Differentiating between endothermic and exothermic reactions

Aims of the experiment

- Getting to know the terminology of exothermic and endothermic reactions.
- Differentiate between exothermic and endothermic reactions.
- Learn the methodology for the experimental identification of exothermic and endothermic reactions.

Principles

In a chemical reaction, there is always a transfer of energy in addition to the redistribution of atoms. The most easily observable energy transfer besides the emission of light is the exchange of heat *Q* since the heat emitted or absorbed during a reaction can be well determined qualitatively by temperature measurements.

In a chemical reaction in a closed or open system, the exchange of heat can be detected either by heating or cooling of the environment. If the environment heats up, ie, if the reactants release heat, the reaction is called exothermic. If the environment cools down, ie, if the reactants remove heat from it, it is called endothermic. An important representative of exothermic reactions are combustions, in which the heat of reaction is directly related to the calorific value, and thus to the quality of the fuel.

In this experiment, we will first study an endothermic reaction by removing water of crystallization from copper(II) sulphate pentahydrate by heating. The course of the reaction is easily followed since it is accompanied by a colour change.

Following this reaction, we will study the reverse reaction, which is exothermic. Water is added to anhydrous copper(II) sulphate and the temperature in the reaction mixture is measured during the reaction.

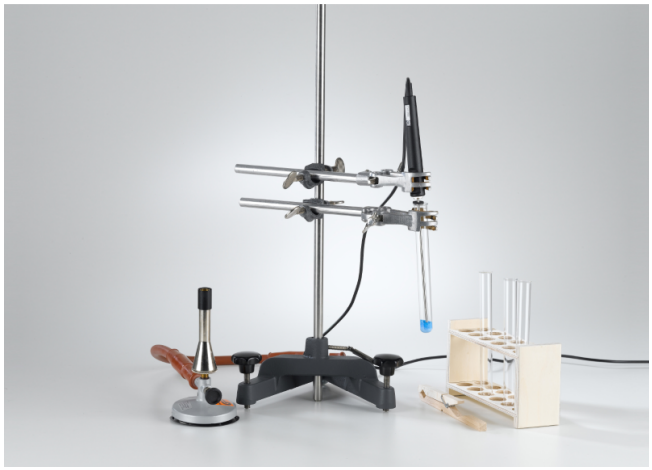

Fig. 1: Experiment set-up.

Risk assessment

Be careful when handling the burner! Tie long hair back!

The copper(II) sulphate used is harmful to living organisms and the environment. It must not enter the drain under any circumstances, and it must be disposed of properly.

Copper(II) sulphate-5-hydrate

Signal word:
Attention

Hazard statements

H302 Harmful if swallowed.
H319 Causes serious eye irritation.
H315 Causes skin irritation.
H410 Very toxic to aquatic life with long lasting effects

Safety Advice

P273 Avoid release to the environment.
P302+P352 IF ON SKIN: Wash with soap and water.
P305+P351+P338 IF IN EYES: Rinse continuously with water for several minutes. Remove contact lenses if present and easy to do – continue rinsing.

Equipment and chemicals

No.	Material	Cat. number
1	Mobile CASSY 2 Wi-Fi	524 005W
1	Temperature probe, NiCr-Ni, 1.5 mm, type K	529 676
1	Stand base, V-shaped, small	300 02
1	Stand rod 50 cm, 10 mm Ø	301 27
2	Bosshead S	301 09
2	Universal clamp 0...80 mm	666 555
1	Test tubes, Fiolax, 16 x 160 mm, set of 10	664 043

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No.	Material	Cat. number
1	Test tube rack, for 10 tubes, 22 mm diam.	667 053
1	Test tube holder 20 mm Ø	667 031
1	Powder spatula, steel, 185 mm	604 5682
1	Teclu burner, universal	656 017
1	Safety gas hose with end clamp, 1 m	667 187
1	Piezoelectric gas igniter	666 733
1	Wash bottle PE 500 ml	661 243
1	Copper(II) sulfate-5-hydrate, 100 g	672 9600
1	Water, pure, 1 l	675 3400

Set-up and preparation of the experiment

1. Set up the stand: Fasten the stand rod in the stand base and attach two universal clamps to the stand rod, each with a bosshead.
2. Clamp the temperature sensor into the upper universal clamp and connect it to the Mobile-CASSY.
3. Fill the test tube with 2 spatulas of copper(II) sulphate pentahydrate (filling height approx 1 cm) and place in the test tube rack.

Performing the experiment

Endothermic reaction

1. Ignite the burner.
2. Carefully heat the copper(II) sulphate pentahydrate in the test tube over the burner flame (using the test tube holder) until the solid is completely decolourised. If the solid clumps when heating, remove the test tube from the flame, carefully break up the solid lumps with the spatula, and continue to heat.
3. Allow the test tube to cool to room temperature in the test tube rack and then clamp it into the lower of the two universal clamps.

Exothermic reaction

1. Lower the temperature sensor into the test tube until the tip is completely immersed in the solid.
2. Switch on the Mobile-CASSY and select the measuring parameters so that a temperature value is recorded automatically every 200 ms.
3. Start the measurement on the Mobile-CASSY.
4. Add approx 4 ml of water (approx 2 cm filling height) to the test tube, using the wash bottle.
5. Run the reaction for about 2 minutes, then stop the measurement on the Mobile-CASSY.

Observation

1. The copper(II) sulphate pentahydrate decolourises from blue to white while heating it over the burner. In the process, the condensation of a colourless liquid can be observed on the upper test tube wall.
2. As soon as water is added to the test tube, the white solid turns blue again. At the same time, a strong increase in temperature to approx 100 °C can be observed on the Mobile-CASSY.

Evaluation

Endothermic reaction

When heating the blue copper(II) sulphate pentahydrate to about 250 °C, a white solid forms, which is anhydrous cupric sulphate:

$$CuSO_4 \cdot 5\,H_2O \xrightarrow{\sim 100\ ^\circ C,\ -4\,H_2O} CuSO_4 \cdot H_2O \xrightarrow{> 200\ ^\circ C,\ -H_2O} CuSO_4 \qquad (1)$$

The heat applied externally allows the water molecules, which are bound in the crystal, to detach from their binding partners and exit the crystal. Since this reaction occurs only through the absorption of energy from the environment, it is an endothermic reaction. It should be noted that the water molecules only release from their bonds at a certain temperature – the reaction does not start until around 90 °C. Some of the expelled water condenses in the upper (cooler) area of the test tube and can be identified with appropriate verification if desired. The anhydrous copper(II) sulphate formed in the reaction is suitable, for example, as a sensitive reagent for detecting water (see exothermic reaction).

Exothermic reaction

After combining water and anhydrous copper(II) sulphate, a vigorous reaction begins. The temperature measurement will record a temperature increase in the reaction mixture to just below 96 °C (this value, however, also depends on the amounts of educt used). A blue reaction product, copper(II) sulphate pentahydrate, forms while releasing heat:

$$CuSO_4 + 5\,H_2O \longrightarrow CuSO_4 \cdot 5\,H_2O \qquad (2)$$

Since heat is released into the environment during this reaction, it is called an exothermic reaction. It can be deduced that the incorporation of water of crystallisation into the crystal lattice of the anhydrous copper(II) sulphate releases energy.

Results

The expulsion of the water of crystallisation from copper(II) sulphate pentahydrate is an endothermic process that absorbs heat from the environment. The heat is supplied here through heating by means of a burner. This shows that energy must be used to break bonds between the water molecules and the ions of the copper(II) sulphate. Conversely, when incorporating water of crystallisation into anhydrous copper(II) sulphate, energy is released in the form of heat. This exothermic process is reflected in the temperature rise of the reaction mixture, which was detected by means of the Mobile-CASSY.

Cleaning and disposal

Copper(II) solutions and copper(II) salts must not be disposed of in the drain or household waste, but must be collected in labelled vessels for liquid or solid inorganic wastes containing heavy metals and then sent to special waste collection.

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