B4 We produce drinking water – Methods of purifying water

The suggested subexperiments are ideal for introducing the basic chemical subject of material separation based on the current topic of water treatment. These experiments allow students to verify their relevant prior knowledge in this field. For biology classes, these experiments lead in to the subject of water as the basis for life. These experiments can also be used in an interdisciplinary approach, e.g., within the context of an environmental project. Except for the hollow fiber membrane, the materials supplied allow eight groups of students to conduct the experiments simultaneously.

1 Main question

For many people, having access to fresh, clean drinking water on a daily basis is not something they can take for granted. The drinking water shortage is one of the largest social problems of the 21st century. Around the world, almost one billion people do not have access to clean drinking water. How is it possible that a planet, two-thirds of which is covered with water, cannot supply its inhabitants with a sufficient amount of drinking water? Among other things, the answer can be traced to the Earth's growing population, regional water shortages caused by climatic conditions, and the deforestation of water-retaining forests. In many areas, though, the main reason is the contamination of natural water reserves (rivers, lakes, and ground water) by households, industry, and agriculture. Students need to become aware of the fact that often not even groundwater can be used as drinking water without first being treated. "How to produce drinking water from contaminated water" is the practical topic that will be used to familiarize students with the basic principles and efforts required for the technical implementation of current water purification methods.

2 Integrating the experiment into the teaching context

2.1 Basic principles

It is preferable, but not absolutely necessary, for students to have prior knowledge of the following (everyday experience is sufficient):

- Water as a solvent
- Water as a "vital substance" for humans, animals, and plants
- Protection of natural bodies of water (→ water as a habitat)

2.2 Relevance to the curriculum

Age group 12 to 15 years
In chemistry classes, the subject of material separation and the use of physical separation methods (→ sifting, sedimentation, decanting, filtration) in separating mixtures (solid/liquid) are an integral part of every curriculum. In addition, the curriculum covers subjects such as the solubility of substances, solutions, and suspensions, emulsions, osmosis, chemical precipitation reactions, and sewage treatment plants as water purification facilities.

Biology classes cover the central subject of water as a vital substance (→ metabolic transport) and include relevant topics such as cell structure (→ membrane) and osmosis. Biological aspects of environmental issues include biological degradation of contaminants, protection of natural bodies of water, and drinking water protection.

This material overlaps with physics classes in a more peripheral way: Topics include how filters work (→ particle size – pore size) and pressure as a state variable in gases and liquids.

Topics and terms: decanting, density, drinking water, drinking water protection, dye, filtration, flavoring, fragrance, habitat, interaction forces (molecular and atomic), ionic solution, liquid, material separation, metabolism, mixtures, pore size, pressure, protection of natural bodies of water, purification processes, sedimentation, separation methods, sewage plant, sifting, solids, solution, solvent, suspended particles, suspension, van der Waals forces, waste water, water as a vital substance, water contamination, water treatment

2.3 Skills

The students will ...

- recognize that separation methods play an important role in everyday life, based on their own practical experiences (e.g., brewing coffee extracts flavor and color, while the coffee grounds are filtered out).
- learn that water plays a critical role in separation methods.
- internalize the fact that our use of drinking water, in whatever form that may take, will ultimately generate waste water.
- recognize that in daily life, we tend not to be involved in the reverse process – producing drinking water from contaminated water.
- develop environmental awareness.
- make the responsible use of water as a “vital substance” an integral part of how they think and behave in a social context.

2.4 Explaining the experiment in the teaching context

These subexperiments will provide a step-by-step practical demonstration of the mechanical processes necessary to purify contaminated water, progressing to increasingly refined methods.

2.4.1 Subexperiment 1: Rough purification of contaminated water with silica sand, activated carbon, and filter paper

Subexperiment 1 begins with the rough purification of a mixture of clay, ink, and table salt by passing it through silica sand and filter paper.
In this subexperiment, the sand acts as a fine sieve primarily due to its pore size. Although the pore size of the paper filter is > 10 µm, the sand filter will filter out any particles with a size of > 0.1 µm. In addition to a pore size of around 100 µm, a sand filter also possesses adhesive forces (interaction forces on an atomic and molecular level, keyword van der Waals forces). In the experiment, the effectiveness of a filter depends on the layer thickness and the quality of the silica sand used in the funnel as well as on the filter paper. Students will see that this method filters out most of the suspended particles, but not the dye particles of the ink.

To remove molecular substances such as ink, students need to add activated carbon to the filtrate and shake the mixture. In practical terms, this works on dyes, flavorings, fragrances, and bacteria thanks to adsorption. Due to the large number of pores in the activated carbon, as well as the very small pore size (1 to 50 nm), the surface area of these pores adds up to around 10,000 times more than the surface area of normal charcoal.

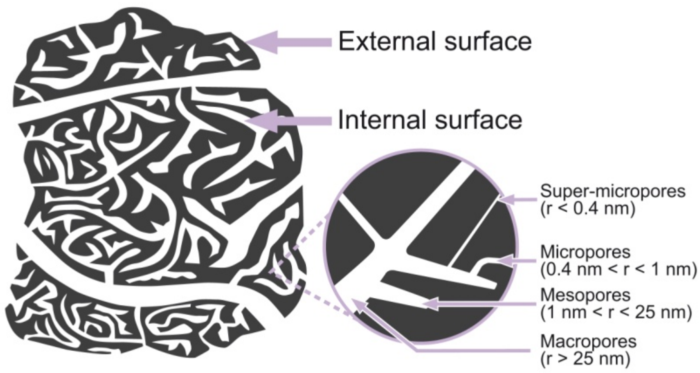

Fig. 1: Surface diagram of activated carbon.

This means that one gram of activated carbon has an internal surface area of up to 1,000 m^2, or roughly one seventh the area of a soccer field. At the end of the experiment, the conductivity test will demonstrate that chemical substances are often dissolved in the water (in this case table salt ions) whose removal requires a great deal of effort in addition to mechanical purification processes.

Overview of membrane filters

Process	Microfiltration (MF)	Ultrafiltration (UF)	Nanofiltration (NF)	Reverse osmosis (UO)
Filter material	Organic material or ceramic	Polyamides, polysulfanes, cellulose acetates, PVdF (polyvinylide fluoride)	Homogeneous polymer layers	Homogeneous polymer layers
Pore size	In the micrometer range 0,05 – 10 µm	Hundredths of micrometers 0.005 – 0.15 µm	In the nanometer range 0.7 – 10 nm	< 1 nm "No pores"
Separable substances	Plankton, algae, turbidity, bacteria, suspended particles, fibers, poss. proteins and large microorganisms (amoeba)	Macromolecules, viruses, colloids, bacteria	Organic compounds, ions (bivalent), dyes, pesticides and also herbicides	Molecules and ions: alkali and earth alkali salts but also heavy metal ions and alcohols as well as sugar
Required pressure difference	0.1 – 2 bar	0.1 – 5 bar	3 – 20 bar	10 – 100 bar
Example	Aftertreatment of purified wastewater	Drinking water treatment (e.g. SkyHydrant)	Pure water treatment, water softening	Ultra-pure water treatment, seawater desalination

Fig. 2: Overview of membrane filters

Compared to the values indicated in the table, the round paper filter we use has a pore size of greater than 10 µm, the membrane filter cartridge a pore size of 0.2 µm, and the hollow fiber membrane tube a pore size of 0.02 µm. Some of the blue dye particles of our ink are apparently larger than 0.2 µm, some particles are smaller than 0.2 µm, and some are even smaller than 0.02 µm. That's why we can considerably reduce the amount of dye contained in the water by means of our filter cartridge and the hollow fiber membrane tube, but not really remove it completely.

2.4.2 Subexperiment 2: Fine purification of water with membrane filter

The ink consists of a dye mixture made up of different molecule sizes, which means that the membrane filter would be able to remove some but not all of the dye. For that reason and for the sake of didactic clarity, this experiment does not use the ink and instead uses only the clay suspended in a table salt solution. In principle, this experiment is very simple and, provided the students work carefully, will guarantee success. After all, millions of such membrane filters are used in the biochemical, medical, and pharmaceutical fields. A procedure is outlined in the student instructions to avoid air bubbles in the membrane filter. Although this procedure may seem excessive, it is crucial that the students follow the steps precisely. Otherwise, if air bubbles come into contact with the wet membrane, they will become trapped in the membrane due to the compressibility of the air combined with the potential pressure in the syringe. The filter will become impermeable and unusable. If the proper procedure is followed, students will recognize the enormous effectiveness of the filter and will obtain a clear solution. The use of membrane filters provides for microfiltration with a particle size of around > 0.1 µm.

2.4.3 Subexperiment 3: Fine purification of water with hollow fiber membrane filter

Ultrafiltration and nanofiltration processes, with pore sizes of up to 1 nm, filter out the finest particles such as bacteria, dye molecules, metal ions, and viruses. These types of filtration typically use hollow fiber membranes. The fine-pore membranes required for seawater desalination projects, for instance, require very high pressures (80 bars and more). For that reason, we use a relatively large-pore hollow fiber membrane in our experiment.

If the nanofiltration process is applied to saline (ionic) solutions, it is referred to as reverse osmosis. In this process, pressure is applied to salty water, pressing it against a semi-permeable membrane with extremely small pores. The pore size allows water molecules of around 0.28 nm to pass through, while salt ions are kept back. (Although salt ions in and of themselves are smaller than water molecules, in this case they are significantly larger due to their bonded hydration shell.) In our experiment, we use a closed hollow fiber membrane tube to build up the necessary pressure. State-of-the-art desalination plants, however, use an open flow process. Due to the low diameter and the length of the fibers, the pressure is high enough to press the water molecules through the pores of the membrane. The advantage of this method is that the flow constantly cleans the membrane thanks to the running water. This process is used in large plants around the world to desalinate seawater in areas with shortages of drinking water.

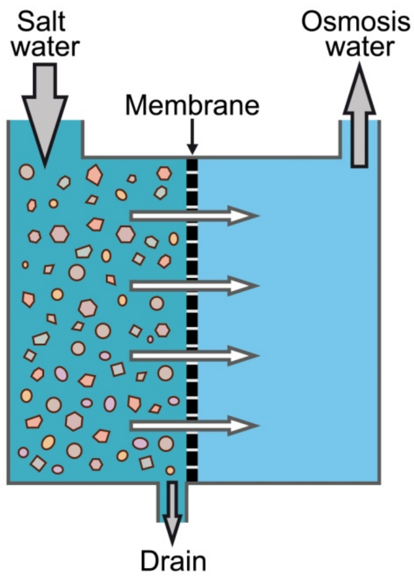

Fig. 3: Reverse osmosis diagram.

2.5 Experimental variations

- Students can work in teams of two for all experiments.
- The subexperiments 2 and 3 can also be conducted simultaneously in two groups. This allows the individual teams to share their expert knowledge from the subexperiments with the other group(s) in the remaining class time or the next time the class meets.
- All subexperiments can be conducted with the age groups mentioned. Teachers can differentiate the lesson by varying the depth of the analysis and follow-up questions, depending on the age group and any prior knowledge the students might have.

3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the Siemens Stiftung Media Portal:
https://medienportal.siemens-stiftung.org

The media package “Humanitarian aid – drinking water filters in use” extensively covers the topics highlighted in this experiment.

4 Notes on conducting the subexperiments

4.1 Facilities

No special facilities are necessary.

4.2 Time required

	Preparation	Execution	Analysis	Discussion
Subexperiment 1	5 min.	10 min.	10 – 20 min. depending on the depth	10 min.
Subexperiment 2	10 min.	20 min.	10 – 20 min. depending on the depth	10 min.
Subexperiment 3	5 min.	20 min.	10 – 20 min. depending on the depth	10 min.

4.3 Safety aspects

The students may conduct the experiments only in the presence and under the supervision of the teacher.
The teacher is to point out to the students that the provided materials may be used only according to the respective instructions.
For these experiments, watch out for the following potential dangers and make your students aware of them:

- Care must be taken to ensure that the accumulator is not short-circuited. This results in a risk of explosion and fire.
- Make sure that no damage can occur to water-sensitive materials and apparatus.

4.4 Apparatus and materials

Required materials that are not supplied:
Water (around 3 liters)

Supplied:
The apparatus and materials supplied are sufficient to allow **eight** groups of students to conduct the experiments simultaneously. This kit contains only one hollow fiber membrane, and groups will need to take turns using it.
Depending on the students' level of knowledge, teachers should explain proper wiring and the proper use of the LEDs in advance, demonstrating if necessary.
The following materials included in the kit are needed for **one** group of students:

Material	Quantity
Accumulator, 9 V	1x
Activated carbon, can	1x for entire class
Clay (“bentonite”)	1x for entire class
Connecting cable, alligator clip/alligator clip	6x
Filter paper (round filter), 12.5 cm	1x
Filter cartridge (membrane filter) with Luer lock	1x
Funnel	1x
Hollow fiber membrane with Luer lock	1x for entire class
Ink, blue (“aquatint”)	1x for entire class
LED, red (red case), 5 V	1x
Nail (steel, “iron”)	2x
One-way cock (to fit 7/4mm tube and Luer lock)	1x
Plastic cup (clear), 500 ml	2x
Plastic cup, 100 ml	4x
Screw-on lid (for 100-ml cup)	4x
Silica sand (“filter sand”)	1x for entire class
Syringe, Luer lock, 10 ml	1x
Syringe, Luer lock, 50 ml	1x
Table salt, package	1x for entire class
Teaspoon	1x

Fig. 4: Apparatus and materials supplied for one group of students.

4.5 Cleanup, disposal, and recycling

All apparatus and nearly all materials from the kit can be reused. Therefore, after the students have completed the respective experiment, they should put the apparatus and materials back in the appropriate boxes and return them to the kit. This practice will ensure that you and your colleagues will find everything again quickly the next time the kit is used.

Apparatus that become dirty during the experiment, such as cups, bowls, spoons, and test tubes, should be cleaned before being returned to the kit. We recommend that you have the students do this immediately after they have completed the experiment.

Also make sure that the apparatus are in working order for the next time. For example, recharge used accumulators immediately (It makes sense to charge the accumulators even if they will not be used for an extended period.).

Materials that cannot be reused, such as used pH test strips and filter paper, should be disposed of properly.

The waste that accumulates during this experiment can be disposed of in the regular trash or poured down the sink.