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Use of Demonstration Experiments in Teaching Molecular Physics in General Secondary Schools

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ABSTRACT

Background. The topics of the molecular physics department study the main fundamental demonstration experiments that confirm the existence of atoms and molecules and their movement.

Purpose. These experiments make it possible to determine physical quantities such as the size, mass, speed and concentration of atoms and molecules. The existence of atoms and molecules is no longer just a hypothesis, but is concrete evidence confirmed by the experimental and practical activities of people.

Method. In school conditions, it is an important educational task to provide new knowledge using experimental methods with the help of available tools and equipment to form these facts in the minds of students.

Results. Also, experiments are important for a deeper explanation of the theory in topics such as hydrostatic pressure and pressure transmission in liquids.

Conclusion. The article deepens the theoretical foundations of molecular physics and hydrostatic pressure, highlights the role of demonstration and laboratory experiments in teaching these topics, and provides information about modern experiments.

KEYWORDS

Demonstration Experiment, Interactive Method, Virtual Laboratory

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INTRODUCTION

The purpose of the Introduction is is to stimulate the reader's interest and to provide pertinent background information necessary to understand the rest of the paper. You must summarize the problem to be addressed, give background on the subject, discuss previous research on the topic, and explain exactly what the paper will address, why, and how (Klautau dkk., 2021; Ward & Tveitereid, 2022). Please explore in more words the Demonstration experiments are of great didactic importance in physics education as a means of connecting theory with practice. However, in recent years, the use of such demonstration experiments in the process of explaining new topics in school lessons has been decreasing. As a result, students' interest in physics is decreasing.

In the educational process, information perceived visually and through the senses makes a stronger and more lasting impression on students (Baikady dkk., 2022; Štambuk dkk., 2023). Therefore, it is necessary to show experiments on the subject as much as possible in each lesson or to give students small practical exercises.

Demonstration experiments visually demonstrate physical phenomena, help to more easily understand abstract theoretical concepts, and increase students' interest and motivation in science. Studies have shown that experiments and demonstrations used in physics lessons significantly improve students' understanding of the subject and their internal motivation. Demonstration experiments perform several didactic functions in the educational process: they explain new knowledge in *an illustrative (demonstrative) way, have* a motivational value (attract students' attention), perform a cognitive function (show abstract ideas in concrete examples) , and sometimes also play a control or confirmation role (provide practical confirmation of the theory). At the same time, experiments serve to form scientific and research equestrian competencies in students: they develop the skills of asking questions, observing, guessing , and drawing conclusions.

Below, the theoretical foundations of the topics of molecular physics and hydrostatic pressure, as well as demonstration and interactive experiments that can be used in their teaching, are examined using examples.

Molecular physics and molecular-kinetic theory

Molecular physics is based on the idea that all matter is composed of tiny particles—atoms and molecules—that is, the molecular-kinetic theory. According to this theory, atoms and molecules are in constant motion and their motion is chaotic (Baikady dkk., 2022; Z. Wilson, 2021). Depending on the aggregate state of matter, the motion and interaction of particles manifest themselves differently: for example, in gases, molecules fly freely between collisions, in liquids they move at relatively close distances, and in solids, atoms vibrate in a crystal lattice. The fact that molecules and atoms really exist and are in constant motion has been proven by numerous scientific and practical evidence.

the 19th century, including the observation of **Brownian motion by Robert Brown** (1827). Brown observed dust particles suspended in water under a microscope and noticed their constant, erratic motion (Casiano, 2021; Gobena dkk., 2024). Albert Einstein later gave a theoretical explanation for this phenomenon in 1905: the particles visible under the microscope were moving due to the collisions of invisible water molecules. The theoretical model of Brownian motion became convincing evidence for the existence of atoms and molecules, and this hypothesis was experimentally confirmed in 1908 by the French scientist Jean Perrin.

Jean Perrin quantitatively studied the Brownian motion of colloidal particles and determined the Bolesmann constant and Avogadro's number of molecules. For this work, he was awarded the Nobel Prize in 1926.

A number of phenomena in everyday life also confirm that matter is composed of tiny particles and that they are in constant motion (Brown dkk., 2023; Soerensen dkk., 2024). For example, the smell of perfume sprayed into a room spreads throughout the room after a while, or a drop of ink dropped into a glass of water mixes evenly throughout the entire volume over time. The spread of odors in the air or the phenomenon of diffusion in a liquid is a simple confirmation of the constant motion of liquid and gas particles. Increasing the temperature accelerates this motion - for example, paint mixes faster in hot water - which shows that the kinetic energy of molecules is related to temperature.

One of the important rules of molecular-kinetic theory - the concept **of pressure** - is also explained in micromodels (Mo & Chan, 2021; Swart dkk., 2021). The pressure exerted by gases on the walls of a container arises from the collision of molecules with the walls. In liquids and gases, the transmission of external pressure is also carried out through the particles that make up them. Since the particles are in constant motion, for example, when external pressure is applied to the liquid inside the container, this pressure is distributed evenly by the particles moving in the intervening space (Hausermann & Adomako, 2022; Swart dkk., 2021). In other words, liquids and gases transmit the external pressure applied to them in all directions unchanged.

This physical phenomenon was studied by Blaise Pascal in the 17th century and is known as **Pascal's law** (Semma dkk., 2024; Whitman, 2021): when an external pressure is applied to a liquid or gas, it is transmitted by the same amount in all directions . From a molecular point of view, the transmission of pressure is explained by the fact that liquid and gas molecules move freely, distributing the effect of the pressure between the particles.

Hydrostatic pressure theory

The pressure of liquids at rest – hydrostatic pressure – is the result of the weight of a column of liquid. If a liquid is stationary in a container filled with air (without external pressure), the pressure at a certain depth inside it depends only on the height of the column of liquid above that point (Perkinson, 2021; Rivera dkk., 2021). The quantitative value of hydrostatic pressure is determined by the following expression:

$$P = \rho g h$$

where is $\rho$the density of the liquid, *g* is the acceleration of gravity, and h is the vertical distance (m) from the surface of the liquid to the surface of the liquid. This formula shows that, given the density of the liquid and the gravitational constant, the pressure depends only on the height of the liquid column (Mathur dkk., 2022). This means that the shape or width of the container does not affect the hydrostatic pressure - only the height determines how much liquid mass falls to the point below. This phenomenon is sometimes called **the hydrostatic paradox** (Hossain & Ahmad, 2024; Johnson, 2022): the same pressure is created at the bottom of a liquid column of the same height in a wide container or a thin tube.

The concept of hydrostatic pressure was first proven experimentally by 17th- century scientists. In particular, in 1648, the French scientist **Blaise Pascal** conducted the famous barrel experiment. He filled a wooden barrel with water and attached a long, thin glass tube to the top of the barrel. When the tube was filled with water, the walls of the barrel burst under the great pressure (Schultz & Garbe, 2023; Zhao dkk., 2024). This experiment amazed Pascal's contemporaries by showing that even a small volume of water (in the tube) could create enormous pressure in the barrel. The scientific conclusion of the experiment was that the pressure of the liquid was confirmed to depend on the height of the column.

Demonstration and laboratory experiments

Real-world examples are very important for deepening and reinforcing theoretical knowledge. Below are a number of demonstration experiments that can be used in teaching the topics of molecular physics and hydrostatic pressure. These experiments can be demonstrated in a classroom setting by the teacher or, in some cases, the students themselves can be involved. After each experiment, the theoretical understanding is reinforced through discussion .

Molecular physics experiments

Observing Brownian motion (microscope experiment). To directly observe the random motion of molecules, Brownian motion can be demonstrated using a microscope (Gokturk, 2024; E. Wilson & Flanagan, 2022). To do this, very small particles (for example, pollen or smoke) are placed in a drop of water and examined under a microscope. As a result, it is noticeable that the particles of the suspension in the liquid are moving continuously and unevenly (along a zigzag trajectory). It is necessary to explain that this phenomenon arises from the constant and random collisions of invisible molecules in the liquid (Rihter & Žiberna, 2022; E. Wilson & Flanagan, 2022). **The Brownian motion experiment** provides students with clear evidence proving the existence and movement of molecules. As a scientific explanation, it is emphasized that the constant oscillation of particles arises from the imbalance of the forces of the liquid molecules around them.

this experiment requires complex white equipment (a microscope), it arouses strong interest in students and reveals the importance of theoretical knowledge.

Demonstrate the phenomenon of diffusion in an experiment. An easy and safe diffusion experiment helps to understand molecular motion. For example, a fragrant gas (perfume or ether) is sprayed into the air in one corner of the classroom and students are asked to observe when they begin to smell it. After a certain time, the same smell spreads throughout the room - this means that the gas molecules are moving irregularly and mixing in the air. You can also take a laboratory beaker of warm water and carefully add a few drops of potassium permanganate ($KMnO_4$) solution to it. Even if the water is not stirred, within a few minutes the dark purple permanganate will spread throughout the beaker and diffuse (Agbawodikeizu dkk., 2024; Szabó dkk., 2022). This experiment shows that the particles of a liquid are also in motion and that over time, substances diffuse from a higher concentration to a lower concentration. If we carry out the same experiment in parallel with a glass of cold water and a glass of hot water, we can see that diffusion occurs faster in hot water. This observation shows that temperature affects the movement of molecules (molecules move faster in hotter conditions). This explains to students the relationship between thermal energy and the kinetic energy of a molecule.

Experiments on hydrostatic pressure

Pascal's Barrel Experiment (Hydrostatic Paradox). Although Pascal's 17th-century experiment is difficult to replicate in a school setting, its concept can be demonstrated with simpler means.

Below is a picture of Pascal's famous "barrel and tube" experiment (Figure 1). When the scientist filled a long tube with water and connected it to the barrel, the barrel burst (hydrostatic paradox) (Jacomuzzi & Milani Marin, 2023; Rodríguez dkk., 2021). This experiment shows that the pressure of a liquid does not depend on the shape of the container, but on the height of the liquid column. In school conditions, hydrostatic pressure can be felt using a small container and a tube. For example, we use a thin glass tube connected to a tall flask or tank. When the tube and the container are filled with water, the pressure exerted on the bottom of the container is significant, even though the water column in the thin tube is high.

Figure 1. Pascal's experiment

This container installed at the bottom rubber curtain rod determination possible (Blaauw dkk., 2024; van der Westhuizen dkk., 2021): if curtain stretched If it comes out, press the available. This thus, Pascal law and hydrostatic wire concept historical experience in the spirit animated k is displayed (Flanagan & Wilson, 2024). Students will understand the role of the height of the liquid column in this.

Experiment with a perforated glass bottle with water. The dependence of hydrostatic pressure on height can be demonstrated using a simple **perforated bottle** (Figure 2). To do this, prepare a plastic bottle (for example, a 1. 5 liter bottle) and drill 3 small holes vertically along its side wall at different heights. Temporarily close the holes tightly and fill the bottle with water. Then close the mouth of the bottle and open the holes simultaneously.

Figure 2. Experiment with a glass container pierced with water

Then, water shoots out of all three holes in the bottle, but at different distances. The water that shoots out of the lowest hole (closer to the bottom of the container) sprays a little farther, while the water that shoots out of the higher hole does not go as far. This phenomenon shows that the water pressure is greater near the bottom, and the pressure decreases as it rises. To make the experiment more interesting, you can ask the students in advance: "Which hole will the water shoot the farthest?" and write down their guesses. Then, by observing and discussing the results together, explain that hydrostatic pressure is inversely proportional to height. Simply put, the higher the column of liquid, the greater the pressure at the bottom.

The pressure inside a liquid is equal in all directions. Another visual demonstration of Pascal's law is to use a rubber balloon (or cellophane bag). For example, fill a regular children's balloon with water and poke small holes in it at various points (Figure 3).

Figure 3. Experiment demonstrating hydrostatic pressure

When conducting the experiment, the holes must be very small in diameter so that the water poured into the balloon does not leak out (or, if it is a package, they are pierced with a needle). Now we close the mouth of the balloon tightly and begin to squeeze it. When we apply pressure with our hands, the pressure of the liquid inside the balloon increases, and as a result, water begins to shoot out from the holes in all directions. This experiment practically confirms Pascal's law: the external pressure applied to the liquid is the same in all directions of the liquid. Also, this experiment can explain the principle of operation of devices such as a hydraulic press when an external force is applied to an incompressible liquid. For example, hydraulic brakes in cars and lifting jacks are based on the ability of the liquid to transmit pressure.

All of the above experiments help students to understand the pressure properties of liquids and gases through simple observation. In school settings, if possible, the experiments can be demonstrated using real equipment or, alternatively, using visual aids (for example, animation or video experiments). It is important to connect each experiment with theoretical knowledge and to increase the thinking activity of students by asking them questions.

CONCLUSION

In the school physics course, demonstration experiments and practical exercises are of great help in teaching theoretical concepts to students in topics such as molecular physics and hydrostatic pressure. As mentioned above, if theoretical ideas such as the existence of atoms and molecules, their motion, and the mechanism of pressure are not demonstrated in real life through experiments, abstract formulas begin to acquire meaning for the student. Also, experiments increase the interest of students in the lesson, encourage them to be active, and enliven the lesson process. Integrating theory and practice in physics lessons – that is, demonstrating formulas and laws not only in writing, but also through live experiments – puts students at the center of the learning process. Such an approach not only consolidates knowledge, but also instills a positive attitude and deep interest in physics in young people. The task of teachers is to carefully plan these methods and creatively apply them to the content of the lesson. Through the combination of innovative and traditional methods , the effectiveness of physics teaching is increased and the opportunities for students to form a scientific worldview are expanded.

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