A2 Storing heat – From heat store to molten salt

Note: This answer sheet will go into the analyses for the individual subexperiments only if experience shows that there could be particular difficulties.

1 Water as a heat store – Not only the tea gets cold

1.5 Analysis

a) Describe the behavior of the graph you drew.

Note: The temperature drops over time. The larger the temperature difference, the faster the heat dissipates. Depending on their grade level, students should recognize that the drop is non-linear.

b) Think about what caused the temperature to drop.

Note: The temperature drops because the heat stored in the water is given off to the ambient air and the test tube (emission, heat transfer, convection of the ambient air).

1.6 Questions

a) How would the results differ if the experiment were conducted outdoors, in summer, in winter?

Answer: In summer, when the outdoor temperature is higher than the temperature in the classroom, the temperature would drop more slowly and remain constant at a higher temperature. In winter, when the outdoor temperature is lower than the temperature in the classroom, the water would cool faster, meaning the temperature would drop faster, and reach a lower value at which it remains constant. To understand this phenomenon, students should keep in mind that many physical and chemical systems strive to reach a state of equilibrium. In this case, the water and the environment are not in thermal equilibrium. The farther away the system is from the equilibrium temperature, i.e. the higher the temperature difference between the water and the environment is, the faster the heat is transferred to the environment. In our case, this means that the temperature drops faster when the equilibrium temperature is lower.

b) What could you do to keep the water hot longer? What possibilities and devices can you think of?

Answer: Examples include a vacuum-insulated thermos or a styrofoam cup. A vacuum does not conduct heat at all; the heat dissipates only through thermal radiation. Heat transfer through thermal radiation can be slowed down by adding reflectors (mirror coating of the thermos).
In insulating materials such as plastic foam, the heat flows only via extremely thin cell walls and must travel a longer path than in solid materials due to the branched structure. Consequently, heat transfer is poorer in porous materials.

c) Can you think of an example of the principle of storing solar heat during the summer that is already being applied on a large scale for heating in the winter?

Answer: As one example, today's modern office buildings are being heated by means of seasonal heat stores: In summer, the sun heats water stored in relatively well-insulated underground gravel-water pits. In winter, this water then releases heat into the heating systems.

2 Water as an effective heat store – Water can stay hot longer if …

2.5 Analysis

a) How much did the temperature drop compared to the measurements you took in a non-insulated test tube?

Note: The temperature drops according to the same curve, but more slowly. The drop of the measurement curve is thus not as steep. Nevertheless, the same final temperature will be reached.

b) Compare the variations in your graph. Is the assumption correct that this time the water cooled more slowly?

Note: The assumption is correct.

c) Which material provided the best insulation? Compare your results with those of the other groups.

Note: Typical values as a reference point:

Material	**Thermal conductivity λ in W/(m · K)***
Vacuum insulation panel	0.004
Polyurethane foam	0.025
Polystyrene foam	0.030
Fiberglass	0.032
Wool	0.035
Cork	0.035
Rock wool	0.035
Bales of straw	0.038
Cellular glass	0.040
Cellulose	0.040
** the lowest known value for each material*	

2.6 Questions

a) Can you imagine how insulation works? Come up with an explanation and discuss it with your partner.

Answer: There are two methods of heat insulation: low heat transfer through poor heat conduction of the material (insulator), and prevention or reduction of heat radiation (reflector).

b) Do you have a theory about why some materials provide better insulation than others?

Answer: When it comes to insulation, three factors will slow the cooling process: poorer thermal conductivity of the material, a smaller cross section, and a longer path through the material. Therefore, a material with low thermal conductivity is selected for insulation. In addition, the material contains spaces filled with gas or air (pores in foam, air in textile fabric or fleece). Although It’s true that the gas enclosed in the material is also heated up, it does not have a direct exchange with the ambient air and thus does little to help transfer heat. Due to the thin fibers or porous walls, very little heat can flow per unit of time because of the small cross section. Furthermore, due to the branched structure, the heat must travel longer paths than in solid materials. Consequently, heat transfer is poorer in porous materials. From this it is clear that the more gas pockets the material has, the better the insulation. Good insulating materials (such as styrofoam, wool, and corrugated cardboard) have only about 1/1000 of the thermal conductivity of steel (approx. 40 W/m · K) or about 1/10 of the thermal conductivity of air (approx. 0.55 W/m · K). Another method of insulation is minimizing the radiation of heat. This method is implemented in the subexperiment through the use of aluminum foil, for example. The heat given off by the water through radiation is reflected back by the aluminum foil, resulting in less heat loss. Polished aluminum has particularly high reflectivity for infrared (IR) and heat radiation. As a result, for this method of heat insulation, the thickness of the reflector is not the decisive factor, but how strongly the material reflects the heat radiation. Depending on the method of heat insulation, what matters is the number of enclosed insulating air cushions or the material’s reflectivity in terms of heat radiation. One example that combines these variants is a fiberglass cushion that has aluminum foil on one side. The fiberglass contains many air cushions, and the aluminum foil provides even more insulation because it reflects back some of the heat that passes through the fiberglass.

3 Heat for cold fingers – Is the heat pack a heat store?

3.5 Analysis

e) Can you explain the results? Formulate a theory.

Note: With proper insulation and precise measurements, the temperature should remain constant at approx. 50°C for a relatively long time (for several minutes; see also the answer to the question in section 3.6).

3.6 Questions

When comparing the measured values, you must have noticed that your values were usually below 58°C. Can you explain why your values were never higher than 58°C? Would it even be possible?

Answer: The phase transition points (such as melting point and boiling point) of pure substances are exact fixed points. (Metal alloys are an exception, because normally they do not have an exact melting point, but rather an exact melting range.) A law of nature states that as long as not all of the material is melted or solidified, the temperature will not change. If the melting point/solidification point of sodium acetate trihydrate is 58°C, it is impossible for the compound to be heated above 58°C as it solidifies. And this temperature must remain constant until all of the compound has solidified. Another example: If a mixture of ice and water is well insulated and well stirred, it will remain at 0°C until all of the ice has melted.
An additional explanation why the transition does not take place at 58°C in the experiment, but at about 50°C: The solid material in the heat pack is generally sodium acetate trihydrate, which has a melting point of 58°C. In the past, this could also be measured as a rule. In heat packs commercially available today, the water content has apparently been changed because of the risk of burning, with the result that the melting point is often only about 50°C. If we do not get a reading of exactly 58°C for our experiment, it primarily has to do with the composition of the heat pack.
Additional explanation: Why does the salt remain a liquid at room temperature despite the higher melting point?
Whereas most other salts tend toward spontaneous seed formation and crystallization (and therefore are not as easily supercooled in a molten mass), this salt remains liquid for a very long period of time, even at lower temperatures. Seed formation and thus crystallization must first be triggered through bending or scraping.

4 How the heat pack stores heat – A salt that changes between solid and liquid states

4.5 Analysis

c) Compare your theories from the previous experiment with the results of this experiment. Do they match?

Note: If students work precisely, they will achieve the same results as in subexperiment 3.

4.6 Questions

a) When the heat pack is placed in boiling water, it is said to be regenerated or "re-charged." What do you think that means?

Answer: This means that the solid salt crystals are melted again. After being cooled, the supercooled molten mass is ready again to fulfill its function, that is, to produce heat "on demand." (Supercooling means that the mass does not harden due to lack of crystallization seeds. These seeds are generated, for example, by bending a metal disk or by scraping the mass with a glass rod, thus triggering the hardening process.) The storage of heat in molten salt is thus similar to the way a car battery is used to turn on seat heating in the car. When the car battery is dead, it must be recharged by the engine so that it can heat the seat again. This recharging is similar to the case with the heat packs, except that heat is being stored instead of electricity, in order to make the heat pack ready to use, that is, to obtain the molten salt.

b) Can you imagine how this "charging" takes place in systems that store large amounts of heat?

Answer: Salts other than sodium acetate can be used to store heat in other temperature ranges. Currently, salt mixtures (such as potassium nitrate and sodium nitrate) with melting point of up to approx. 800°C are being used. The energy is often fed back into a technical process – for example, to preheat a material prior to a chemical reaction. Solar thermal power plants such as Andasol in southern Spain also use molten salt storage. With a mixture of potassium and sodium nitrate that melts at 400°C, the plant can also run at full power for 7 hours after the sun goes down. In this case, the solar heat collected in the parabolic trough mirror collectors is used to charge, that is, to melt the salt.