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Title Inquiry Based Learning Approach in Teaching “Phase Transitions” for Experimental Skills Formation in Nearly Sixteen-Year-Old Students

Daniela Ivanova*a*,* and Prof. Zhelyazka Raykova, PhDb *b*

aHigh School of Mathematics Baba Tonka,
18 Ivan Vazov Str., Ruse, Bulgaria

bUniversity of Plovdiv "Paisii Hilendarski", Vice-dean of the Faculty of Physics and Technology, Head of the Department "Educational Technologies",
24 Tzar Asen Str, Plovdiv, Bulgaria

E-mail: d.ivanova@mg-babatonka.bg, janeraik@uni-plovdiv.bg

Inquiry-based learning is an important pedagogical approach through which teachers can introduce students to the world of science and scientific research. Learning through inquiry is an active learning that requires students to take responsibility, make decisions, cooperate and self-assess. The role of the teacher is crucial when using the research approach in physics lessons, so it is important that he knows the experience of other colleagues, their ideas and good practices. The teacher is the one who guides the students in conducting research, supplying equipment and processing experimental data. We are convinced that the best way for students to understand the essence of science is by doing their own scientific research. The report offers an idea for the formation of experimental skills by conducting inquiry on several specific problems related to thermal phenomena. Teams of students are formed, who choose to work on one of several proposed experimental tasks related to phase transitions. These tasks are borrowed from the International Young Physicists Tournament (IYPT) and are adapted to the conditions of the Bulgarian school and the respective curriculum. In solving them, students follow the steps of a scientific research - discuss the specific situation and formulate a scientific question, perform a physical experiment, collect and analyse results, draw conclusions that are confirmed experimentally. The proposed tasks are related to the following topics:

- Melting and solidification of crystalline and amorphous bodies (two tasks)
- Conditions on which the evaporation process depends (one task)
- The specifics of the boiling process (one task).

The formation of experimental skills occupies an important place in the physics curriculum for 8th grade Bulgarian schools. In recent years, there has been a tendency in the teaching of physics to develop more and more active practical and experimental skills. Teachers are looking for ways to do this both during classes and extracurricular activities, using modern interactive methods and approaches. The report describes the methods by which the learning process is organized and offers a proven technology of training on these physics topics.

Key words: inquiry-based approach, experimental skills, physics training, phase transitions.

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*Speaker

1. Introduction

Development of experimental skills has always been an important part of physics and natural science education. For a deep and meaningful scientific education, knowledge of facts alone has never been enough. Learning by doing and active learning are becoming increasingly important to education at a time when information is becoming more and more accessible. In recent decades, experiential skills have become increasingly important in education systems around the world. In light of the readily available information, the question is what one can do with it. Experiments are an integral part of science education at all levels of the education system for two main reasons. Firstly, for a deep understanding of scientific concepts and principles and secondly, the experimental skills learned while conducting experiments can be transferred and used in different areas of life. In recent years, the importance of experiments as a means of understanding scientific concepts is no longer a primary goal of education, the focus has shifted to the skills acquired in experimental work [17]. The best way to learn a variety of experimental skills while acquiring deeper knowledge in physics is to engage students in experimental research work. The inquiry approach is fostered in physics education in Bulgaria, although in the educational programs for the Bulgarian school it is not regulated. It is applied only sporadically due to lack of time during the lessons. The skills that can be developed through the research approach, however, are defined as expected outcomes in the Bulgarian physics curricula. For PISA, experimental skills are part of science knowledge, about 'how science works and how it doesn't work' and an important distinguishing feature of being scientifically literate. The assessment strategy PISA 2024 [14] addresses several important competences of young people - active use of scientific knowledge for decision-making, assessment of probability and risk, design of scientific research, scientific interpretation of data and evidence [14]. The use of inquiry tasks allows students to improve their understanding of academic content and scientific practices. It leads to the realization that science is driven by questions and that it is an open-ended process. Inquiry-based learning is challenging for both students and teachers because it requires background knowledge from students to analyze and interpret results. Usually, it is necessary to devote a significant amount of study time to the solution of the tasks - to plan, coordinate and manage the work of the teams, if it is necessary to make changes in the course of the work.

The purpose of this report is to share experience in applying a didactic model when using an 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 borrowed from the International Young Physicists Tournament (IYPT) [1] and the Flying Circus of Physics [2], but 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. As program outcomes, students are expected to be able to describe transitions between states of matter, calculate the amount of heat exchanged during transitions, and give examples of applications of transitions in nature, life and technology. Two laboratory exercises are planned - to determine the specific heat capacity of a solid body and the latent heat of melting of ice. In these laboratory classes students follow very detailed instructions that allow them to become familiar with equipment used to study thermal phenomena, gain experience measuring with different types of thermometers and calorimeters, and process collected data. These 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..

1. Experimental skills

Experimental skills are seen as part of scientific skills and scientific literacy, which includes problem and problem solving skills, certain mathematical skills, modeling processes, building and confirming hypotheses, conducting experiments, collecting and analyzing data [11]. According to R. Khaparde and A M Shaker, experimental skills can be divided into somewhat distinct categories [15]:

- Knowledge and theoretical understanding of physics - knowledge of laws, physical principles, understanding of theoretical models and relationships between physical quantities, understanding of the limitations of the theory.

- Psychomotor skills - skills for working with laboratory equipment and tools, setting up equipment, measuring skills, recording data, creating graphs, safe work skills.

- Mathematical skills – skills in using appropriate equations and solving methods, numerical calculations, graphing data, interpreting data, using appropriate software.

- Skills in using measurement information, methods and instruments - skills in using appropriate scientific methods, instruments and sensors, knowledge of resolution, instrument range and error calculation.

- Cognitive skills and data processing skills - skills for analysis, synthesis, building hypotheses, skills for observation and classification, skills for choosing procedures and making decisions, skills for asking questions and solving tasks.

- Skills for communication - skills for presenting data, for writing a scientific text, skills for speaking and making presentations.

Following the logic of scientific research, student research goes through several successive stages - building a model of the phenomenon; proposing a hypothesis; experiment design and conduct; analysis and evaluation of results; presentation of results [4, 6].

3. Didactic model

The scientific method dates back to the 16th-17th century, from the time of Galileo, Descartes and Newton. In recent decades, the question of mastering the methods of scientific knowledge has been the subject of numerous publications [9]. 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. Particular experimental skills are learned in the process of inquiry work, and the deepening and widening of knowledge about transitions can be assessed by having students answer the following questions at the end:

- ✓ What are the conditions for a phase transition to occur?
- ✓ What happens to the substance during the transition between the states?
- ✓ Is an amount of heat absorbed or radiate during the transition?

- ✓ What is the physical meaning of the concept of latent heat?
- ✓ How do the concepts sensible and latent heat differ?

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. The geologist Sir Edward Bullard says: “I think it is best to work for a bit at a subject before reading what other people have done. If you read other people’s papers for several days on end you get into their way of thinking and may miss ideas that would otherwise have occurred to you.” [10]. 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.

3.1 Essential questions

This may take about 15 minutes at the beginning of the first lesson. Students work in teams. Brain storming methods can be used. The questions should be about under what conditions the phenomenon occurs, what the independent variable parameters that can be changed are and how this changes the course of the processes. The questions "what," "how," "how much," and "why" should define the dependent and independent parameters. Thus, asking questions turns into an analysis of the problem. This develops cognitive skills for critical thinking.

3.2 Experimental setup design

This stage takes up the next 20 minutes or so of the first lesson. The observation of the phenomenon in the initial experiment, the questions asked, the determined independent and dependent parameters guide the students to ideas about what the experimental setup should be. They come up with ideas how to measure the relevant parameters, what instruments can be used. It is difficult for students to make and understand the experimental setup from start to the end. Therefore, the teacher can provide a list of materials and equipment to facilitate the students in the design of the experiment. When designing the experimental setup, the teacher should pay attention to the students that only one of the independent parameters should be changed in a given experiment. This will allow to draw a conclusion about its influence on the phenomenon. This stage of research work develops skills in the use of laboratory equipment and instruments.

3.3 Qualitative explanation of the phenomenon

At the end of the first lesson, students can try to build a quantitative explanation of the phenomenon. This develops skills for making connections between different parameters, for understanding physical concepts and principles and their correct use. During this stage, students can fill in missing knowledge, read additional information from teacher-provided printed materials and online resources. With this stage of the research work, the second lesson of the classes begins.

3.4 Building a hypothesis

It is difficult for students aged 15-16 to build an accurate quantitative theoretical model of the real physical phenomena under consideration. Often the explanations go beyond the school curriculum, requiring a lot of additional physical knowledge and mathematical skills. Trying to make a theoretical model of the phenomena, the students, with the help of the teacher, make a simplified model of the phenomena. In this way, student acquire skills to analyze the conditions for the applicability of a given theoretical model and so critical thinking skills. „ Hypothesis is not a question, it is a testable statement” [3].

3.5 Conducting the experiments

This is the longest stage of the inquiry work. The selected research tasks are related to relatively slow phenomena. During the experiments, the students acquire skills for working with various devices and tools, for setting up the devices, changing the scope of the scale. The teacher directs the students' attention to the controlled conditions of conducting the experiment, so that there is repeatability of the measurements.

3.6 Collecting and organizing data

This is the beginning of the third lesson. In many cases, the data is captured from video, often recorded with a high-speed camera. Mobile phones already have such capabilities. Thus, students acquire skills for working with software (e.g. Tracker) that allows analyzing the video frame by frame and capturing the necessary data. Mathematical skills are developed for calculating and presenting data organized in tables.

3.7 Data Analysis

Here, the important skill that students acquire is the presentation of data on graphs and the ability to interpret them. Thus, critical thinking skills related to the interpretation of how far the resulting graph has real physical meaning can be developed. Comparing the expected and obtained results develops logical thinking skills and leads to making sense of the phenomena.

For successful work in the implementation of inquiry tasks, it is important to have a clear time schedule, so that students know what they are doing during the individual stages of the task.

4. Application of the model

Four independent tasks are considered.

<u>4.1. Problem 1:</u> A metal wire with weights attached to both ends is placed on top of a block of ice [1]. The wire can pass through the ice without cutting it. Investigate the phenomenon. (Regelation Phenomenon) (IYPT 2010)

It is very popular task that has been known since the 19th century, when it was first described by Bottomley [16]. There are videos available on the internet that students could view. At home, they can conduct a preliminary experiment using water bottles as weights.

<u>Essential questions</u>

- ✓ 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	Dependent variables
diameter of wire	time
thermal conductivity/material	velocity
mass of weights	

<u>*Qualitative explanation*</u>

The water is interesting substance for many reasons. The solid phase of water has a lower density than the liquid phase, and as a result, as the pressure increases, the melting temperature decreases. 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. When the wire passes, the pressure decreases behind it, but the temperature is below 0°C and the water freezes again. In this way, the wire can pass through the ice without splitting it in two. This phenomenon sounds familiar to students because the same effect is responsible for ice skating.

<u>*Experimental setup*</u>

The ice is placed on a wooden stand. Weights are placed on both sides of the wire. Camera is placed in front of the ice cube to record the penetration of wire in the cube.

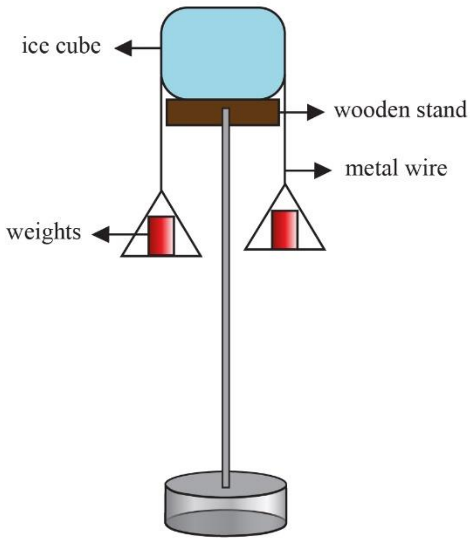

Figure 1. Experimental setup

<u>*Hypothesis Building/Quantitative Explanation*</u>

The pressure exerted by the metal wire is defined as: $p = \frac{mg}{Ld}$,
where m is the mass of the weights, d is the diameter of the wire, L is the side of the cube along which the wire is passed (Figure 2). The pressure is higher with a thinner wire and a greater mass of the weights, so the velocity of the penetration is bigger

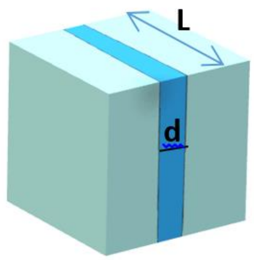

Figure 2. Ice cube

Conducting the experiments/Collecting the data

Since the phenomenon proceeds relatively slowly, several experiments can be carried out in parallel, for example with three different ice cubes and the same wire. Then again at the same time - three identical ice cubes with three different wire diameters. Finally - 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. This allows several measurements to be taken in parallel. A line is placed next to the cube to determine the scale of the photo and the displacement for given time interval is determined from the photos.

Data analysis

The data is organized in tables. 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. It turns out that if the wire is thick (e.g. on the order of 0.5 mm) at large cube dimensions (10 cm) the effect is not observed (Figure 3)

Figure 3. The hardening effect behind the wire is not observed with the thicker wire

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

Essential questions

- ✓ What shapes are obtained? How many types of shapes are obtained? 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 solidification process work?
- ✓ Is there a difference between paraffin drops and wax drops?
- ✓ Does the depth of the water they fall into matter?

Independent variables	Dependent variables
drop height	droplet forms
water temperature	
paraffin temperature	

Qualitative explanation

The drop falling into a bath of liquid has been repeatedly studied [12, 8]. 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 5a). As the drop enters the water, a cavity is formed (Figure 5b). It quickly collapses and the pressure difference ejects some of the water in the form of a jet called the Worthington jet (figure 5c).

a) b) c)

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

The difference between any other drop of liquid falling into a bath of liquid and the drop of paraffin is that when the latter falls, after contact with the surface of the water, it begins to cool and harden. After the ejection of the jet, practically no second drop appears, and the solidified paraffin remains floating on the surface of the water. When falling from a low height, the cavity is very small and this forms shapes such as ellipsoids [13]. When falling from a greater height, a larger cavity is formed and upon solidification, mushroom-like shapes are formed [13]. 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.

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.

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 in a tray (Figure 6).

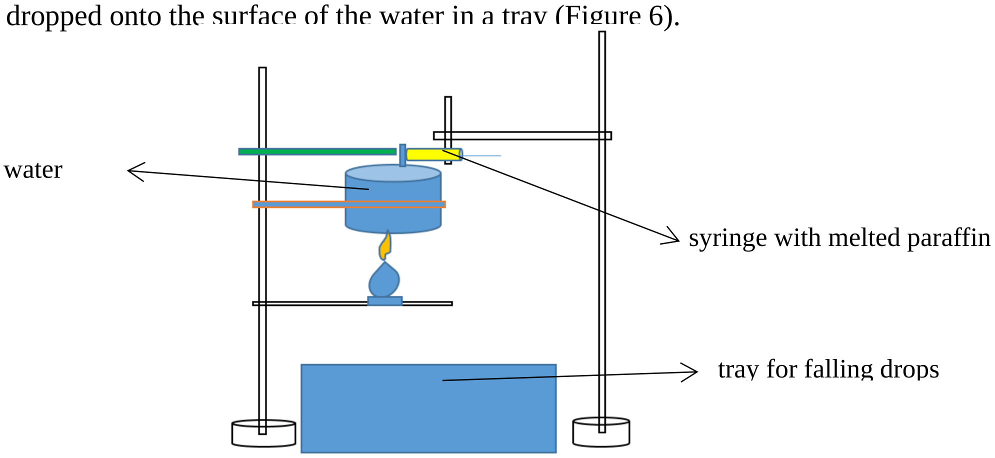

Figure 6. Experimental setup for obtaining paraffin drops

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. They infer the reasons why the solidified drops take this shape. Since the paraffin from the candle does not have a certain melting point, when it falls into the water and gives off a certain amount of heat to the water, it gradually solidifies, which allows these shapes to be obtained (Figure 7).

a) paraffin ellipsoids b) paraffin flakes

Figure 7. Examples of obtained different forms of solidified paraffin drops

4.3. Problem3: ***A simple evaporative cooling system consists of two ceramic pots of different diameters placed inside each other [1]. 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)

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	Dependent variables
diameter of inner pot	temperature of inner pot
diameter of outer pot	time to lower the temperature
width of the porous layer	mass of vaporized liquid

Qualitative explanation

The reason for cooling the inner vessel is evaporative cooling. The latent heat required for evaporation is obtained from the environment, which cools it down. [5]. The level of evaporation depends on the temperature and humidity of the surrounding air. More active evaporation occurs at a higher temperature (above 25°C) and lower humidity (up to 40%). 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 8).

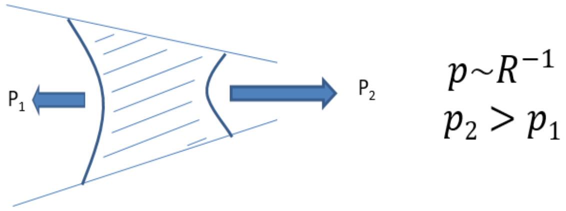

Figure 8. Capillary tube with different cross section

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 9). To avoid moisture entering the inner vessel, it is glazed

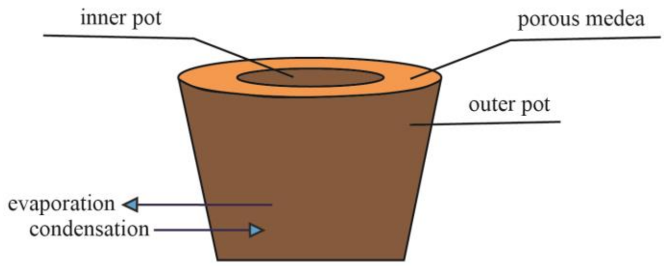

Figure 9. Pot system

.*Experimental setup*

The container on top is covered with an insulated lid or a wet cloth, which further increases the efficiency of evaporation. The thermometer is put in the inner pot. The outer pot is completely in contact with the air (Figure 10), initially maximally isolated from air currents. In order to be able to carry out the experiment in the classroom, the porous substance is only sand and the liquid is water.

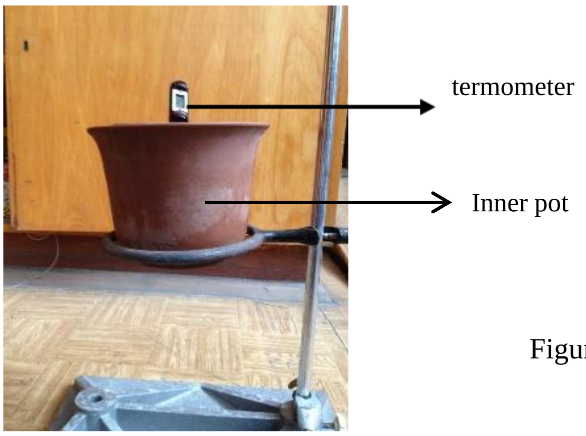

Figure 10. Experimental setup

Building a hypothesis

In reality, it is not possible with the knowledge of students of 8-9 th grade to obtain a theoretical equation for the change of temperature with time [9]. 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, m_p is mass of the inner pot, c is specific heat of the clay pot.

Conducting experiment/Collecting data

With several different pot diameters, the change in temperature over time is measured. When 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 11). 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.

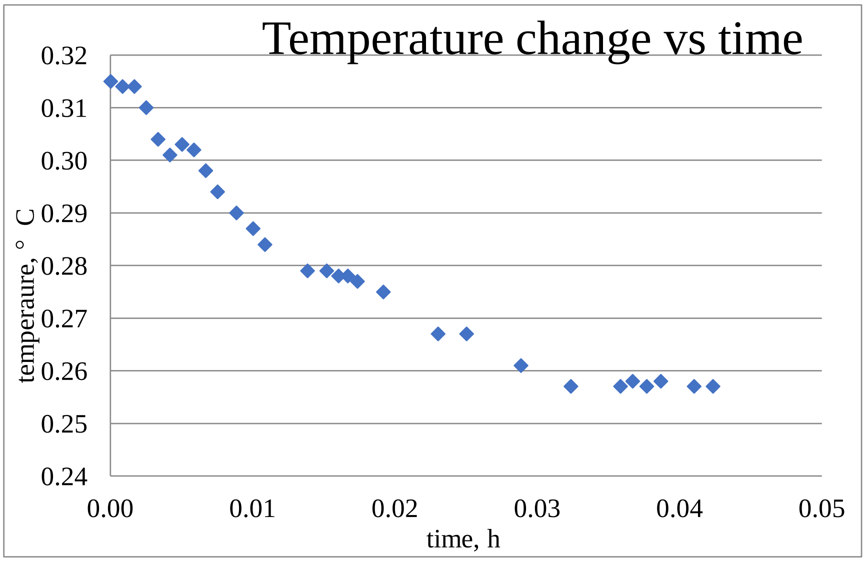

Figure 11. Temperature change as a function of time

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

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?
- ✓ How do different temperatures of the surface affect the changes in drop radius?
- ✓ Why do the drops bounce and move on the surface?
- ✓ Do they perform other types of movements?

Independent variables		Dependent variables
droplet's volume		droplet's lifetime
surface temperature		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. The Leidenfrost effect occurs when a drop falls on a very hot surface.

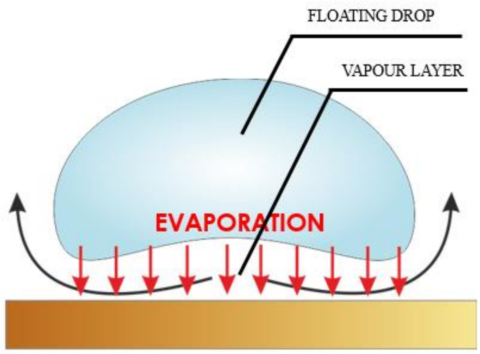

Figure 12 Leidenfrost drop.

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 12) Thus, the drop has no direct contact with the surface, which prevents boiling. The drop slowly evaporates, its size decreases and after a while it disappears. The movement of the drop is due to the reduced friction with the surface due to the presence of the vapor layer. The form of the drop is determined by surface tension, pressure of the vapor layer during the evaporation process and gravity. Surface tension is dominant for smaller drops with radius approximately equal to capillary length $l_c = \sqrt{\frac{\sigma}{\rho g}}$ (around 2,7 mm for water). Large drops are flatter, for gravitation is dominant. During the evaporation and reduction of the drop sizes, the flat ones become spherical. When a drop falls on a hot surface, the vapor layer formed under it leads to an increase in the size of the drop compared to falling on a cold surface.

Experimental setup

The drops are obtained through a syringe and placed on a surface heated on the stove (Figure 13). The temperature of the heated surface is measured with a thermocouple.

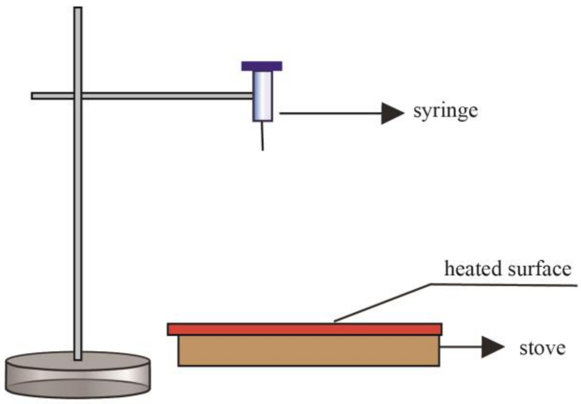

Figure 13. Experimental setup for studying the Leidenfrost effect

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. An example of a graphic for changing of droplet radius for three different temperatures of the surface 200ºC, 300ºC and 400ºC is shown below (Figure 14).

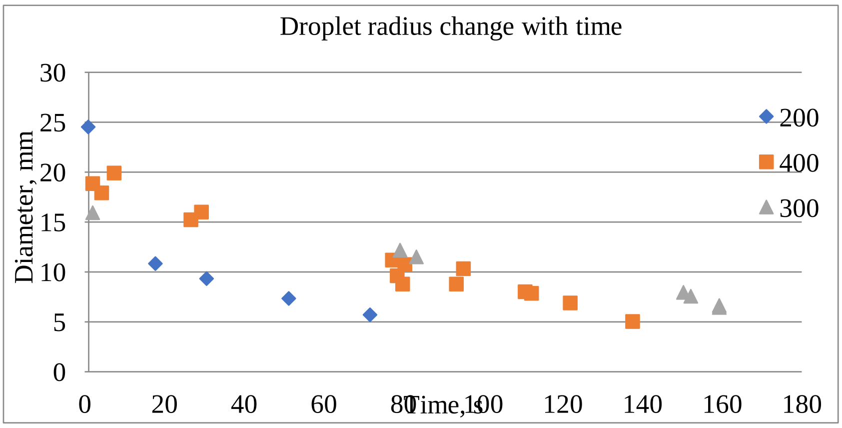

Figure 14. Radius change vs. time

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.

5. Conclusion

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 presentation 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. This kind of research work is associated with serious preparation on the part of the teacher. Conducting such research is associated with a lot of study time. But at least once a year it's worth doing, regardless of the enormous challenges ahead. 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.

References

[1] https://archive.iypt.org/ [20.08.2022]

[2] http://www.flyingcircusofphysics.com/ [20.08.2022].

[3] https://www.storyboardthat.com/articles/e/experimental-design [20.08.2022]

[4] https://www.coursera.org/lecture/teachingscience/identifying-and-fostering-students-experimental-competences-PQSe3 [20.08.2022]

[5] https://en.wikipedia.org/wiki/Evaporation [20.08.2022]

[6] Райкова, Ж, *Съвременни тенденции в обучението по физика*, Университетско издателство „Паисий Хилендарски, (2019)

[7] A. Chemin, V. Dit Vehel, A.Caussarieu, N.Plihon, N. Taberlet, *Heat transfer and evaporative cooling in the function of pot-in-pot Coolers*, American Journal of Physics , **86**, 206 , (2018) [doi.org/10.1119/1.5016041]

[8] A. L. Yarin, *Drop Impact Dynamics: Splashing, Spreading, Receding, Bouncing*, Annu. Rev. Fluid Mech. **38**:159–92, (2006) [doi: 10.1146/annurev.fluid. 38.050304.092144]

[9] B. Crawford, *Embracing the Essence of Inquiry*: New Roles for Science Teachers, Journal of Research in Science Teaching, Vol. **37**, NO. 9, PP. 916± 937, (2000)

[10] C. Cooke. *An introduction to experimental physics*, UCL Press, (1996)

[11] D. Klahr, C. Zimmerman, and. B.J. Matlen, , *Improving Students' Scientific Thinking*, The Cambridge handbook of cognition and education (pp. 67–99). Cambridge University Press,(2019), [https://psycnet.apa.org/doi/10.1017/9781108235631.005]

[12] F. Minami, K. Hasegawa,, *Cavity and jet formation after immiscible droplet impact into deep water pool*, Physics of Fluids **34**(3):033315, (2022)

[13] N. Shilpa Beesabathuni, Seth E. Lindberg, Marco Caggioni, Chris Wesner, Amy Q. Shen, *Getting in shape: Molten wax drop deformation and solidification at an immiscible liquid interface*, Journal of Colloid and Interface Science **445** ,231–242, (2015) [https://doi.org/10.1016/j.jcis.2014.12.089]

[14] PISA 2024 *Strategic directions and visions for science*

[15] R. Khaparde. A.M. Shaker, *What are experimental skills? A study with in-service teachers*, J. Phys.: Conf. Ser. 1512 12022, (2020) [doi:10.1088/1742-6596/1512/1/012022]

[16] S. C.Colbeck, , Pressure melting and ice skating, American Journal of Physics, **63**, 888 (1995); [doi: 10.1119/1.18028]

[17] V.M. Talisayon, *Development of Scientific skills and values in Physics Education*, (2008) https://web.phys.ksu.edu/icpe/publications/teach2/talisayon.pdf