A4 Evaporation heat – How to cool with heat

The materials supplied allow eight groups of students to conduct the experiments simultaneously. If all subexperiments are conducted in the sequence below, they can be used to complement a learning unit on evaporation heat and "evaporative cooling." This provides a good basis for further study of general thermodynamics down to the particle level.

1 Main question

To cool your hands, you can bring them into contact with something cold. Then the heat flows from your hands to the cold object. However, there are other ways that heat can be conducted away. Evaporation plays a role in this. We will investigate the following questions in two subexperiments:

- Why do you freeze in wet clothing?
- How does a wet cotton pad cool you?

2 Integrating the experiment into the teaching context

2.1 Basic principles

The following prior knowledge and experience may be helpful for integrating the theory behind the experiments into observations on energy:

- Knowledge on the states of matter and transitions (solid, liquid, gas, melting, vaporization, condensation, freezing)
- Knowledge that energy is needed for transitions between the states of matter.

The following prior knowledge is needed for an explanation using the particle model:

- The temperature of a substance is a measure of the average velocity of the particles.
- The velocity of the particles in a substance is distributed statistically at a given temperature.

2.2 Relevance to the curriculum

Experiments on evaporation heat or "evaporative cooling" are so simple that the phenomenon of cooling by evaporation can be demonstrated as early as in elementary school. Based on this phenomenon, experiments can be developed together to make the phenomenon measurable and to investigate it in more detail. The students can become acquainted with aspects of scientific work through the process. It is not absolutely necessary at first to explain the phenomenon at a theoretical level. The instructions for the students are geared to a non-theoretical level (age group up to 14 years).
Observations on energy during transitions between the states of matter are necessary for a deeper theoretical study for students from about age 14 and up. An explanation of the phenomenon at the particle model level can also contribute to the students' understanding.

Topics and terms: bonding forces, "evaporative cooling", evaporation heat, heat pump, particle model, refrigerator, states of matter (liquid, gas), temperature, thermoregulation in nature, vaporization/condensation

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2.3 Skills

The students will become acquainted with the phenomenon of “evaporative cooling” based on a typical scientific method. The students will first explore this phenomenon in more detail in subexperiment 1, where they will work out influencing factors. In subexperiment 2, the students will make their observations more precise through systematically prepared quantitative measurements.

The student will learn the following main points based on subexperiment 1:

- To describe the phenomenon of “evaporative cooling.”
- To interpret the influence of adding ventilation as an increase in the evaporation rate.
- To differentiate the propensity of different liquids to evaporate.
- If applicable, to attribute the greater cooling effect of alcohol to faster evaporation.

The student will learn the following main points based on subexperiment 2:
To quantitatively verify the dependencies discovered qualitatively in the first subexperiment through measurements.

2.4 Explaining the experiment in the teaching context

The phenomenon of “evaporative cooling” is a consequence of the energy needed in the transition of a substance from the liquid state to the gaseous state. At the particle level, the different states of matter can be described in terms of the different interparticle bonding forces. Energy is necessary to break these bonds.
People generally understand the transition from one state of matter to another as a result of the increase in temperature and not as the result of additional energy. The proof that the temperature remains unchanged for a while when ice is melted on a heat source can make this aspect clear. When energy (melting heat) is added, it is not reflected in an increase in temperature, but in the fact that solid water (“ice”) at 0°C changes to liquid water at 0°C. By comparison, the energy needed during the transition from the liquid state to the gaseous state (evaporation heat) is more difficult to prove in an experiment. See also heat of fusion and heat of crystallization in experiment A2 (We store heat – From heat store to molten salt).
When a liquid evaporates, it means that the liquid has transitioned to the gaseous state. Energy is also necessary for this. If this energy is not added from an external source, it is extracted from the environment, which cools down as a result.

“Cold” is not a physics term. Therefore, the term “evaporative cooling” is not entirely fitting. On the other hand, the term has become established in normal language use. To indicate the difference from a physics term, we put this term inside quotation marks in this document. The correct technical term for this phenomenon is evaporation heat. This piece of information clarifies the paradoxical-sounding title of the experiment, “How to cool with heat”.
The decrease in temperature upon evaporation can also be understood in another way, specifically, as a decrease in the average velocity of the particles. The following table compares macroscopic observations with understanding at the particle level.

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Macroscopic	In the particle model
A liquid has a specific temperature.	The temperature is a measure of the average velocity of the particles. (More precisely: The temperature is proportional to the mean squared velocity.)
Some of the liquid evaporates.	Some particles may move at significantly higher velocities than others. The fastest particles have enough energy to escape the liquid's bonding force.
The liquid cools in the process.	Because the fastest particles are escaping the liquid's bonding force, the slower particles remain and thus lower the average velocity of the particles.

The evaporation of water also depends on air humidity. Water will evaporate more slowly when humidity is high. Evaporation can be accelerated by blowing on the surface of the water. The blowing replaces air rich in water molecules with drier air, which can absorb correspondingly more moisture.
The amount of energy required during evaporation also depends on the liquid itself. Alcohol evaporates more easily than water. As a result, the cooling effect with towels soaked in alcohol (e.g., "towelettes") is greater than with towels soaked in water. The greater propensity of alcohol to evaporate is related to its lower boiling point. At the particle level, this is equivalent to the lower bonding forces between the molecules in the liquid.

2.4.1 Subexperiment 1: Why do you freeze in wet clothing?

The test ties in with an experience from everyday life – the fact that you feel much colder in wet clothing (e.g., in a wet swimsuit) than in dry clothing. The students are able to consciously experience this phenomenon by moistening their hands with water. In a second step, they fan air over their wet skin with a piece of cardboard or similar item.

Transfer

The phenomenon of "evaporative cooling" shows up in many everyday applications.

- The human body uses the cooling effect from the evaporation of sweat.
- Dogs evaporate water from their tongues by panting.
- Clay cooling vessels work according to the same principle. Before it is used, the cooler is moistened with water. In African countries, people use clay jugs soaked in water to cool food in order to store it longer.
- Damp towels hung up in a room can provide cooling at the height of summer.
- Clay houses in desert regions are natural air conditioners without needing electricity: At night, the moisture in the air condenses on the walls and heats the house. During the day, the moisture evaporates again and heat is drawn from the walls.

The cooling effect of liquids containing alcohol is utilized, for example, in towelettes, medicated ointments, and sprays or deodorant.

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2.4.2 Subexperiment 2: How does a wet cotton pad cool you?

This experiment objectifies the phenomenon of “evaporative cooling” and makes it possible to measure the process. The students can systematically investigate the extent of the cooling effect under certain conditions. They can more precisely define the influence of ventilation and of the liquid itself through measurements. In the simplest variant, the experiment is conducted with water only. In addition, the students can also investigate liquids containing alcohol in this experiment. The following figures show the results of digital measurements for a cotton pad soaked in water and in alcohol, as well as for two cotton pads soaked in water, one of which was fanned using a cold-air hairdryer. The measurements were each conducted over a 10-minute period.

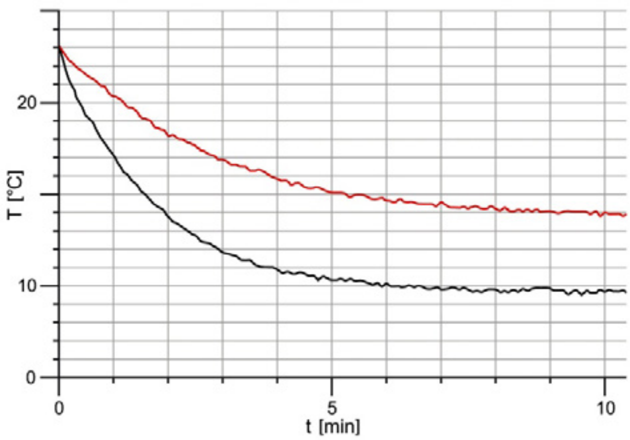

Fig. 1: The curves show the cooling of two cotton pads over a 10-minute period. Red: water-soaked pad, black: alcohol-soaked pad.

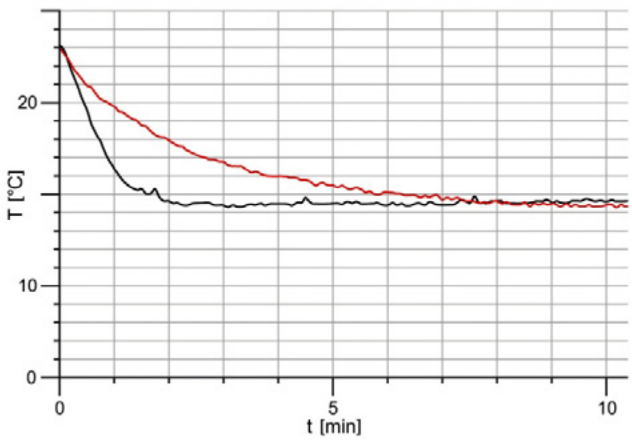

Fig. 2: The curves show the cooling of two cotton pads over a 10-minute period. Red: not fanned, black: fanned using a cold-air hairdryer.

The measurements do not have to be taken digitally, as shown in the figure, but can also be taken manually using a watch or stop watch. The graphs are used to estimate the effects.

- The temperature drops over a period of approximately 10 minutes. After 10 minutes, very little additional change will be observed.
- The temperature difference is approx. 9°C in the experiments with a water-soaked cotton pad.
- With alcohol, the temperature difference is clearly greater, approx. 14°C. It sets in very early.
- The temperature cannot be forced any lower through fanning using a hairdryer. The lowest temperature is however reached much sooner (in the figure above, after only 2 minutes instead of after 9 minutes).
- The fanning also enhances the effect of the temperature equilibrating with the environment. For this reason, a higher temperature will be measured for the fanned cotton pad after 10 minutes than for the unfanned cotton pad.

2.4.3 Transfer

In a compressor refrigerator, the cooling is ultimately induced by the evaporation of the coolant inside the refrigerator. A pump ensures that the coolant is condensed again outside of the cooling chamber. During condensation, the energy that was extracted from the cooling chamber during evaporation is released again to the environment. The same principle applies to a heat pump, but in the reverse direction.

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2.5 Experimental variations

Cooling through air movement can be achieved in various ways (fanning with a hairdryer, using a hand fan, blowing with the mouth, moving the thermometer). The students can also come up with their own ideas for intensifying the cooling effect and then try them out.

3 Additional information on the experiment

The Nigerian teacher Mohammed Bah Abba has received several awards for inventing a "refrigerator" based on the "evaporative cooling" principle. This invention means that people no longer have to make daily trips to the market.

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

4 Notes on conducting the subexperiments

4.1 Facilities

The students can conduct the experiment in any classroom under the teacher's instruction and supervision.

4.2 Time required

	Preparation and execution	Analysis, questions
Subexperiment 1	10 to 15 minutes	
Subexperiment 2	35 minutes*	15 minutes

*To reduce the amount of required time, the students can split into groups and conduct one of the three experimental variations each.

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.
There are no particular dangers with this experiment.
In subexperiment 1, make sure that drinkable alcohol is not used and inform the students that it is unsuitable for consumption.

4.4 Apparatus and materials

Required materials that are not supplied:

- Water
- Towels
- A small bottle of undrinkable alcohol, e.g., denatured alcohol or propyl alcohol
- Towelettes, optional (instead of alcohol).
- Stopwatches or watches with a second hand
- Cardboard, a spiral notebook, or something similar as a fan

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Supplied:
Enough apparatus and materials are supplied to allow **eight** groups of students to conduct the experiments at the same time.
The following materials included in the kit are needed for **one** group of students:

Material	Quantity
Digital thermometer*	1x
Cotton pad, package	1x for the entire class

*Remove the plastic sleeve before the first use. Press the "on/off" button to turn on the thermometer. After completing the experiment, turn off the thermometer again (press "on/off" again). Press the "°C/°F" button to switch between the Celsius and Fahrenheit temperature scales.

Fig. 1: 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.

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