Homemade foam fire extinguisher

Note:
This task is designed so that it can be solved with the incremental hints.
The hints are available on the media portal for printing, or the students can use them online on a tablet or smartphone via the QR code included on the worksheet.
The worksheet for the students and the hints for printing are available as separate files on the media portal of the Siemens Stiftung. General information on using tasks with incremental hints in the classroom is provided in the “Tasks with incremental hints – an introduction” document, which is also available on the media portal.

1 Topical aspects

This task addresses how the students apply their knowledge about the reaction of sodium bicarbonate with an acid. The students should develop a model of a foam fire extinguisher, that is, a container in which the chemical reaction can take place and from which extinguishing foam can be sprayed in a specific direction.

2 Learning prerequisites and level of difficulty

In order to complete the task, the students must have previously learned about the reaction of sodium bicarbonate (baking soda) with citric acid and how to interpret it. Information about the relevant reactions and their scientific explanation is available on the media portal of the Siemens Stiftung, for example, in the “Experiments with carbon dioxide – From explosion to fire extinguisher” teaching methods and in the related experimentation instructions for the students.
Depending on the grade in which the task will be used, it can be worked through on a purely experimental level or else with prior knowledge of chemistry. The students should definitely have the basic idea that gases formed in a closed container generate pressure.
The level of difficulty of the task is medium.

3 Background on the task

Carbon dioxide is a gas that is heavier than air and that prevents combustion from continuing, which makes it suitable for suffocating flames and for extinguishing fires. When used as an extinguishing agent, carbon dioxide has the advantage that it is not associated with secondary damage, like when water is used for extinguishing. CO_2 extinguishers consist of steel cylinders containing liquefied CO_2 under high pressure. When the extinguisher is opened, the CO_2 flows out and vaporizes immediately; due to the energy required for vaporization (evaporation heat), it generally cools off so rapidly that a solid CO_2 “snow” forms. This snow and the gaseous carbon dioxide displace the atmospheric oxygen away from the burning object. In addition, the extinguishing agent cools the burning object so much that it cannot reignite. However, in the past, fire extinguishers used CO_2 that was formed through a chemical reaction of a carbonate with an acid. Before the extinguisher was used, the chemicals stored separately inside the extinguisher had to be mixed to start the reaction. For this purpose, a separator had to be broken by actuating a pin from the top of the extinguisher.
The foam fire extinguisher to be designed in this task largely follows this principle. The following reactants are to be used:

- Sodium bicarbonate ($NaHCO_3$)
- Citric acid

They can be mixed as solids without triggering a reaction. The carbonic acid and sodium citrate do not form until water is added to the mixture. The carbonic acid breaks down into water (H_2O) and carbon dioxide (CO_2), which can be observed as the formation of gas:

$$NaHCO_3 + H\text{-}Cit \rightarrow H_2CO_3 + Na\text{-}Cit$$

Sodium bicarbonate + citric acid → carbonic acid + sodium citrate

$$H_2CO_3 \rightarrow H_2O + CO_2$$

Carbonic acid → water + carbon dioxide

Even though CO_2 as a gas is also capable of suffocating flames by itself, a foam fire extinguisher that can be made by adding powder detergent is preferred for two reasons.

- One practical reason is that, due to the thermal current generated by every flame, the CO_2 gas is quickly blown away from the fire source, and so suffocating the flame is not easy. Whether in the model experiment or in real life, extinguishing foam is better able to cover and therefore suffocate a flame due to its greater mass.
- The second reason is of a didactic nature: CO_2 as a gas is not visible, but as foam that is generated in the reaction when powder detergent is added, the gas formation can be better observed and extinguishing the flame is easier.

4 The task

The task formulation selected here assumes that the students have previously experimented with sodium bicarbonate and citric acid, for example, to examine the effect of baking powder.

Homemade foam fire extinguisher
You recently experimented with sodium bicarbonate (baking soda) and citric acid and learned why a mixture of the two substances is suitable for baking, for example.
You should now apply your new knowledge to design a fire extinguisher. The following substances are available for this purpose:

- Sodium bicarbonate (baking soda)
- Citric acid
- Powder detergent
- Water

When designing the fire extinguisher, think about the experiments you have already conducted. Write down how you want to proceed, and give your reasons. Consider what containers and other materials you could use for the fire extinguisher.
At the end, you should do the following:

- Make a sketch/drawing so that others can also see what your fire extinguisher will look like.
- Briefly describe how the fire extinguisher will work.

The goal of working on this task is for the students to work out the principle of a foam fire extinguisher, thus a closed container with the mixed solids. In addition, the container must provide a way to easily add water and have a discharge tube for directing the resulting foam at the flame to be extinguished.

At the end of the class discussion of the designs, promising solutions should be implemented and tested. At this point, it should be clarified that the container must be sealed again after the water is added. The sketch in the hints does not show this.

Important reminder while testing the extinguishers: **Observe the safety precautions!**
(safety goggles, fireproof surface for the candle to be extinguished, water nearby to wash off any splatters of the extinguishing foam)
The foam fire extinguisher can easily be made with the resources of the experimentation set for Experimento | 10+:
A suitable reaction container is a cup (100 ml) with a screw-on lid into which two holes have been drilled. A syringe can be used for adding the water in a controlled manner, and a flexible straw or a length of silicone tube (7 mm) is suitable for discharge and directed spraying of the extinguishing foam.

Experiment setup for the foam fire extinguisher.

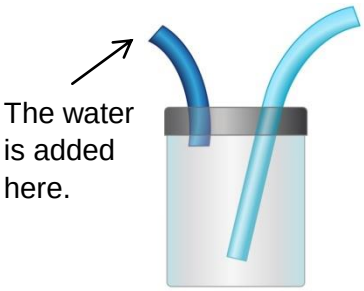
5 Variations

To be able to solve the task, the students do not necessarily need to know the chemical background of the reaction of sodium bicarbonate and citric acid. It suffices if the students have learned that this reaction produces gas and they can apply this phenomenon sensibly in the new context. For higher grades, the hints should be designed accordingly to go further into the subject. Depending on the learning group, the number of hints can be decreased or increased.

6 Overview of the hints

Note: The hints have been prepared as a separate file for printing or can be used online via the QR codes on the worksheet.

Hint 1 Explain the task to each other again in your own words. State what you understood the task to be and what is still unclear to you.	**Answer 1** We're supposed to design a foam fire extinguisher that works with sodium bicarbonate (baking soda), citric acid, powder detergent, and water. At the end, we're to make a sketch to show what the fire extinguisher might look like and explain how it works.
Hint 2 Recall what you have already learned about the reaction of sodium bicarbonate, citric acid, and water.	**Answer 2** When we add some water to a mixture of sodium bicarbonate and citric acid, the mixture begins to bubble. Gas is produced: carbon dioxide.
Hint 3 Powder detergent is included in the ingredients for the fire extinguisher. What purpose do you think it has?	**Answer 3** If we dissolve powder detergent in water and shake the mixture, it makes foam. If the mixture of sodium bicarbonate and citric acid also contains powder detergent, the resulting carbon dioxide will also make foam. The foam can cover and suffocate the fire.
Hint 4 Now you need a suitable container in which you can make the extinguishing foam. Remember that you want to extinguish the fire from some distance away.	**Answer 4** The extinguishing foam should be forced out by itself. That's why the container should have only a very small opening. There must be a way to add the water in order to start the reaction. Our foam fire extinguisher must have a flexible discharge tube so that we can aim the foam at a flame.

Hint 5	**Answer 5**
Now you have everything you need. Make a sketch of the foam fire extinguisher and describe how it works.	 The fire extinguisher consists of a container with a lid. There is an opening where the water can be added and a nozzle where the foam comes out. When water is added, the reaction starts and carbon dioxide gas forms. Because powder detergent is present, foam is produced. When we seal the opening for adding water, the pressure inside pushes the extinguishing foam out through the “nozzle”. We can extinguish a small flame in this way.