A2 Inclusion: Storing heat – From heat store to molten salt

1 Main question

Many technical processes – and especially those related to renewable energy sources – produce heat, which is often discharged unused into the environment. An important question for the future, therefore, is how this heat can be stored and used. Storing heat by means of water is commonly investigated in class.
The suggested experiments demonstrate that heat can be stored, even over longer periods of time. One example of a storage medium is molten salt, which can release large amounts of heat as it solidifies (crystallizes). The experiments use commercially available heat packs filled with a sodium salt of acetic acid.

2 Integrating the experiment into the teaching context

2.1 Basic principles

Although everyday experience has already taught students at a very young age about the transitions between solid, liquid, and gas – water being the prime example – they are not always aware that every transition is associated with energy transfer. The experiments can be used to build on this prior practical knowledge and develop a deeper understanding of the fact that the heat of fusion and of evaporation can also be used to store energy.
For further study, the topic can be examined at the particle level, at which heat is interpreted as motion and entropy plays a role in a material's energy content.

2.2 Relevance to the curriculum

Areas of expertise in selected curricula from Saxony-Anhalt

Physics in grade 6:

Determining and influencing heat transfers
- Describing the forms of heat transfer based on examples
- Naming possibilities for improving and hindering heat transfer

Physics in grade 7/8:

Explaining thermal effects and balancing heat exchange processes
- Calculating the heat absorbed or released by a substance
- Explaining properties and changes in aggregation states of substances using the particle model

Chemistry in grade 7/8:

Examining and comparing acids, bases, and salts in everyday life
- Explaining correlations between structure, properties, and use based on a representative substance from each substance class

Technical subjects in grade 9/10:

Describing and analyzing technical systems

- System for using renewable energies (based on examples)
- Influence of structural and external conditions on efficiency
- Advantages and disadvantages of use

The students will …

- learn about the transition between liquid and solid states of aggregation as a source of heat release.
- recognize the possibility of storing the heat produced for later use.
- come to understand that all transitions between states of matter are associated with energy transfers.

2.3 Explaining the experiment in the teaching context

It is recommended that the experiments be used in pairs:

- The first pair deals with the possibility of using commercially available heat packs to store heat.
- The second pair uses the heat pack, or rather its contents (a sodium salt of acetic acid), to calculate and demonstrate the energy transfer of transitions between states of aggregation (in this case, crystallization).

2.3.1 Subexperiment a): Change in a heat pack's temperature

The basis for the first experiment on the heat of fusion and crystallization is the phenomenon by which heat packs with liquid contents heat up during crystallization and release heat over a longer period of time at a constant temperature. Students know from everyday experience (for example, candle wax) that a solid requires additional energy (in the form of heat) to melt. The reverse, however – that heat is released during the hardening process (also called solidification or crystallization) – may be surprising. Heat packs are especially suitable for demonstrating this effect, because the liquid is a supercooled molten mass that crystallizes only after a metal disk is bent. (Bending causes crystallization seeds to form, similar to scraping with a glass rod – see subexperiment 4.)
This experiment can be repeated as often as desired by placing the heat pack in extremely hot water (approx. 90 °C) for about 10 minutes or until the crystals have completely melted. (It is recommended that the teacher do this using an electric kettle during the preparation or follow-up period for the experiment.)
Students should track the temperature variation by taking measurements, enter the measured values in a table, and prepare a graph (temperature over time). The finished graphs are a good illustration of how the heat pack's temperature slowly drops.

2.3.2 Subexperiment b): Increase the heat pack's effectiveness: The heat pack remains warm for a longer time if …

For the heat stored in a heat pack to remain usable over a longer period of time, it must be insulated as well as possible. Students should repeat subexperiment 1 using various commonly available materials. The temperature progression then indicates the quality of the heat insulation and the practical storage options. If the material chosen insulates well, the temperature drops more slowly than it does without insulation.

2.3.3 Subexperiment c): Determine how much heat a heat pack gives off

In this experiment, students examine the transfer of heat from the heat pack to water. It is assumed that the heat given off by the heat pack is exactly the same amount of heat that is absorbed by the water.
The students should have no trouble recording the measured values in this experiment. The challenge lies in the mathematical evaluation of the measured values using the fundamental equation of thermodynamics $Q = m \cdot c \cdot \Delta T$.
A hint has been added to the experiment to help all students successfully complete this task.

2.3.4 Subexperiment d): How the heat pack stores heat – A salt that changes between solid and liquid states

To examine the processes in more detail, a heat pack is cut open. Some of the contents are then transferred to a test tube, melted, and caused to crystallize again after cooling by scraping with a glass rod. The temperature is monitored throughout the entire process.
The experiment demonstrates that solidification always occurs at the same temperature (approx. 50 °C to 58 °C, depending on the type of heat pack), which corresponds to the solid's melting point. (Actually, the values measured in student experiments are often lower due to heat losses.)
This experiment can be repeated only to a limited extent because some water escapes each time the contents are heated. This changes the composition of the salt and solid material and eventually a clear liquid will no longer form.
Note: It is recommended that the teacher cut open a hardened heat pack and distribute the salt to the students. The remaining salt can be preserved in a tightly sealed container and used for experiments with other classes. (If necessary, occasionally add a few drops of water to compensate for losses through evaporation.) Since the box contains nine heat packs, this will ensure that there will always be enough packs for eight groups of students.

2.4 Experimental variations

- All experiments can be conducted individually and in small groups. Temperature progressions should be measured in teams of at least two students so that the measured values can be read and recorded separately.
- To obtain an accurate, reproducible reading, it is recommended that students work on an insulated surface (for example, corrugated cardboard), that the heat packs be wrapped around the thermometer's probe, and, if possible, that they be secured with rubber bands (or string).
- If your school has enough test tubes and stoppers on hand, at the end of subexperiment 4, the students could seal the test tube containing the hardened sodium acetate with a stopper. Stored in this manner, the sodium acetate can be used repeatedly.
- Perform subexperiments 1 and 3 as per the instructions. Subexperiment 2 can also be elaborated by the students themselves and then conducted. This procedure gives the students an excellent opportunity to deliberately use and apply scientific methods.
  To ensure that the heat pack in subexperiment 2 is well insulated, the students must test several different insulating materials. When the heat pack is wrapped in a woolen cloth, the temperature drops only 3 °C less over a 20-minute period than it does without any insulation (see table).

	Starting temperature	**After 3 min.**	**After 6 min.**	**After 9 min.**	**After 12 min.**	**After 15 min.**	**After 18 min.**
Water in test tube	46.5 °C	41.4 °C	37.6 °C	35.1 °C	32.5 °C	30.3 °C	28.5 °C
With woolen cloth	47.4 °C	43.5 °C	40.5 °C	37.9 °C	35.5 °C	33.5 °C	31.6 °C

- So that students can better understand the absorption of heat during the melting process, they can measure the temperature progression when heating a mixture of water and ice: As long as there is any ice remaining, the temperature of the mixture stays at 0 °C. Another suitable demonstration experiment would be the boiling and evaporation of water. In this case, the temperature of the liquid remains at 100 °C until the very end (or slightly lower, depending on altitude and air pressure).
- For older students and higher grades, heat can also be explained on the particle level.
- Be sure to discuss the technical and practical applications of long-term heat storage. For example, today's modern office buildings are already being heated by means of seasonal heat stores: In summer, the sun heats water stored in well-insulated underground gravel-water pits. In winter, this water then releases heat into the heating systems.
  Salts other than sodium acetate can be used to store heat in other temperature ranges. Currently, salt mixtures with melting points 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.

3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the Media Portal of Siemens Stiftung: https://medienportal.siemens-stiftung.org
(See Experimento | 10+: A2 Storing heat (teacher instructions).)