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Situated learning: from idealized model to real physical situation

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(Received 6 October 2016, accepted 18 December 2017)

Abstract
The possibility of situational approach in the formation process of concepts about scientific limit transition models in physics is considered. Two criteria are proposed for the analysis of such a type of models. We show how using the situational approach applies to the formulated criteria for the analysis of two scientific models important in the Physics Education.

Keywords: Situated learning, ideal models, the point particle, the ideal gas.

Resumen
Se considera la posibilidad de un enfoque situacional en el proceso de formación de conceptos sobre modelos científicos de transición límite en física. Se proponen dos criterios para el análisis de dicho tipo de modelos. Mostramos cómo el uso del enfoque situacional se aplica a los criterios formulados para el análisis de dos modelos científicos importantes en Educación en Física.

Palabras clave: Aprendizaje localizado, modelos ideales, la partícula puntual, el gas ideal.

PACS: 01.40.gb, 07.05.Hd, 07.05.Tp **ISSN 1870-9095**

I. INTRODUCTION

The ideal models represent the objects not existing and unrealizable in the real world, but having their pre-images in it. Such an idealizations in physics can be divided into the model of: 1) systems; 2) interactions; 3) processes; 4) phenomena [1]. From the epistemological point of view idealizations are versions of scientific abstractions. In this case one may distinguish the identification abstraction or minimalist idealization, the limit transition abstraction or Galilean idealization and the abstraction, which is introduced by definition (the so-called multiple models idealization) [2]. In the first case there is elimination of an infinitely large number of real object characteristics (eliminative abstracting), in the second one there are limit transitions for the selected number of characteristics to their maximum or minimum value (productive abstracting). For example, a solid body is the identification abstraction and a rigid body is the limit transition abstraction. Under the term of the abstraction, which is introduced by definition, one understands theoretical construct defined by one or several postulates (electromagnetic field, electron, photon, etc.).

After the pioneering work of Hestenes [3] the interest to the model approach in physical education is steadily increasing. Generally in the process of training it is customary to distinguish scientific models (aimed at the development of hypotheses, theories, and verification thereof) and educational models (the models constructed for solving educational tasks, models-algorithm for carrying out educational activities, and visual (material and virtual) models). In this article we consider the possibility of situated learning with the formation of students' understanding of scientific physical limit transition models. The point is that the concepts of ideal models due to the high level of abstraction are poorly conceived by the students. For deeper understanding it is necessary to consider application of these models in a various possible cases.

Situated learning was first suggested by Lave and Wenger in 1991 [4]. At the present time under situated learning one understands a collective term which includes such methodologies as simulations, context-based instruction, case studies, scenario-based learning and online role-plays, real life problems [5]. The main idea of such approaches consists in contextualizing subject material because “pure” science is an abstract topic often incompatible with everyday life. It is also permits to students move from the traditional system of learning to problems solving. As a consequence of using such strategy one can observes growing of students' motivation. The nature of situated learning comes from situated cognition, which accentuates the context in which something is learned so knowledge forms the part of activity, culture and life.

Simulations facilitate situated learning by providing interactive practice of real-world skills, focusing on the essential elements of a real problem or system. The instructional use of simulations is a relatively new phenomenon about which the research is limited. Usually, in the practice of situated learning the teacher initially formulates a particular problem situation in the classroom which problem may be encountered in the real world; than the learners create and analyze different models for solving this problem. In the study of scientific models we propose the opposite approach: from a model to specific situations in which it can be applied or in other words the deductive method.

For the analysis of scientific model one should use two criteria:

1. The purpose of theoretical description (qualitative criterion): which real objects can (or can not) be described within the framework of the analyzed model;

2. The accuracy of theoretical description (quantitative criterion): Whether it is possible to neglect the modelling errors in the quantitative description, i.e. errors arising as a consequence of neglecting several factors considered to be insignificant in the construction of the model.

Hereafter we show how using of the situational approach applies to the formulated criteria for the analysis of two scientific models important in the physics education.

II. THE POINT PARTICLE MODEL

Let us first consider the point particle model, the model of the real body which size under may be neglected certain conditions. Instructor should keep in mind that there exist two contextually different points of view concerning treatment of the phrase ``under certain conditions''. In the first (kinematic) approach the point particle is considered as a body whose dimensions are much smaller than the distances to other bodies or distances which body travels. As a classic example the teacher may suggest to consider the motion of the Earth around the Sun using data on the averaged size of the Earth, Sun and Earth's orbit. Students make a correct conclusion about the applicability of point particle model in calculating the characteristics of the Earth's orbit. Then teacher asks students whether it is possible to explain sunrise and sunset and their exact time in the framework of this model. In this way students can grasp that there are always effects that are not described even qualitatively by a certain model.

After these illations it is preferably to proceed to analyzing the following situation: the 10 meters long bus starts from a stop passes 7 meters. Can we consider it in this case as a point particle? This example helps students in the case of translational motion of the body. The point particle model is applicable even in cases where its dimensions are comparable to the distance it passes.

The condition "much smaller" begins to play an important role in the quantitative description of the object investigation. In this case the example of hundred-meter sprinter will be very demonstrative. Can it be considered as a point particle? The answer to this question depends on the accuracy with which one carries out the timing of running.

If such time is determined by means of a manual stopwatch with the accuracy $\Delta\tau \approx 0.1$s, then the error in identifying the moment of crossing finish border by the runner $\Delta l/\upsilon >$ (at the speed run $\upsilon \approx 10$ m/s and cross runner size $\Delta l \approx 0.2 - 0.5$ m) is less than $\Delta\tau$. Therefore, in this case the point mass model is quite reasonable and usable. If the time measured by an electronic stopwatch with an accuracy $\Delta\tau \approx 0.01$s, than error $\Delta l/\upsilon > \Delta\tau$; so a sprinter can not be considered as a point particle really, the competition sprinters sharply bend at the finish, winning the victorious hundredths of a second.

The above mentioned criteria should be also illustrated for this model within the framework of the second (dynamic) approach. In the study of inert properties of the body it is necessary to remember that the mass is inertia measure of the body only for the translation movement. During rotation not only body mass is essential but also its distribution relative to the rotation axis, i. e. the moment of inertia. In this regard one can analyze the elastic oblique collision of two identical balls, in which, before the collision, they move translationally, and after the collision, there is also rotational motion excited as a result of the interaction of their surfaces [6].

The second criterion assumes the separation properties of the body into the inert and gravitational ones (in this case very often point particle model is named as point mass model). It is convenient to consider the deviation of the inert properties of the body from point mass on the example of the following task. The homogeneous ball with radius *r* hanging on a thread *l* long performs small oscillations in a vertical plane. It is required to find the relative error in determining of the oscillation period which arises when we neglect: 1) the shape and the size of ball i. e. consider this pendulum as a simple one with *l* length; 2) only the ball's shape i. e. consider this pendulum as a simple one with *l*+*r* length. Using the formula for the oscillation period of a physical pendulum and parallel axis theorem the students obtain that relative error amounts 5% when ratio *r*/*l* is approximately equal to 0.1 (in the first case) and approximately equal to 1 (in the second case).

A similar task can be offered with the analysis of the deviation of the binary star gravitational properties from point mass. The first reason for such a consideration is that binary stars are quite common objects in the Universe. The second one is that they have a big quadrupole moment which causes deviation from point mass model in the case when dipole moment is equal to zero (this can be achieved by placing the origin at the center of mass of the system).

Let us find the relative error δ in determination of the gravitational field potential of the system two stars with equal masses *m* which arises by replacing this system on the point mass 2*m* located at its center of mass. We will determine this error along the line passing through these stars and perpendicular to it the line passing through their center of mass. Applying the principle of field superposition and the formula for the potential of the gravitational field of a point mass students obtain that δ amount 5% on appropriate distances approximately equal to 2.2 *l* 1.6 *l*, where *l* is the distance between the stars.

These specific physical situations help students to experience the magnitude to which the point mass model is applicable. In addition, they are beginning to realize that the applicability limits of the model depend on the situation itself.

III. THE IDEAL GAS MODEL

The second important model which we consider is the above mentioned model of an ideal gas. In the study of molecular physics, it is advisable to consider a classic example of widespread misconceptions associated with the model of the ideal gas.

Very often in the school textbooks the ideal gas is considered as a set of non-interacting point particles. Indeed, in a rarefied gas the size of molecules is very small compared with the average distance between them. It seems that in this case they could be considered as point particles. In fact, it is not so, since molecule, except for the translational motion can also make the rotational and vibrational motions. For example, in the theory of the ideal gas the average kinetic energy of molecules is given by expression: $ikT/2$, where i is the number of degrees of freedom, in which rotational and vibrational degrees are included. Thus, the rotation and vibration of the molecule is an important ``reservoir" of internal energy of the molecule, which "capacity" is determined by the molecule's capacity for deformation and rotation around its own axis.

Therefore, the first criterion of the model applicability is not performed in this case.

The most real physical situation in this case concerns the thermodynamic properties of the components of air under standard conditions for temperature and pressure ($T_0 = 273\,\mathrm{K}$, $p_0 = 10^5\,\mathrm{Pa}$,). Is it possible to consider them near these conditions as ideal gases? To answer this question it is necessary to analyze Wan der Waals equation describing behavior of the real dense gas.

Amendments to the pressure and volume of ideal gas due to intermolecular interactions and own volume of molecules are, respectively, $\nu^2 a/V^2$ and νb, where a, b – Wan der Waals' constants. Since $\nu = m/\mu$ ratios $\nu b/V = b/V_\mu$ $\nu^2 a/V^2 p = a/V_\mu^2\, p$, where V_μ is the molar volume (under standard conditions $V_{\mu 0} = 22.4\ \mathrm{dm^3/mol}$). The instructor can offer students to make and complete the following table for the two major components of air:

TABLE I. Amendments to the pressure and volume of ideal gas for two basic components of air.

gas	a, $\mathrm{kPa \cdot dm^6/mol^2}$	b, $\mathrm{dm^3/mol}$	$\nu^2 a/V^2 p$, %	$\nu b/V$, %
N_2	140.8	0.0391	0.28	0.17
O_2	137.8	0.0318	0.28	0.14

From the analysis of this table, students may conclude that the deviations of the properties of air components from the ideal gas are negligible in this case. As an effect which is not described even qualitatively by this model it is preferable to consider liquefaction of gases for example when they are compressed isothermally (in such a way liquids Cl, CO_2, NH_3 were first obtained).

The second criterion may be illustrated by the example of Joule-Thomson expansion because of its important practical application as a method of producing low temperatures. Let two pistons move in the tube with thermally insulated walls divided by porous barrier. At first 1 mole of some Wan der Waals' gas at the temperature T_1 and pressure p_1 occupies the volume V_1 between the left piston and the barrier. Initial volume between the right piston (which is under pressure p_2) and the wall is equal to zero (Fig. 1 a).

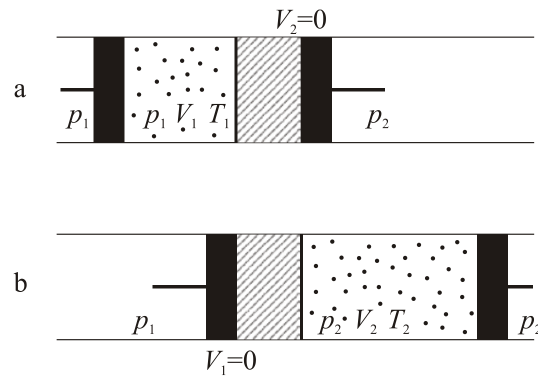

FIGURE 1. The Joule-Thomson expansion scheme.

Further the left piston slowly pushes the gas through barrier at constant pressure p_1. At the same time the right piston moves under pressure p_2 (Fig. 1 b). As a result, the gas occupies volume V_2 at temperature T_2 and pressure p_2 of the right side of the wall. Such a process was called throttling gas. With throttling gas the outside forces perform work $A' = p_1 V_1$. Expanding after passing through the barrier gas performs work $A = p_2 V_2$. Applying the first law of thermodynamics to the adiabatic process, we have: $U_2 - U_1 = A' - A = p_1 V_1 - p_2 V_2$. For simplicity, we assume that volume V_2 is so large that the gas after throttling can be considered as ideal. Under this condition, and taking into account the expression for the internal energy of the real gas the last relation can be written in the following form:

$$c_{\mu V} T_1 - \frac{a}{V_1} + p_1 V_1 = c_{\mu V} T_2 + p_2 V_2 , \qquad (1)$$

where $c_{\mu V}$ is the constant volume heat capacity. Transforming Eq. (1) with consideration of the Van der Waals and Mayer equation, we obtain:

$$\frac{\Delta T}{T_1} = \frac{1}{c_{\mu p}} \left(\frac{Rb}{V_1 - b} - \frac{2a}{V_1 T_1} \right), \qquad (2)$$

where $c_{\mu p}$ is the constant pressure heat capacity.

For the quantitative estimation of temperature change effect the teacher might consider two essentially different cases with the students on the example of hydrogen ($a = 24.7\ \mathrm{kPa} \cdot \mathrm{dm}^6/\mathrm{mol}^2$, $b = 0.0266\ \mathrm{dm}^3/\mathrm{mol}$): 1) initial volume and temperature respectively amount to $0.1\ \mathrm{dm}^3$ and 50 K; ; 2) initial volume and temperature respectively amount to $0.1\ \mathrm{dm}^3$ and 500 K. Using Eq. (2) and relation $c_{\mu p} = 7R/2$, where R is the gas constant, the students obtain that in the first case the temperature decreases by 24% and in the second case it increases by 7%. Both effects can be explained by the presence of the interaction forces between molecules. At low temperatures the attractive forces dominate in such a way that during the expansion of gas the kinetic energy of the molecules (and therefore the temperature of gas) increases. On the contrary, at high temperatures when the repulsive forces prevail, the effect of temperature increasing with the expansion of gas takes place.

VI. CONCLUSIONS

In summary, we can conclude that for successful implementation of situational approach in the formation process of concepts about scientific physical limit transition models it is necessary to:

– Use deductive method – from introducing concept of model to specific physical situations in which it can (or can not) be applied;

– In the selection of these situations one should take into account two criteria for their theoretical description;

– These situations should have real life context.

The strategy described in section 1 was successfully tested by the author during the last ten years. For this purpose in the classroom a wide range of physical idealizations of all sections of the course of physics has been considered and analyzed. The result of using this methodology was an increasing and in-depth students' understanding of peculiarities and the essence of concepts about this class of models in physics.

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