

Simple hands-on experiments and the computer modelling for better understanding

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Abstract

The paper presents an example of the SCHOLA LUDUS complex approach to simple physical experiments at the high-school level, with emphasis on computer modelling. Effective learning process should consist of a challenging key experiment followed by students' "free playing" with similar experiments and qualitative observation. Teachers provocative questions encourage students' to looking for agencies affecting observed phenomena. Further discussion on physical interpretation directs students to recognition of the successive phases of the process and to quantitative formulation of observed phenomena. Students should try to create simple mathematical models and verify them.

The presented example concerns the experiment with the inverted covered glass with water. A computer is used to calculate the model related to the "before equilibrium state" of the process while the boundary conditions are given as the balance of forces on the cover. The results lead to better understanding of the whole process and to universal concepts such as open non-linear system, mathematical modelling and its limits etc.

Introduction

The SCHOLA LUDUS educational process [1] usually starts from the simple-to-realise surprising key experiment - here a glass partially filled with water, covered by sheet of paper and turned upside down. (first in the Fig.1.)

1 Structure of teaching and learning process

1. Initiation of key experiment, students' prediction of process development (*What will happen after removing the hand from the cover?*), first complete realisation.
2. Heuristic finding of factors influenced the process development, modification of the key experiment (Fig. 1), additional experiments. *Is it better to have at the beginning more or less water in the glass? When will the water outflow? At which materials, shapes, sizes etc. is the cover remaining on the vessel longer?*



Figure 1. The key experiment and some of its modification

3. Class discussion on physical interpretation of observed phenomena including new, more detailed observations. *What happens after turning the system upside-down? Which forces act on the cover? What are the consequences of water drain?*
4. Recognition of the successive phases of the process. *Filling the glass; turning the covered glass upside down; phase before equilibrium state (including equilibrium state of forces), phase after equilibrium state; a collapse of system.*
5. Creation of physical model. *Which forces are acting on the cover in respective phases and what are the boundary conditions of the respective phases? Attempt to create mathematical model and computer modelling [1]. In this case possible for "before equilibrium phase".*
6. Application - prediction of process development under changed conditions and its experimental verification. *How much water should drain in order to remain the cover? How depends this amount on initial amount of water in the glass? How will the process develop with another liquid, with more or less dense or strong cover, on the board of Space Station etc? Where are limits of the experiment functioning[2]?*
7. Class presentation of outcomes, their interpretation. Concerning to ICT in teaching and learning process - more detailed description of 5th and 6th point follows.

2 A model of the "before equilibrium state"

Considering the process, before turning there is certain amount of water and certain amount of atmospheric air in the glass. After the turning the glass, the water can drain (and / or infuse itself into paper). Water also creates a layer between the covering and the glass that provides two mutually isolated systems of air outside and inside the vessel. The change of air pressure inside could be described by the equation of state at isothermal expansion of ideal gas: $p_a \cdot V_1 = p_2 \cdot V_2$ (1)

V_1, V_2 – initial, final volume of air inside the vessel.

If the glass is cylindrical

$$V_1 = S \cdot (L - h),$$

$$V_2 = S \cdot (L - h + \Delta h),$$

whereas for $L, h, \Delta h$ see Fig.2

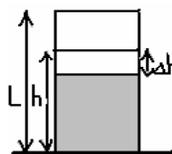


Figure 2. After turning the Δh column of water is replaced from the glass

p_a – initial (atmospheric) pressure, p_2 – the pressure in equilibrium phase,
 S - surface of the contact area.

The boundary conditions of this model are given by forces: hydrostatic pressure force F_h , atmospheric pressure force F_a , pressure force caused by air closed in the glass F_c , gravitational force G and adhesive forces.¹ Without adhesion the phenomenon could not be established but the force of adhesion at the balance condition is negligible:

$$F_h + F_c + G = F_a \quad \text{or} \\ h \cdot \rho \cdot g \cdot S + p_2 \cdot S + G = p_a \cdot S \quad (2)$$

ρ – density of liquid, g – acceleration of gravity,

Solving system of equations (1) and (2) we can get quadratic equation with respect to Δh :

$$0 = (\Delta h)^2 + \left(\frac{p_a}{\rho \cdot g} + L - 2 \cdot h - \frac{m \cdot g}{\rho \cdot g \cdot S}\right) \cdot \Delta h - \left(h + \frac{m \cdot g}{\rho \cdot g \cdot S}\right) \cdot (L - h) \quad (3)$$

that, solved in normalised form (Fig.3), enables more general understanding of the phenomenon.

Figure 3. directs students to consider the variation of hydrostatic and in the vessel closed air pressure, and their relationship due to water drain. *How much water must be displaced from the glass before the equilibrium is reached and also what does it mean that the process is not linear?*

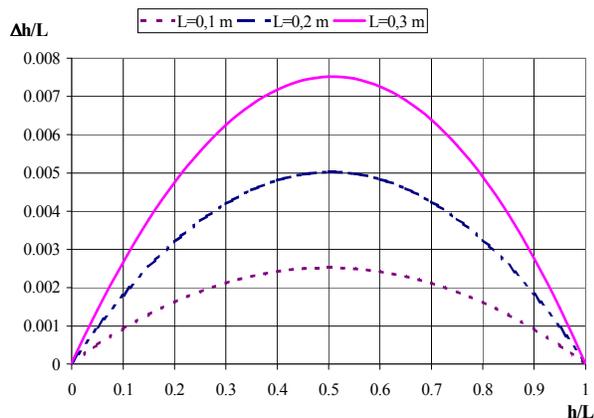


Figure 3. Relative height change of water column $\Delta h/L$ necessary for establishment of the equilibrium state in dependence on relative height of initial water columns h/L .

Students are surprised by the causes of the non-linearity. Close to limit conditions [2]: in almost a full glass ($h/L \rightarrow 1$) even a relatively small change of water column height causes a sufficiently large change of closed air pressure; in an almost empty glass ($h/L \rightarrow 0$) even a relatively small change of closed air pressure is enough to provide equilibrium. This is still better visible (Fig. 4.) if instead of eq. (3) the system of eqs. (1) and (2) is solved in the form:

$$0 = \left(\frac{\Delta p}{p_a}\right)^2 + \left(-\frac{m \cdot g}{p_a \cdot S} - \frac{\rho \cdot g \cdot L}{p_a} - 1\right) \cdot \frac{\Delta p}{p_a} + \frac{1}{p_a} \left(\frac{m \cdot g}{S} + \rho \cdot g \cdot L \cdot \frac{h}{L}\right)$$

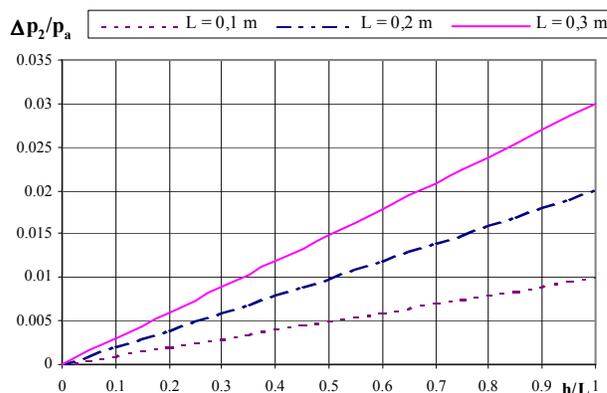


Figure 4. Relative change of closed air pressure $\Delta p_2/p_a$ in dependence on relative initial water columns' height h/L .

3. Back to real experiments

Using computer gives students possibility to easily change initial values of particular parameters and effectively compare theoretical and experimental results. From the product $S \cdot \Delta h$ students get dependence of water amount that is necessary to be replaced from the vessel volume in order to establish equilibrium state. This theoretically gained amount is very small and shows that it is not necessary that the water during the experiment visibly outflow. Relocation - creation of a thin sheath between the vessel and the cover or absorption the water into the cover could be sufficient.

One of the most interesting questions for pupils concerns the mass of covering that can be retained.

Conclusions

The presented model represents only the “before equilibrium phase” e.g. until surface tension and adhesion forces are neglected. Students aware of these limits are prepared for better qualitative understanding of the whole process that represents a complex dynamic problem.

References

- [1] TEPLANOVÁ, K.: Computers and modelling at SCHOLA LUDUS teaching of physics – GIREP 2004, Ostrava, pp.
- [2] MARENČÁKOVÁ, A.: Simple experiments at extreme parameters - GIREP 2004, Ostrava, pp.

¹Except the adhesive forces, students (according to the Slovak curricula) are able to calculate their intensities.

