COMPETENCY ASSESSMENT OF HIGH-SCHOOLSTUDENTS IN "FUNDAMENTALS OF THERMODYNAMICS"

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Abstract

The presented work examines the importance of studying thermodynamics in the school curriculum. The theoretical section highlights the fundamental laws of thermodynamics, their interpretation, and their influence on shaping students' scientific worldview. Examples of the practical application of thermodynamic principles in daily life, science, technology, and ecology are described. The role of thermodynamics in developing critical thinking, analytical skills, and fostering interest in science is emphasized. Particular attention is given to the research aspect related to assessing the competencies of high school students in the module "Fundamental Concepts of Thermodynamics. The Molecular Kinetic Theory of the Ideal Gas." As part of the study, a test (Annex 1) was developed to evaluate the students' understanding of key thermodynamic concepts and their connection to the molecular kinetic theory. The work underscores the interdisciplinary significance of thermodynamics, its contribution to fostering ecological literacy, and its role in understanding the global challenges faced by modern society.

Key words: laws of thermodynamics, scientific understanding, practical application, students' competencies.

Theoretical Framework

Thermodynamics is a branch of physics that studies the laws governing the interactions between heat, work, and energy. It encompasses fundamental principles that define the behavior of systems during various physical and chemical processes. Studying thermodynamics in school is essential not only for shaping students' scientific worldview but also for its practical applications in daily life, science, and technology. *"Thermodynamics plays a critical role in forming a scientific worldview as it unites the understanding of macro- and micro-processes, describing the behavior of physical systems both on a particle level and on a global scale"* [1].

1. Fundamentals of Thermodynamics

Thermodynamics is built upon several key laws that explain how energy is transformed and transferred within different systems. Its four fundamental laws form the foundation [2]:

1. **The Zeroth Law of Thermodynamics**: Establishes the concept of temperature and thermal equilibrium.
2. **The First Law of Thermodynamics**: Reflects the principle of energy conservation, stating that energy cannot be created or destroyed but only transformed from one form to another.
3. **The Second Law of Thermodynamics**: Asserts that in any closed process, entropy (the measure of disorder) cannot decrease.
4. **The Third Law of Thermodynamics**: States that absolute zero, where entropy theoretically becomes zero, cannot be achieved.

These laws form the basis for understanding thermodynamic processes observable in everyday life.

2. Applications of Thermodynamics in Daily Life

Studying thermodynamics in schools helps students recognize its relevance in their daily lives. *"Thermodynamics teaches us to apply physical laws to solve practical problems, from choosing household appliances to designing energy-efficient buildings"* [3]. Examples include:

- **Cooking**: Thermodynamic principles apply to food preparation. For instance, boiling water involves using heat to increase temperature, altering water's internal energy per the First Law of Thermodynamics.
- **Climate**: Understanding thermodynamic processes sheds light on weather phenomena, such as cloud formation and condensation cycles.
- **Devices and Mechanisms**: Automobiles, refrigerators, and air conditioners function based on thermodynamic cycles. For example, a refrigerator uses the Second Law of Thermodynamics to transfer heat from inside to the environment, keeping food cool.

- **Energy Systems**: Thermodynamics underpins the functioning of thermal and nuclear power plants. Students learn how energy transforms and how resource usage can be optimized to minimize losses.

3. Scientific Research and Technology

Thermodynamics plays a significant role in research and technological advancements:

- **Space Technology**: Understanding thermodynamics is crucial in designing spacecraft and satellites, ensuring life support systems function effectively in microgravity and extreme environments.
- **Medical Technology**: It aids in developing medical techniques like thermal therapy and cryotherapy, and in studying metabolic processes in living organisms.
- **Ecology**: Thermodynamics is vital for assessing the ecological impact of energy use and developing sustainable technologies. *"Ecosystems are open, non-equilibrium thermodynamic systems that exchange energy and matter with their environment, decreasing internal entropy while increasing it externally, in line with thermodynamic laws"* [4].

4. Education and Critical Thinking

Studying thermodynamics nurtures critical thinking and analytical skills. *"Learning thermodynamics fosters the ability to analyze complex systems and understand cause-and-effect relationships"* [5]. Students learn to:

- **Solve Problems**: Thermodynamics requires applying mathematical and physical concepts to real-world problems, developing versatile analytical skills.
- **Understand System Interactions**: It demonstrates how systems interact and how changes in one variable influence others, offering transferable insights into other scientific disciplines.
- **Cultivate Interest in Science**: Exploring thermodynamics can inspire students to pursue physics and engineering, understanding science's role in shaping the world.

Research Question

Evaluation of high school students' competencies in the module "Fundamental Concepts of Thermodynamics and the Molecular Kinetic Theory of an Ideal Gas."

Research Methodology

To assess students' competencies (11th grade), a module-based test on *"Fundamental Concepts of Thermodynamics and the Molecular Kinetic Theory of an Ideal Gas"* was designed (Annex No. 1).

The discipline was administered in accordance with the National Curriculum, edition 2019 [6] and:

- Annual Schedule of Physics Hours for Grade 11 (Humanities Profile)
- Physics Textbook, Grade 11, 3rd Edition, 2020, Ştiinţa, authors Mihai Marinciuc and Spiridon Rusu [7], [8].

Table 2. Annual Schedule of Physics Hours for Grade 11 (Humanities Profile)

Unități de conținut	Numărul de ore	Numărul de ore			
		Recapitulare	Predare-învățare	Evaluare	Lucrări de laborator
Semestrul I					
I. Noțiuni termodinamice de bază. Teoria cinetico-moleculară a gazului ideal	**13**	2	9	1	1
II. Bazele termodinamicii	**13**	2	10	1	
III. Electrostatica	**4**		4		
Total (semestrul I)	**30**	**4**	**23**	**2**	**1**
Semestrul II					
III. Electrostatica	**11**	2	8	1	
IV. Electrocinetică	**16**	2	12	1	1
V. Curentul electric în diferite medii	**9**	2	6	1	
Recapitulare finală	**2**	2			
Total (semestrul II)	**38**	**8**	**26**	**3**	**1**
Total	**68**	**12**	**49**	**5**	**2**

Analyzing the students' work yielded the following data (see Figure 1):

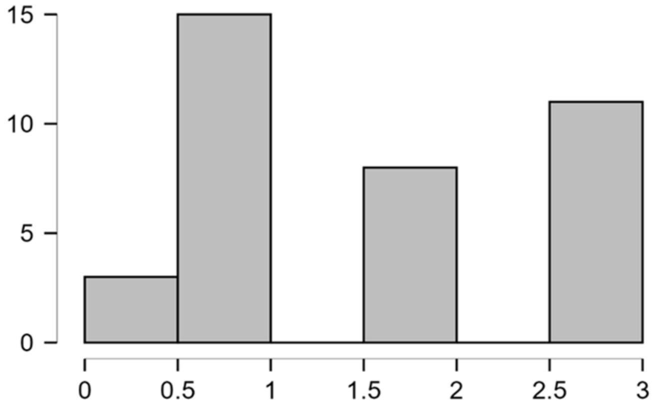

Fig. 2. Results for Item 1 *(Define the concept of an isochoric process and provide an example).*

As we can see from the Fig. 1, only 18 out of 37 students were able to correctly define the isothermal process and provide an example, which points to several potential issues:

1. Misunderstanding of the isothermal process itself: Students confuse the terms and are unable to precisely define its conditions.
2. Lack of examples for understanding: It’s possible that students do not connect theory with practical examples, which makes it harder for them to grasp the concept.
3. Need for review of thermodynamic processes: Mistakes might indicate that thermodynamic processes, such as isothermal, isobaric, and isochoric, require more in-depth study and repetition so that students can clearly distinguish between them.

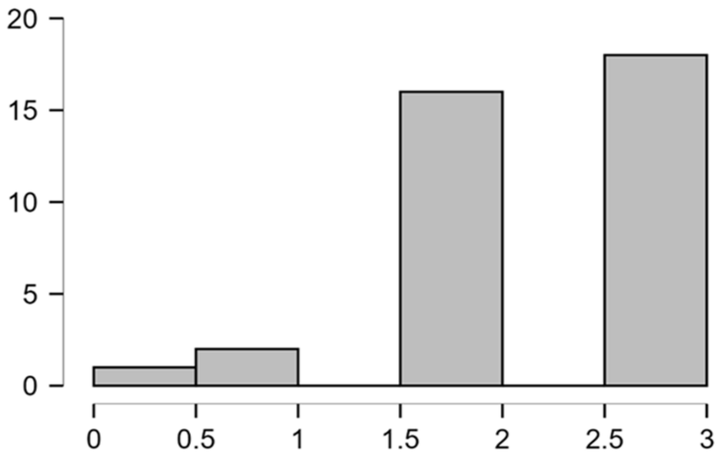

Fig. 2 Results for Item 2 *(Fill in the missing word)*

According to Fig. 2, most of the students, 34 out of 37, correctly completed the task, which is about 92%. This indicates that the basic concepts of the isochoric process have been understood by the majority.

In the Fig. 3 the understanding of physical quantities is presented. We obtained that 32 out of 37 students, or 86.4%, successfully completed the task to match physical quantities with their symbols and units of measurement.

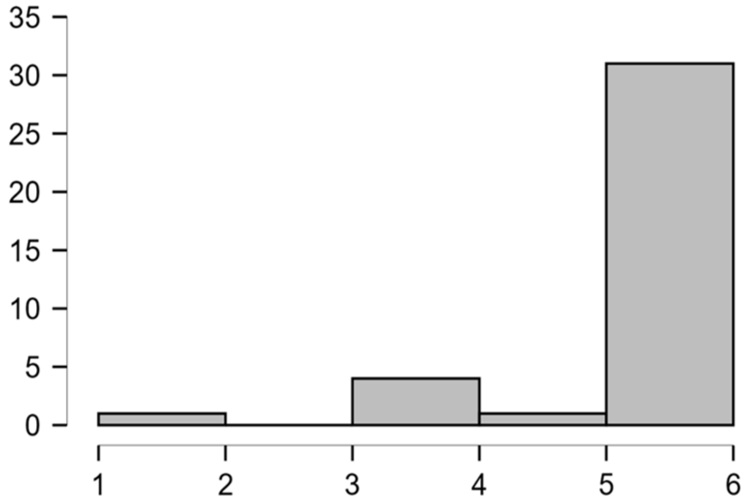

Fig.3 Results for Item 3 *(Match the physical quantities with the measuring instruments using arrows)*

The following conclusions can be made for Item 3:

1. Good understanding of basic physical quantities and units: The majority of students successfully completed the task, indicating that they have a good grasp of the basic concepts and the correspondences between physical quantities and their units in the SI system.
2. Need for additional support for the remaining students: Six students who did not succeed may be struggling with memorizing the symbols or units for certain physical quantities. This suggests a need for additional review or exercises to reinforce the symbols and units.
3. Reinforcement through various formats: To improve understanding for those struggling, alternative formats could be suggested, such as flashcards with terms, matching exercises, or crosswords involving physical quantities and units of measurement.

In the Fig. 4 the results for Item 4, which describes the understanding of graphics, are presented.15 out of 37 students (approximately 41%) correctly described the change in gas pressure at constant volume. This indicates some difficulties with understanding this material for the majority of students (60%).

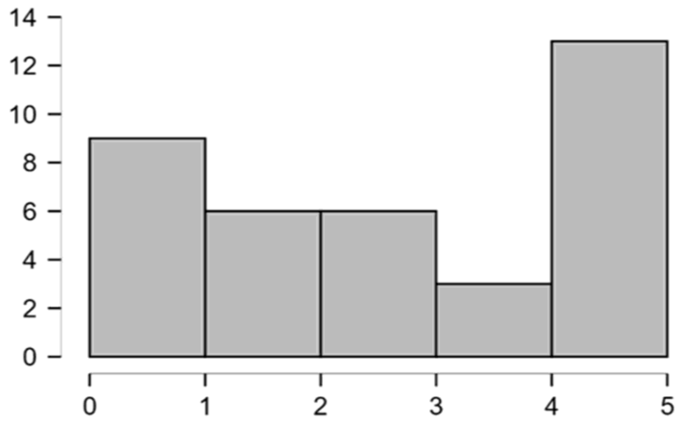

Fig. 4 Results for Item 4 *(Graphical Representation)*

Here is the analysis and possible conclusions based on this result:

The task of understanding the graph of an isochoric process requires not only knowledge of this relationship but also the ability to interpret graphs of physical quantities. If most students made mistakes, this could indicate the following difficulties:

- **Misunderstanding the isochoric process**: Students may not fully understand the principle of volume conservation and the influence of temperature on pressure.
- **Difficulties with graphs**: The ability to analyze graphs and draw conclusions from them is an essential part of physical thinking, and some students likely lack the skills to interpret graphical data.
- **Theoretical understanding and practical application**: Students may understand the theory but struggle with applying it to specific situations, especially when working with abstract graphs.

In the Fig. 5 the results for Item 5, which describe the understanding of the notion of molecular mass, are described.

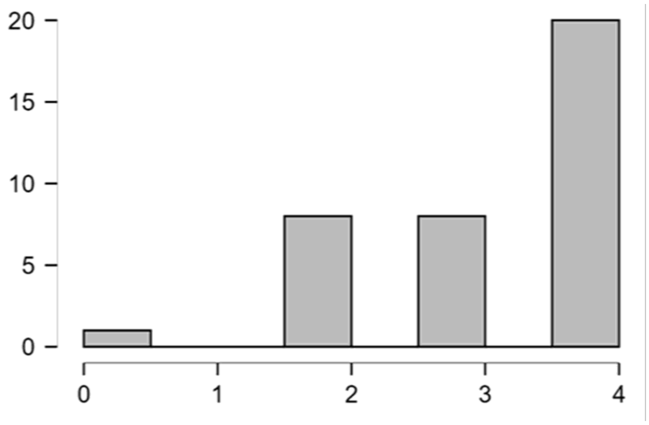

Fig. 5 Results for Item 5 *(Definition of Molecular Mass, Chemistry-Physics)*

We have obtained that out of 37 students, 28 solved the task correctly, which is about 75%. This indicates that most students understand the concept of molecular mass and are able to calculate it for various molecules. However, it also shows that there is room for improvement in understanding, especially in the context of trans-disciplinarity, where knowledge of molecular mass needs to be integrated with other disciplines, such as physics and chemistry. For example, molecular mass is related to calculations in the ideal gas law, which demonstrates the need to connect chemical concepts with physical ones. It's important to emphasize the interrelationship between chemistry and physics, as this will help deepen the understanding of the nature of substances and their behavior under various conditions. In order to achieve this, it is necessary to:

- Use practical examples: It is important to provide real-life examples where knowledge of molecular mass is essential. For example, explaining how this knowledge is used in drug dosing, food production, or chemical reactions in daily life.
- Visualization of molecules and their mass: To improve understanding, especially in classes where many students may struggle with the abstract concept of molecules, models and demonstrations can be used to visualize how atoms form molecules and how their mass is calculated.
- Additional tasks: After the theoretical explanation, several problems of varying difficulty should be solved. For example, problems where molecular mass must

be calculated for complex organic compounds or used in ideal gas law calculations.

- Integration with laboratory work: To reinforce knowledge, practical laboratory work can be included, where students measure the mass of a substance and calculate its molecular mass based on the collected data. This will help them see how theoretical knowledge is applied in practice.
- Use of technology: The application of multimedia tools and interactive programs for demonstrating molecular structures and their calculations can significantly improve the perception of the material and make it more accessible.

In the Fig. 6 the results for the task related to ideal gas equation are presented. The results show that only 19 out of 37 students managed to solve the task using the ideal gas law equation.

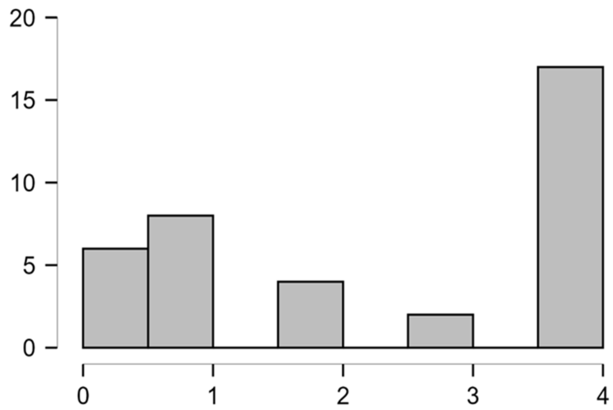

Fig.6 Results for Item 6 *(Ideal Gas Equation)*

Possible explanations for mistakes:

1. Theoretical gaps: The relationships between the gas parameters (p, V, T, n, R) may not be fully understood; Difficulties in manipulating formulas and isolating the required quantity.
2. Lack of calculation skills: Errors in mathematical computations; Incorrect use of units of measurement (e.g., converting Celsius to Kelvin).
3. Context of the task: Students may not always see the connection between the equation and real-life situations, which reduces their motivation.

The results for transdisciplinary task (physics – chemistry) on the Fig. 7 are presented. We have obtained that six students from the entire group were able to fully solve the problem of calculating the number of quinine molecules in a glass of tonic.

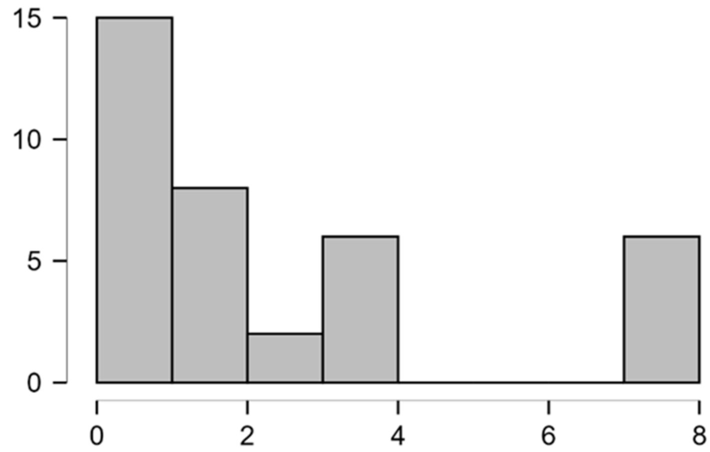

Fig. 7 Results for Item 7 *(Transdisciplinary Task)*

Here the following conclusions can be made:

1. Problems with applying the concepts of amount of substance and Avogadro's number: The task requires a solid understanding and application of Avogadro's number to convert from the mass of a substance to the number of molecules. Some students may be struggling with this concept or not fully understanding how to use it in practice.
2. Weak mathematical skills and computational abilities: Basic calculation skills, such as division and multiplication, as well as the ability to work with scientific units of measurement, are needed for successful problem-solving. This indicates a need to strengthen computational skills.
3. Need for more detailed explanation of solution methods: Students may require additional explanation on how to transition step-by-step from the mass of a substance to the number of molecules. Practice with step-by-step examples could help improve their understanding and confidence.
4. Motivation for independent problem-solving: If most students did not attempt to fully solve the problem, it may indicate difficulties with independent work or a lack of interest. It might be helpful to offer similar problems that motivate students to apply their knowledge independently.

In the Fig. 8 the results for problem situation task are presented. Only 8 out of 37 students were able to answer the question about the effect of altitude on the boiling point of water and cooking time.

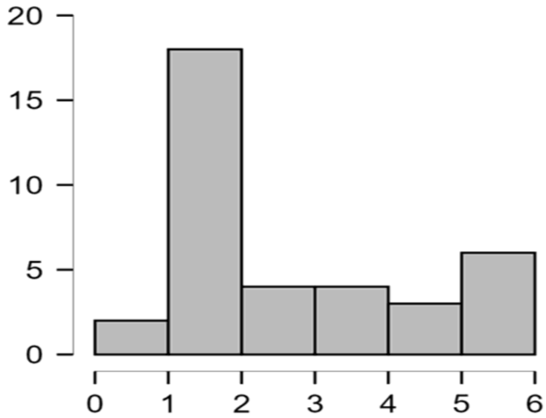

Fig. 8 Results for Item 8 *(Problem Situation)*

From this, several conclusions can be drawn:

1. Difficulties with understanding iso-processes and thermodynamic principles: The questions are related to isobaric processes, changes in pressure, and boiling temperature, which require a solid understanding of thermodynamics. It is possible that students lack fundamental knowledge or understanding of how atmospheric pressure affects boiling.
2. Need for practical context: The task is based on real-life conditions (changes in altitude, pressure, and their effect on boiling), which should spark interest in the topic. However, it seems that not all students connect theory with practice, indicating a need for additional practical examples or experiments.
3. Challenges in applying logic and cause-and-effect relationships: Answering the question requires linking several physical concepts and phenomena. This can be challenging for some students, especially if they are not used to this type of complex thinking.
4. Need for reinforcement of basic concepts: Many students did not understand the task, which could indicate gaps in knowledge that should be addressed by reviewing key thermodynamic concepts and their practical application.

Final Conclusions

1. Strengthening theoretical explanation: First and foremost, the principle of iso-processes should be further clarified, possibly with simple examples and visualizations, such as animations or lab simulations showing parameter changes.
2. Practice with graphs: Additional practice with graph analysis might be useful for students, such as exercises on recognizing dependencies between various parameters in different types of processes (isothermal, isobaric, isochoric, and adiabatic). Teaching graph analysis can be enhanced with visual tasks and interactive exercises.
3. Differentiated approach: If the group's level of understanding varies greatly, tasks could be broken down into different levels of difficulty. This would allow stronger students to deepen their knowledge, while those who need more time could focus on basic concepts and ask questions.
4. Additional real-life examples: Iso-processes and parameter dependencies can be demonstrated with real-life examples (e.g., changes in pressure in a closed container when heated, etc.)—such examples can help students better understand the physical meaning of the process.
5. Ongoing collaboration with math teachers: Strengthening the mathematical framework, working with graphs, and exploring functional dependencies.

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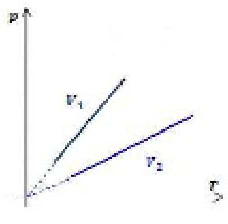
Суммативный тест №1
по физике в 11(Г) классе
Тема «Термодинамика»

Фамилия,имя ____
Дата **Кол-во баллов** **Оценка**

Nr	**Задания**	**баллы**
	I. В 1-4 задании дайте правильные ответы согласно условиям:	
1	**Дай определение понятию изохорный процесс. Приведи пример.** ____ ____ ____ ____ ____	L 0 1 2 3
2	**Вставь пропущенное слово:** А)В изохорном процессе для данной массы газа произведение ______________ на______________ – величина постоянная. Б) Изохорный процесс подчиняется закону ________________________________. В)Графически изохорный процесс в координатах (p,T) представляют в виде ________________, которая называется ________________.	L 0 1 2 3
3	**Установите соответствие (при помощи стрелок) между физическими величинами и измерительными приборами:** (см. таблицу ниже)	L 0 1 2 3 4 5 6

Название	Обозначение	СИ
Число Авогадро	• p	• 1м/с
Объем	• T	• 1кг
Температура	• v	• 1моль$^{-1}$
Давление	• N_A	• 1м^3
Скорость	• V	• 1Па
Масса	• m	• 1К

4	**Используя график, опишите изменение давления газа при постоянном объеме. Считать массу газа одинаковой.**  ____ ____ ____ ____ ____ ____ ____ ____	L 0 1 2 3 4 5
	II. В заданиях 5-8 ответь на вопросы или представь решение в отведенном месте.	
5	**Вычисли молярную массу** вещества. В эту самую минуту, пока Вы читаете, Ваши *глаза используют* органическое соединение – **ретиналь ($C_{20}H_{28}O$)**, который преобразует световую энергию в нервные импульсы. ____ Пока Вы сидите в удобной позе, мышцы спины поддерживают правильную осанку благодаря химическому расщеплению **глюкозы($C_6H_{12}O_6$)** с высвобождением требуемой энергии. ____	L 0 1 2 3 4

6 Каким может быть наименьший объем баллона, содержащего кислород массой 6,4 кг , если его стенки при 20 °С выдерживают давление 1568 Па? R = 8,31 Дж/(моль·К)

L 0 1 2 3 4

Дано	**СИ**	**Решение**
Ответ		

7 Уже в 16 веке был известен **алкалоид – <u>хинин ($C_{20}H_{24}N_2O_2$)</u>**, который получают из коры хинного дерева (Южная Америка) и используют против малярии. В 2020 году его активно использовали для лечения тяжелых больных вирусом **COVID – 19.**

- Знаете ли вы, что дин стакан с тоником (Schweppes) содержит около 20 мг хинина, такое количество является безопасным для человека и не сказывается на здоровье? Вычисли количество молекул хинина в стакане тоника.

L 0 1 2 3 4 5 8

Дано	**СИ**	**Решение**
Ответ		

8 **Проблемная ситуация:**

- Представьте, что вы путешествуете по горам. Для приготовления пищи вы используете газовую плитку с небольшим баллоном. Когда вы находились на уровне моря, приготовление пищи на плитке занимало 15 минут. Поднявшись на высоту 2000 метров, вы заметили, что вода закипает быстрее, но приготовление пищи стало занимать больше времени. Вас это удивило, и вы решили понять, что происходит.

L 0 1 2 3 4 5 6

Вопросы:

1. Назовите изопроцесс, который описан в данной ситуации.

____

3. Как изменяются давление и температура кипения воды с увеличением высоты?

____

____

4. Как можно объяснить это явление с точки зрения изобарного процесса?

____

____

Успехов!