temperatures.
Check this with the further information provided.

Evaluation of the experiments A

Test setup



Instructions for carrying out the experiment

- It is essential to ensure that the carbon dioxide sensor is not immersed in the water.
- The introduction of carbon dioxide into the water must take place at approximately the same speed (number of drops per time unit).

Results of experiment A1 and A2

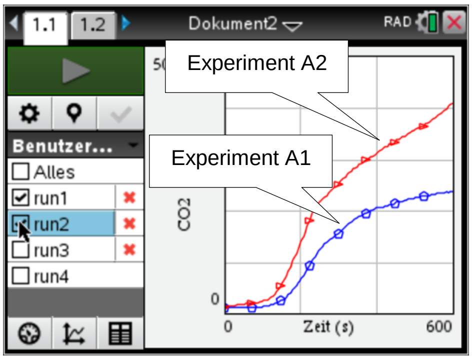
Introduction of carbon dioxide, produced by the reaction of an effervescent tablet with 50 ml of water, into

- 500 ml tap water $\vartheta \approx 20$ °C (Experiment A1)

and

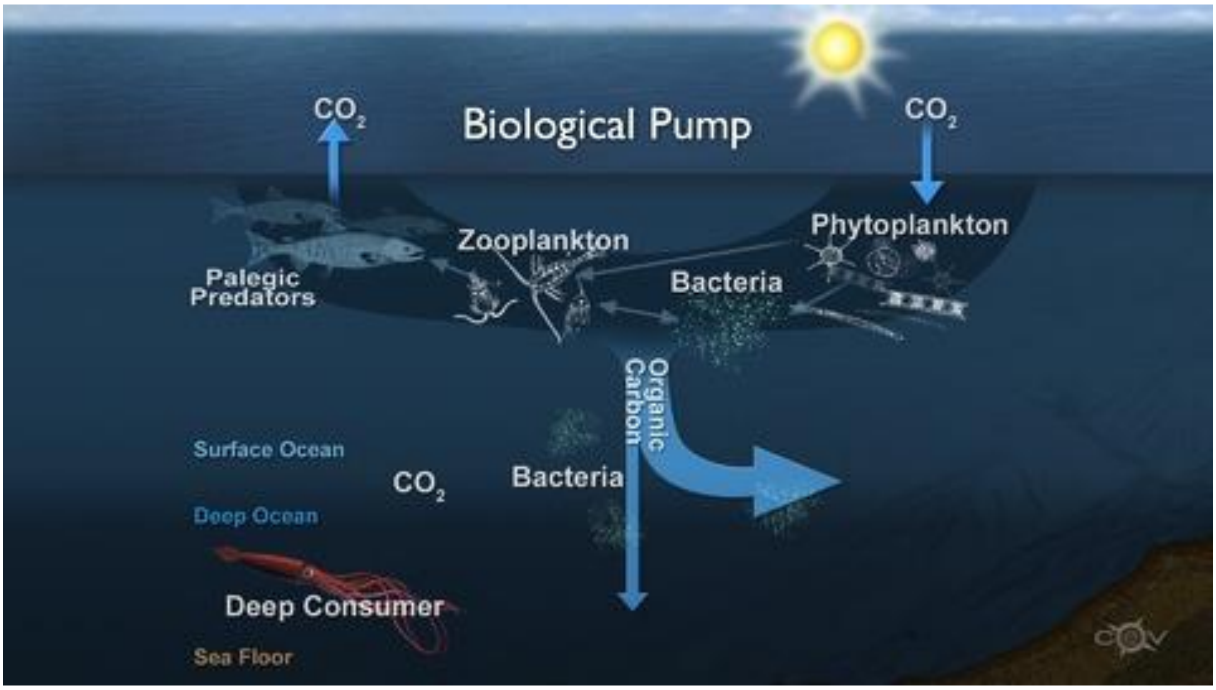
- 500 ml tap water $\vartheta \approx 60$ °C (Experiment A2)

In each case, the carbon dioxide content was measured using a sensor above the water surface in the closed chamber.



Explanations of the test results can be found in the section "The solubility of carbon dioxide as a function of A) the temperature" of the further information.

Experiment B
Solubility of CO_2 in tap and salt water

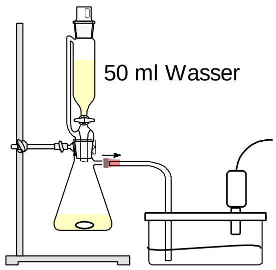


Examine the solubility of carbon dioxide in tap and salt water.

1 The carbon dioxide required for the test can be obtained, for example, from an effervescent tablet containing, inter alia, solid citric acid (H_3Ci) and sodium carbonate, by adding water.
For the reaction of citric acid solution with sodium carbonate, develop the reaction equation in ion notation

2 Perform the experiments described below.
Sketch or print the recorded graphs

Experiment B1
Place an effervescent tablet in the Erlenmeyer flask with side attachment. Fill the dropping funnel with approx. 50 ml water.
Pour 500 ml tap water into the measuring chamber. Determine the temperature of the water.
Assemble the test apparatus as shown in the sketch opposite together.



Make sure that
- the drain pipe is immersed in the water,
- the CO_2 sensor does not come into contact with the water and
- the chamber is tightly closed so that no carbon dioxide can escape.

Prepare the computer with connected CO_2 sensor for data recording in such a way that a measured value is recorded every 10 seconds for a period of 600 seconds.
Start the data acquisition. After approx. 30 seconds, open the tap on the dropping

funnel so that water is directed drop by drop to the effervescent tablet and carbon dioxide is slowly introduced into the water.
Save the recorded data at the end of the measurement.

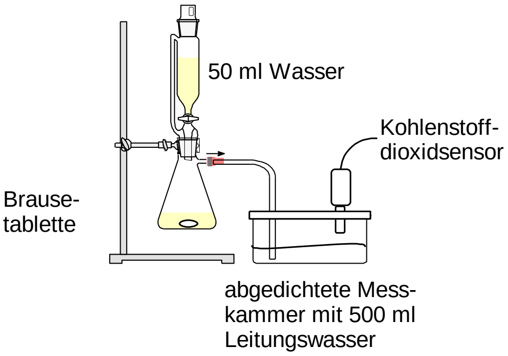
Experiment B2
Add approx. 50 g table salt to 500 ml tap water.
Repeat experiment B1 with the salted water.
If necessary, dry the Erlenmeyer flask with the side attachment slightly.
Make sure that the introduction of carbon dioxide into the water at a comparable speed (number of gas bubbles per time) follows experiment B1.

3.1 Interpret the graphic representation.

3.2 From the experiment carried out, derive a statement on the solubility of carbon dioxide.
Check with the further information provided.

Evaluation of the experiments B

Experimental setup



Notes on performing the experiment

- It is essential to ensure that the carbon dioxide sensor is not immersed in the water.
- The introduction of carbon dioxide into the water must take place at approximately the same speed (number of drops per unit of time).

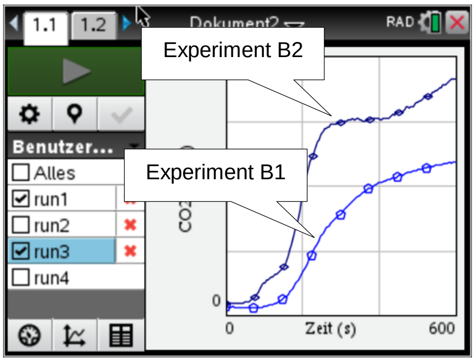
Results of experiment B1 and B2

Introduction of carbon dioxide, produced by the reaction of an effervescent tablet with 50 ml of water, into

- 500 ml of tap water (experiment B1)

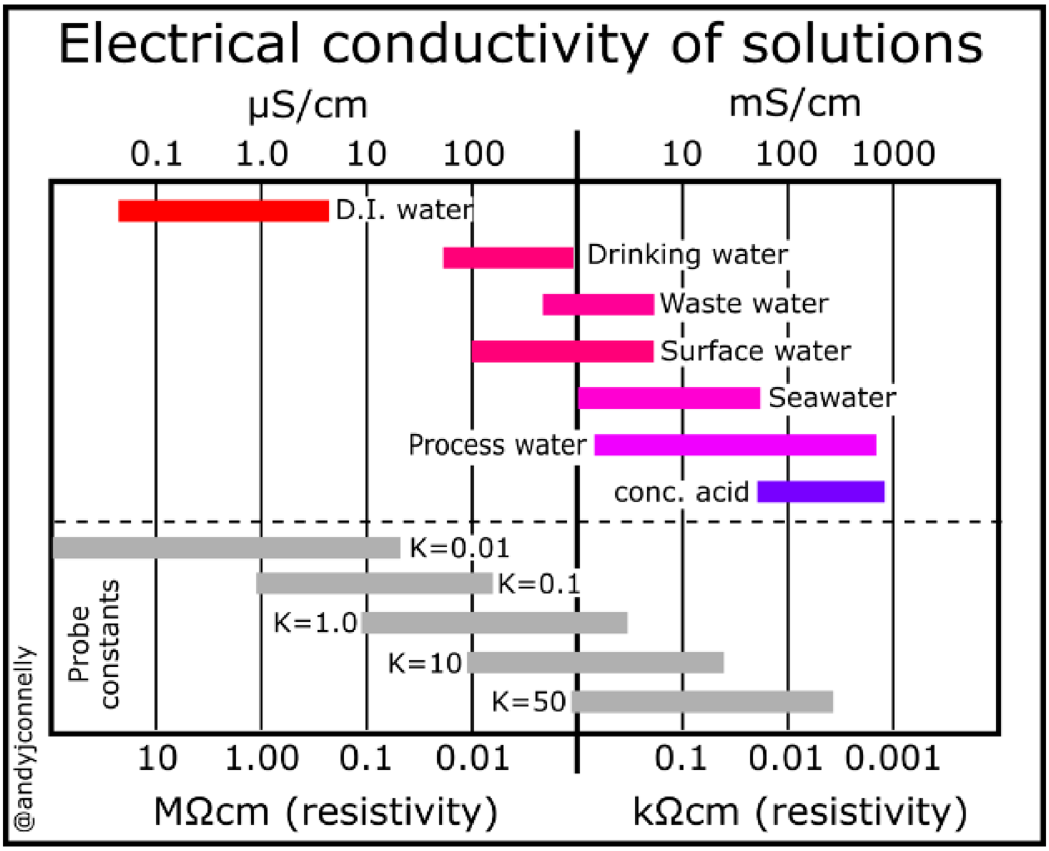
And

- 500 ml tap water, mixed with approx. 50 g table salt (Experiment B2)
-



The carbon dioxide content was measured in each case by means of a sensor above the water surface in the closed chamber.
The explanations of the test results can be found in the section "The solubility of carbon dioxide as a function of C) the salt content" of the further information.

Experiment C
Change in electrical conductivity when CO_2 is injected into distilled water



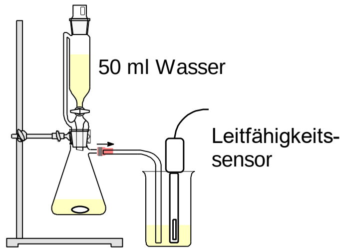
Examine the change in electrical conductivity when carbon dioxide is introduced into distilled water.

1 The carbon dioxide required for the test can be obtained, for example, from an effervescent tablet containing, inter alia, solid citric acid (H_3Ci) and sodium carbonate, by adding water.
For the reaction of citric acid with sodium carbonate, develop the reaction equation in ionic notation

2 Perform the experiments described below.
Sketch or print the recorded graphs

Experiment C1

Place two effervescent tablets in the Erlenmeyer flask with side attachment. Fill the dropping funnel with approx. 50 ml water. Pour approx. 150 ml dist. water into a beaker. of distilled water into a beaker. Place two effervescent tablets in the Erlenmeyer. Assemble the test apparatus as shown in the sketch on the right. Make sure that the drainage pipe and the conductivity sensor are immersed in the water until just above the beaker bottom.



Prepare the computer with connected conductivity sensor (measuring range 200 µS) for data recording so that a measured value is recorded every 5 seconds for a period of 300 seconds.

Start the data acquisition. After approx. 20 seconds, open the tap on the dropping funnel so that water reaches the effervescent tablet drop by drop and carbon dioxide is slowly introduced into the water.

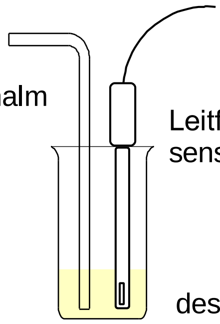
Save the recorded data at the end of the measurement.

Experiment C2

Fill a drinking beaker or cup with enough dist. Water so that the measuring unit of a conductivity sensor standing in the vessel is completely covered with water.

Prepare the computer with the conductivity sensor connected (measuring range 200 µS) for data acquisition in such a way that a measured value is recorded every 2 seconds over a period of 120 seconds.

Start the recording of the measured value. Blow exhaled air into the water using a drinking straw.
Save the recorded data after the measurement has been completed.



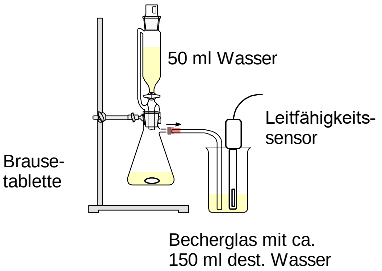
3.1 Interpret the graphical representations.

3.2 Explain the change in electrical conductivity of the solution when carbon dioxide is introduced.

Evaluation of experiments C1 and C2

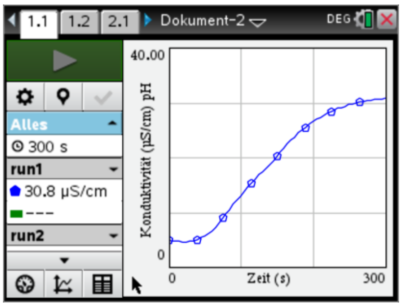
Experiment C1

Experiment setup



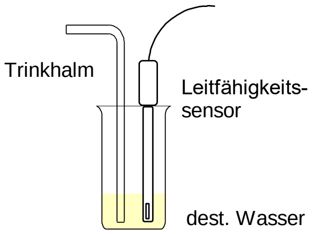
Instructions for carrying out the experiment

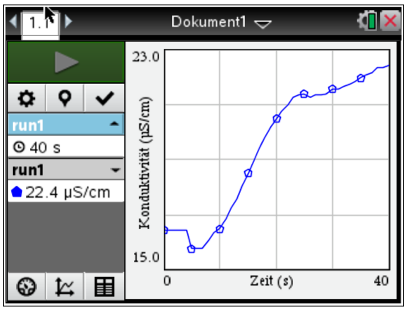
The introduction of carbon dioxide into the distilled water must be slow and continuous.



Result of experiment C2

Experiment setup





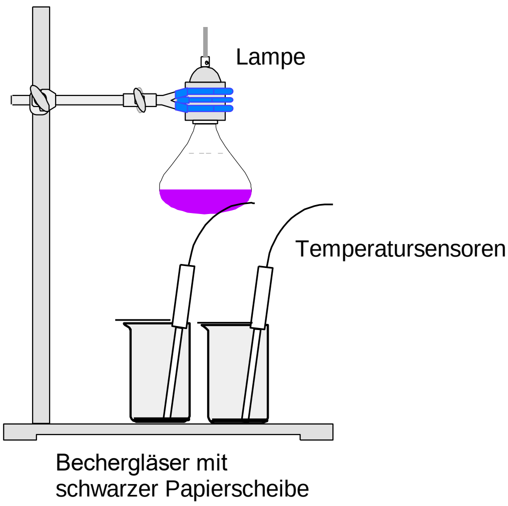
The explanations of the experimental results can be found in the "Principle considerations on the solubility of carbon dioxide" section of the further information.

Experiment D
The anthropogenic greenhouse effect

Investigate the effect of carbon dioxide on global warming.

1 Perform the experiment described below.
Sketch or print the graphs you recorded.

Experiment D
Set up a desk lamp or heat lamp (at least 60 watts), two beakers
(V = 250 ml) and two watch glass dishes or glass plates to cover the beakers.
Cut two discs from black paper so that they fit exactly on the bottom of the beaker.
Place the two discs on the bottom of the beakers and place a temperature sensor in each beaker.
Prepare data acquisition so that readings are taken every 10 seconds over a period of 400 seconds.

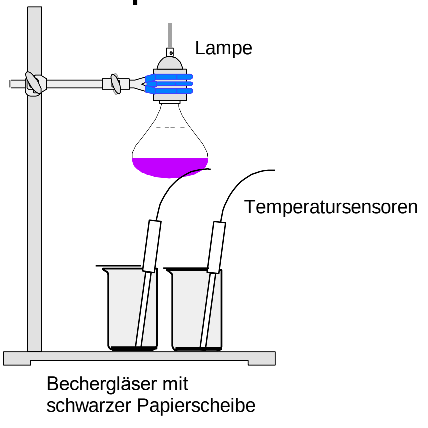


Fill one of the beakers with carbon dioxide and cover each of the two beakers with a watch glass dish or glass plate. Switch on the lamp and start the data acquisition.

2 Interpret the graphical representation.
If necessary, research the material provided.

Evaluation of the experiment D

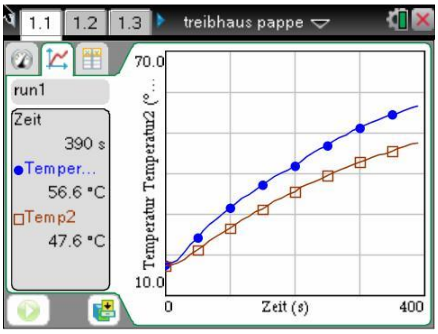
Test setup



Instructions for carrying out the experiment

- The measured values can be recorded individually and consecutively.
- If a laptop or TI-Nspire™ LabCradle is available, the temperature change in both beakers can be determined simultaneously.

Experiment D result



The explanations of the experimental results can be found in the section "The Greenhouse Effect" of the further information.

This experiment was taken from the material

Dr. H. LANGLOTZ; F. LIEBNER; From measurement acquisition to programming-sensor technology with and without TI-Innovator™; T³ Germany; 2019..

Experiment E
Introduction of carbon dioxide into tap water

Investigate the change in pH when carbon dioxide is introduced into tap water.

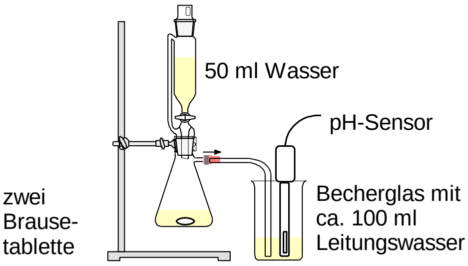
1 The carbon dioxide needed for the investigation can be obtained, for example, from an effervescent tablet containing, among other things, solid citric acid (H3Ci) and sodium carbonate by adding water.
Develop the reaction equation in ionic notation for the reaction of citric acid solution with sodium carbonate.

2 2 Perform the experiments described below.
Sketch or print the recorded graphs.

Experiment E1

Place two effervescent tablets in the Erlenmeyer flask with lateral neck. Fill the dropping funnel with 50 ml of water.

In a beaker, add approx. 100 ml of tap water. Set up the experimental apparatus as shown in the adjacent sketch. Make sure that the discharge tube is immersed in the water.



Prepare data acquisition so that a reading is taken every 5 seconds over a period of 300 seconds.
Start the data acquisition. After about 10 seconds, open the tap on the **dropping** funnel so that water reaches the effervescent tablet drop by drop and a **slow** introduction of carbon dioxide into the water takes place.
Save the recorded data after the measurement has been completed.

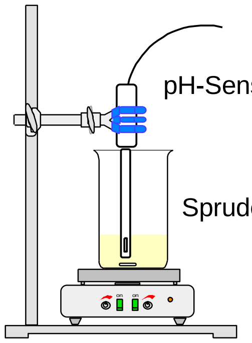
Experiment E2

Fill a beaker (V = 150 ml) with enough sparkling water to allow vigorous stirring with a stirring fish. Note that the measuring unit of the pH sensor must be completely immersed in the water and must not be damaged by the stirring fish.

Prepare a data acquisition so that a measured value is recorded every 5 seconds over a period of

600 seconds a measured value is recorded.

Set the magnetic stirrer to full speed and start recording the measured value after approx. 20 seconds..



3.1 Interpret the graphical representation.

3.2 Explain the changes in pH values during the experiments performed

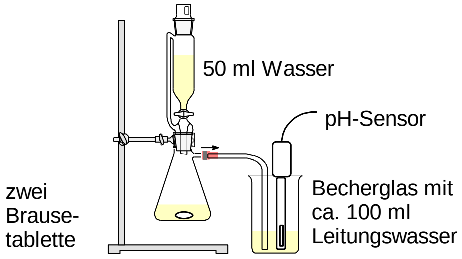
Experiment E2 was taken from

F. LIEBNER; Naturwissenschaftlichen Phänomenen auf der Spur; T³ Germany; 2011.

Evaluation of experiments E1 and E2

Experiment E1

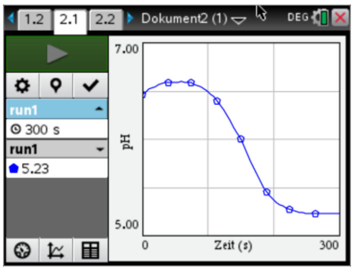
Test setup



Instructions for carrying out the experiment

– The introduction of carbon dioxide into the tap water must be slow and continuous.

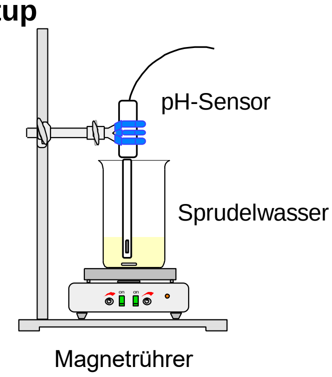
Results



Explanations of the experimental results can be found in the "Principle considerations on the solubility of carbon dioxide" section of the material.

Experiment E2

Test setup

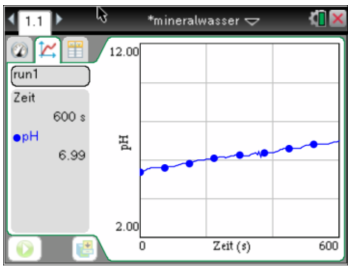


Instructions for carrying out the experiment

– The pH value change is also dependent on the stirring speed. A faster increase in the pH value is recorded at higher stirring speeds..

Results

Explanations of the experimental results can be found in the "Principle considerations on the solubility of carbon dioxide" section of the further information.



Further Information

When you enter "carbon dioxide" as a search term in Google, you will get around half a million hits (June 2020). These include properties and uses of carbon dioxide, explanations of how the molecule is built, its chemical reactions, and reports on accidents and natural disasters.
A large number of articles also relate to carbon dioxide as a contributor to global warming. These deal with causes, effects, and measures to limit global warming, among other topics.

Principle considerations on the solubility of carbon dioxide

Carbon dioxide is readily soluble in water. At normal pressure (p = 0.1 MPa) and a temperature of 20 °C, 0.9 liters of the gas dissolves in one liter of water.
If we look more closely at the solubility of carbon dioxide in water, we find that only about 0.2% of the gas dissolved in water reacts with it, and the majority of the carbon dioxide is physically dissolved.

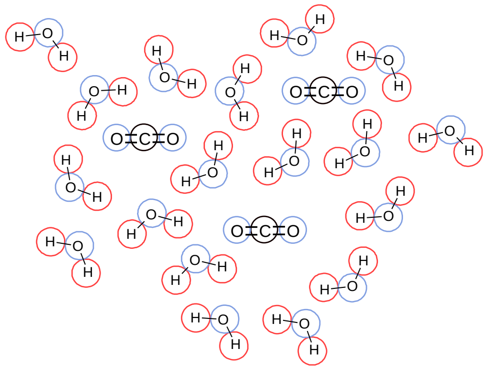
The amount of carbon dioxide dissolved in water depends on many different factors. Even if these parameters are investigated individually, it is important to consider them in context wherever possible.
Tap water usually has a pH value of pH ≈ 7. This pH value is determined, among other things, by the following chemical equilibrium:

$$\mathbf{H_2CO_3 \rightleftharpoons H_2O + CO_2 \rightleftharpoons HCO_3^- + H^+ \quad (1)}$$

This equilibrium is in turn influenced by the different ions in the water.
When we speak of equilibrium reactions or chemical equilibrium in chemistry, we are referring to chemical reactions that are reversible and incomplete, and in which starting materials and reaction products are present simultaneously in certain proportions.
Starting materials react to reaction products (outward reaction) and reaction products can react again to starting materials (backward reaction).
The ratio of starting materials and reaction products can be influenced by external factors such as temperature, pressure or the presence of other ions in aqueous solutions.
For example, the solubility of carbon dioxide in distilled water, which contains very few ions, is somewhat greater than in tap water. This has the consequence that dist. water often has a pH value of pH < 7.

What happens when the limited solubility of carbon dioxide in water is ignored is shown by isolated natural disasters such as the "carbon dioxide eruption" in 1986 at Lake NYOS.
A landslide disturbed the lower layers of the lake sending water from the bottom to he top. Since the lower water was already supersaturated with carbon dioxide, the gas evolved at the lower pressures, entered the atmosphere and killed many inhabitants (more than 1700) and their animals (more than 3500) living near the lake.

Physically dissolved carbon dioxide



Carbon dioxide molecules diffuse into the the water and are surrounded by water molecules without the particles reacting with each other.
the particles react with each other.

Reactions of carbon dioxide with water

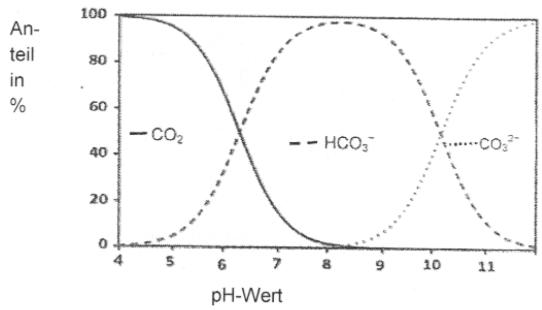
Carbon dioxide reacts with water in a very slow reaction to form unstable carbonic acid (2). This decomposes in a very fast reaction into hydrogen and hydrogen carbonate ions (3).

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \quad (2)$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \quad (3)$$

If carbon dioxide is introduced into water, the properties of the water are affected.
This can be seen, for example, in the change in electrical conductivity and pH value (reactions (2) and (3)).
It should be noted that there are other ions in the water, which result in chemical equilibria that influence the dissolving process of carbon dioxide, and that these equilibria are changed by the introduced carbon dioxide.

A chemical equilibrium is established between the carbon present in the atmosphere, the carbon physically dissolved in water and the inorganic carbon compounds such as carbonate and hydrogen carbonate ions contained in water.
The pH value of water is determined, among other things, by the amount of dissolved carbon dioxide.
Other factors that influence the pH value of water also determine the ratio of these ions to one another.
to each other.



pH dependence of carbon dioxide, hydrogen carbonate and carbonate equilibrium in aqueous solution
Werte nach: https://link.springer.com/chapter/10.1007/978-3-642-17813-9_3

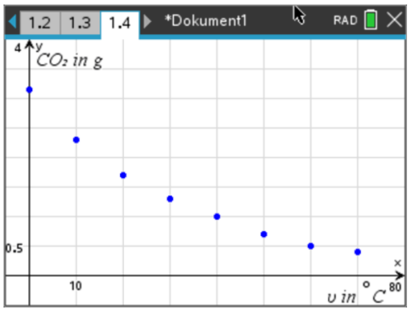
If carbon dioxide is dissolved in water, the pH value of the solution decreases because the equilibrium reactions (2) and (3) are each shifted in favor of the reaction products.
If, on the other hand, carbon dioxide is expelled from mineral water, for example, its pH value increases because the equilibrium reactions (2) and (3) are each shifted in favor of the starting materials and the concentration of hydrogen ions thus decreases.

The solubility of carbon dioxide as a function of various physical properties

A) Temperature

At a water temperature of ϑ = 20 °C and a pressure of p = 0.1 MPa, about 1.7 g (0.9 l) of carbon dioxide in one liter of water.
The solubility of this gas is strongly dependent on temperature.

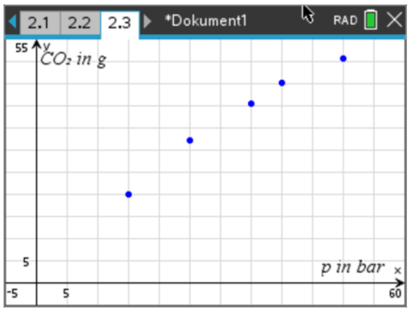
When the temperature of the water increases, the particles move faster and more disorderly. Physically dissolved carbon dioxide can thus escape from the water. This shifts the equilibrium reactions (2) and (3) in favor of the respective starting materials. As a result, the concentration of hydrogen ions decreases and the pH value of the water increases.



Solubility of carbon dioxide in g per liter of water as a function of temperature at p = 1 bar

B) Pressure

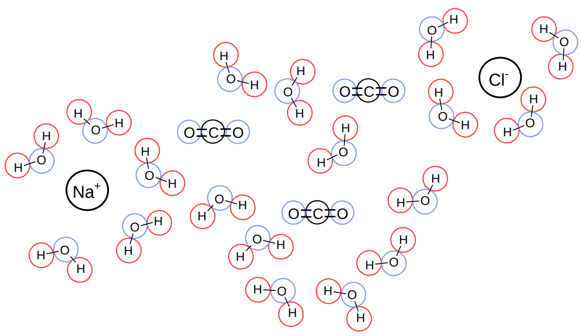
If the proportion and thus the partial pressure of carbon dioxide above the water surface increases, more carbon dioxide dissolves in water within certain limits. As a result, the equilibrium reactions (1) and (2) shift in favor of the reactive products and the pH value of the water decreases.
In addition to increasing the carbon dioxide content, the total pressure above the solution is also increased, the solubility of the carbon dioxide increases, with all the consequential effects described.



Solubility of carbon dioxide in g per 1 liter of water as a function of pressure at a temperature of ϑ = 20 °C.

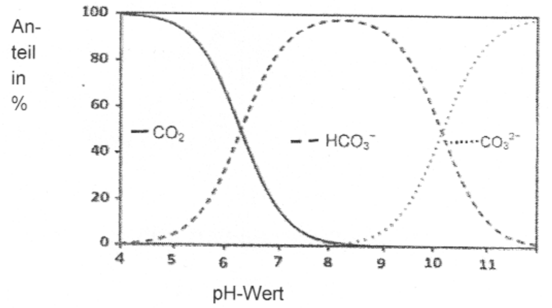
C) Salinity

The ions contained in salt water are surrounded by water molecules. (hydrated).
This results in a "rearrangement" of the water molecules among themselves.
The rearrangement of the carbon dioxide by water molecules is partially cancelled out, so that the physically dissolved carbon dioxide can escape from the water.



D) pH-value

The pH value of water is not only determined by the dissolved carbon dioxide.
Many other factors contribute to the establishment of a certain pH value.
However, there is a close correlation between the pH value, the proportion of carbon dioxide and the ratio of hydrogen carbonate and carbonate ions (see equations (2) and (3)).



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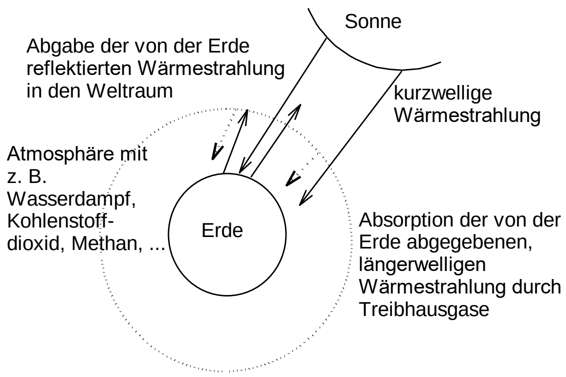
The Greenhouse Effect

The short-wave radiation emitted by the sun reaches the earth's surface through the Earth's atmosphere. In the process, the radiation "passes through" the gases contained in the atmosphere, such as water vapor, carbon dioxide, oxygen and ozone.
The heated earth's surface emits longer-wavelength radiation into the atmosphere. A part of this radiation is absorbed by the greenhouse gases. Thus less emission of the thermal radiation into outer-space takes place.
This leads to global warming.



Gases that partially absorb the longer-wave heat radiation from the earth's surface are called greenhouse gases.
The most important natural greenhouse gas is water vapor, which is mainly responsible for the natural greenhouse effect, without which life on earth would not be possible.
If the trace gases contained in the atmosphere, such as carbon dioxide, methane and nitrous oxide, accumulate, the natural greenhouse effect is disturbed, which means that in the long term global warming will occur.