Inquiry Based Learning Approach in Teaching "Phase Transitions" for Experimental Skills Formation in 16 Years Old Students

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Objectives

The purpose of this report is to share experience in applying a didactic model when using a inquiry approach in the lesson activity in studying the topic "Transitions between states of matter". An application of the model to several specific inquiry problems is proposed. They are adapted to the curriculum for 15-16 year old students in the Bulgarian school. According to the curriculum, the topic is covered for two school lessons. The basic knowledge and experimental skills can be further developed by solving inquiry problems relevant to the topic.

The choice of the topic of phase transitions allows the selection of tasks related to interesting phenomena from the world around us. The thermal phenomena, the study of which at first sight does not make it difficult for students, are connected with a difficulty in realizing the nature of the thermal energy needed for the phase transition. Here, the inquiry approach can be used to fill gaps in knowledge, to deepen knowledge of vaporization and boiling processes, to compare solid-liquid transitions of crystalline and amorphous bodies.

Didactic model

A didactic model for learning through inquiry was applied during the 2021-2022 school year at the "Baba Tonka" High School of Mathematics in the city of Ruse to four separate independent problems united by the common theme of transitions between states of matter. Experiments related to thermal phenomena are usually continuous, so the work is carried out during three class lessons. Since we are working with 15-16 year old students, with relatively little life and experimental experience, they first perform a preliminary experiment to observe the phenomenon. This can also be done at home as a preliminary preparation. By conducting preliminary experiments, students enter the problem, unlocking their natural curiosity and propensity to ask questions. Thus, scientific research can begin with the formation of an important experimental skill - asking key important questions. And goes through the following stages: Essential questions; Experimental setup design; Qualitative explanation of the phenomenon; Building a hypothesis; Conducting the experiments; Collecting and organizing data; Data Analysis.

Problem 1: A metal wire with weights attached to both ends is placed on top of a block of ice. The wire can pass through the ice without cutting it. Investigate the phenomenon. (Melting Phenomenon) (IYPT 2010) (1)

Essential questions

- What is the observed phenomenon? What and why is it happening?
- What are the parameters we can change?
- How do the thickness of the wire, the material from which it is made, the mass of the weights affect?
- Do the sizes of the ice block matter?
- What is the shape of the downward wire inside the ice?
- Is there a minimum weight of weights that can cause the effect?
- Does the temperature of the ice matter?
- What are the dependent parameters? What could we measure? The time to cross the ice block, the speed of the wire?
- Does it matter if the ice is transparent or not? How do its properties change?

Will the phenomenon be observed if the wire is not metallic?

Independent variables: diameter of wire; thermal conductivity/material; mass of weights
Dependent variables: time; velocity

Experimental setup
The ice is placed on a wooden stand (Figure 1).

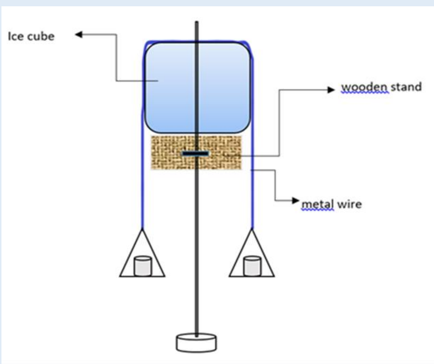

Figure 1

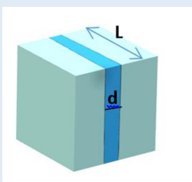

Figure 2. Ice cube

Qualitative explanation
The ice taken out of the freezer has a temperature of -15 °C. Under the action of increasing pressure when the wire is pressed, the melting temperature decreases and the ice under the wire melts.

Hypothesis Building/Quantitative Explanation
The ice taken out of the freezer has a temperature of -15 °C. Under the action of increasing pressure when the wire is pressed, the melting temperature decreases and the ice under the wire melts (Figure 2).

$$p = \frac{2mg}{\pi dL}$$

Conducting the experiments/Collecting the data
Several experiments can be carried out in parallel - with three different ice cubes and the same wire ; three identical ice cubes with three different wire diameters (Figure 3); three different types of wire - copper, steel and nichrome under the same other conditions. Since the process is slow, individual pictures can be taken every few minutes

Data analysis
After determining the time to move and the distance traveled, the speed (in this case of the order of mm/min) is determined. Velocity graphs are constructed for various wire diameters and materials. It turns out that the dependence is linear. It is determined how the speed changes with different masses of the weights and pressures on the wire. It is determined how the speed changes with different masses of the weights and pressures on the wire. Several graphs are plotted- time of the movement of wire as a function of load mass and as a function of wire diameter.

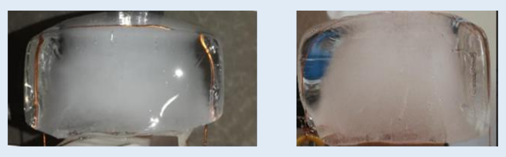
Figure 3. Identical ice cubes with different wire diameters

Problem 2: When a drop of melted paraffin or wax drips into a container of water, bizarre shapes are produced. Investigate how shape depends on drop height. (Solidification phenomenon) (IYPT 1991)(1)

Essential questions

- What shapes are obtained? How many species? Can they be classified into groups?
- How does the size of the drop affect it?
- Does the temperature of the paraffin matter?
- What effect does the different water temperature have?
- How does the drop height change the shape formed?
- How is the curing process?
- Is there a difference between paraffin drops and wax?
- Does the depth of the water they fall into matter?

Independent variables: diameter of inner and outer pots; width of the porous layer
Dependent variables: temperature of inner pot; time to lower the temperature; mass of vaporized liquid

Experimental setup
Paraffin is melted in a water bath in a syringe with a needle diameter of 1 mm (or larger) and drops are dropped onto the surface of the water. (Figure 4)

Qualitative explanation
The drop falling into a bath of liquid has been repeatedly studied (13, 16). The phenomenon goes through several different phases. This also happens when a drop of molten paraffin falls into a bath of water. When falling from a great height, the contact of the folder with the water leads to a splash (Figure 5 a). As the drop enters the water, a cavity is formed (Figure5b). It quickly collapses and the pressure difference ejects some of the water in the form of a jet called the Worthington jet (Figure 5c).

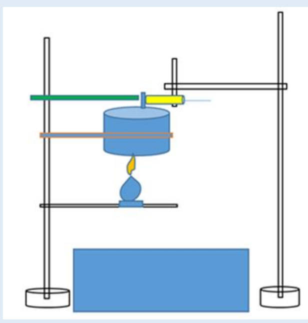
Figure4

Figure 5. Different phases of droplet impact on liquid bath: a) liquid splash; b) cavity formation c) Worthington jet formation.

Building a hypothesis
Here the students' knowledge is not enough to build a theoretical model, but as a result of the analysis they can expect to learn at least three types of shapes depending on the temperature of the water (14). They can do a detailed study on the composition and structure of paraffin. Pure paraffin has a certain solidification temperature, and the commercial paraffin that we can buy in the form of candles contain several types of isomers and solidify in a certain temperature range, similar to amorphous bodies.

Conducting the experiments / Data collection
Experiments are conducted at different heights of the drop, at the same water temperature. The second group of experiments is conducted at a given and different water temperatures. The data is collected in the form of photos and videos, from which the shape of the solidified drop is determined.

Data analysis
Students analyze and group the solidified drops by shape obtained depending on height and temperature. When falling from a low height, the cavity is very small and this forms shapes such as ellipsoids (15). When falling from a greater height, a larger cavity is formed and upon solidification, mushroom-like shapes are formed (15) (Figure 6). As for the formation of these forms, the water must be warmer. When falling into cold water, paraffin does not give off any amount of heat to the water, but solidifies quickly, forming a kind of flakes with many branches.


Figure 6. Examples of obtained different forms of solidified paraffin drops

Problem3: A simple evaporative cooling system consists of two ceramic pots of different diameters placed inside each other. A moist porous substance (e.g. sand) is placed between them. Explore the temperature in the inner pot. How could better cooling be obtained? (Evaporation phenomenon) (IYPT 2014)(1)

Essential questions

- How does the temperature change in the inner pot?
- What is the reason for the cooling in the inner pot?
- What is the role of the porous layer?
- How does the temperature of the environment affect it?
- How does air humidity affect it?
- Why should the dishes be clay?
- Does the temperature of the wet porous medium matter?
- Is the thickness of clay pot important?
- Does the interior affect the cooling in the inner pot?
- Does atmospheric pressure affect and how?

Independent variables: diameter of inner and outer pots; width of the porous layer
Dependent variables: temperature of inner pot; time to lower the temperature; mass of vaporized liquid

Qualitative explanation
The reason for cooling the inner pot evaporative cooling. The latent heat required for evaporation is obtained from the environment, which cools it down. (5). At higher relative humidity, evaporation slows down (5). The role of the porous medium is to provide stability to the inner vessel and fluid flow outward to the environment. A simplified model of evaporation through a porous medium can be considered, in which the air gaps between the pores can be considered as a network of capillaries with different cross-sections (Figure 7).
As a result, the pressures of the liquid in the sections with different cross-sections are different and this leads to the movement of the liquid. As a result, the liquid seeps through the porous clay pot to the outside, some of it condenses and returns back (Figure 8).

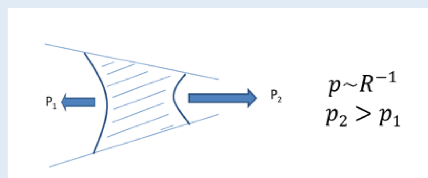

Figure 7. Capillary tube with different cross section

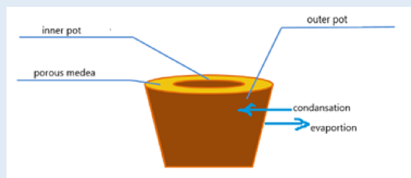

Figure 8. Pot system

Building a hypothesis
In reality, it is not possible with the knowledge of students of 8-9th grade to obtain a theoretical equation for the change of temperature with time (7). We neglect thermal energy diffusion and thermal conductivity of the pots and consider a simplified model. We assume that the amount of heat given off by the inner vessel is equal to the amount of heat required for evaporation:

$$r\, m_v = c\, m_p \Delta T$$

where r is latent heat of vaporization, mv is vapor mass, mp is mass of the inner pot, c is specific heat of the clay pot
.

Experimental setup

The container on top is covered with an insulated lid or a wet cloth, which further increases the efficiency of evaporation. The outer pot is completely in contact with the air, initially maximally isolated from air currents.
The porous media is sand, the liquid is water.

Conducting experiment/Collecting data
With several using a digital or alcohol thermometer, the data is recorded in a table and graphs of the change in temperature with time are constructed in different cases. In this way, students acquire skills in constructing graphs and working with data. When using a Fourier temperature sensor, the graphs are obtained directly and it remains only to analyze them. The pots are placed on a balance so that during the cooling process the change in mass is measured and the mass of evaporated water is determined. A graph of the change in the amount of evaporated water with time is constructed.

Data analysis
At first the temperature drops rapidly and gradually the cooling capacity decreases until a constant temperature is reached (Figure 10). This is due to a decrease in the amount of water that evaporates. A constant temperature does not mean that evaporation stops, but that an equilibrium has been reached between heat loss by evaporation and heating by the warmer ambient air.

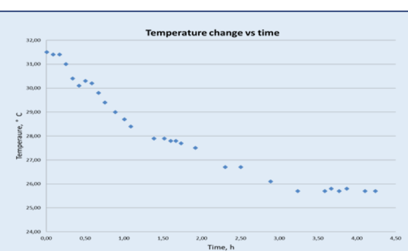

Figure 10. Dependence of temperature on time

Problem 4: When water drops are placed on a hot surface, they do not disappear, but bounce along the surface. The phenomenon is called the Leidenfrost effect. How drop height affects the length of droplet life? (Boiling phenomenon) (Effect Related Problem – IYPT 2017) (1)

Essential questions

- Under what conditions do the drops bounce and move on the surface?
- What would the surface temperature have to be for this to happen?
- How does the size of the drops affect the effect?
- What is the difference between evaporation and boiling?
- How do different surfaces affect the effect?
- Why do the drops bounce and move on the surface?
- Do they perform other types of movements?

Independent variables: droplet's volume; surface temperature
Dependent variables: droplet's lifetime; droplet's diameter

Qualitative explanation
Boiling is a complex process that goes through different stages, as the temperature of the bottom surface of a vessel containing a liquid increases (Figure 11a). At a sufficiently high surface temperature, some of the liquid in the drop evaporates as it falls, forming a cushion-like layer of gas (Figure 11b). Thus, the drop has no direct contact with the surface, which prevents rapid evaporation. The movement of the drop is due to the reduced friction with the surface due to the presence of the vapor layer. However, the drop slowly evaporates, its size decreases and after a while it disappears.

Experimental setup (Figure 12)
The temperature of the heated surface is measured with a thermocouple

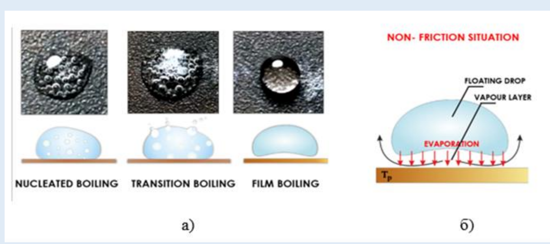

Figure 11 Different stages of boiling with increasing surface temperature

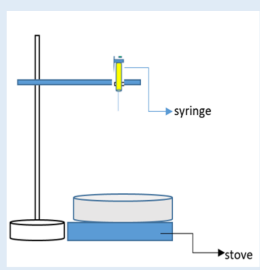

Figure 12 Experimental setup for studying the Leidenfrost effect

Conducting the experiment/Collecting data
Data is captured by video processing using special software (e.g. Tracker). Graphs are constructed for droplet lifetime versus size, drop height, and surface temperature. A graphical dependence of the drop sizes over time at different surface temperatures can also be constructed (Figure 13).

Data analysis
With larger droplet sizes, it exists longer. At a higher surface temperature, droplet sizes decrease faster, evaporate faster and live shorter. Students draw conclusions from the resulting graphs about the reasons why the drops have different lifetimes. Here, students can only make intuitive, qualitative predictions, they do not have sufficient knowledge to create an accurate theoretical model that can predict the behavior of the drop.

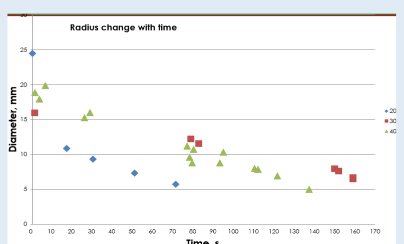

Figure 13. Radius change vs. time

Conclusions

As a result of the conducted experiments, students deepen their knowledge of transitions between aggregate states and better understand the essence of thermal phenomena. The presentation of each team's results consists of preparing a scientific report and presenting it to the class, with everyone being able to ask questions.
As a result, all students become familiar with the different types of transitions between states of matter and their applications.
The tasks are independent of each other, but at the same time they are united by a common theme. Thus, students can gain a new perspective on the unity and beauty of nature.
Through research tasks, experimental skills are formed and developed better, because they are absorbed meaningfully in the process of carrying out an activity.
Our observations show that the research approach is the best way for students to get closer to the work of scientists, to understand "how" science works and how the knowledge that is described in their textbooks is obtained.

Contact

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