A couple of physics teaching ideas

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We would like to present here some simple experiments from different areas of physics, which could help teachers to improve their lectures both at grammar and high schools.

Introduction

Experiments and experimental work have an essential role in physics education and can be used for demonstrations of physical phenomena and also as good motivators. The experiments could enhance discussion about interesting problems and those involved in this article could be presented in a form of problematic tasks, asking students 'Why' or 'Explain!'. The simplicity of these tools allows students to perform these experiments by themselves and think about their physical origin.

Mysterious 'kinder'-egg (a small plastic egg consisting of two parts)

A thin thread or silicon wire is thread through the kinder egg with a steel ball mounted on one end and a wood ball placed on the other one. Hang the system in a vertical position keeping the steel ball in a hand. We can observe that the egg slides down the thread into the proximity of the wooden ball. Repeat the experiment changing the position of balls, so the steel ball is on the upper side of the thread and we are keeping the sling holding the wooden ball in a hand. We perceive in this case that the egg is not moving down but stays in a stable position on the wire. What is trapped inside the egg?

There is a thin plastic tube with the thread passing through. If the light wooden ball is at the bottom, the thread is not stretched and there is no friction between the thread and the hose; thus the egg can move easily. If we turn the whole system and the steel ball is at the bottom end, in this case the thread is stretched and pulled to the tube which significantly increases the friction until the moment at which the egg is not moving any more. It is necessary to remark that a similar effect could be obtained in different ways and it is not bad to ask the students to discover them - to create the same system in which the described egg's behaviour is realized differently.

Fig. 1

Against the tide

Take a long transparent pipe closed on one end, whose diameter is not much larger than the diameter of the kinder-egg. Let the egg fall inside, to the bottom of the pipe. When water is added inside the tube, the egg goes up. Fill the whole tube with water, close it and turn it afterwards. Holding the tube in an upside-down position, we observe that the water is flowing away whereas the egg is not moving in the same way but floats against the flow. How can we explain the egg's behavior?

To explain it, we have to consider that there is a lift force acting both in the air and the water which come into play when the tube is turned. The lower edge of the egg lies (is positioned) in the air so the pressure at this point is equal to the normal atmospheric pressure. The pressure at the upper edge is decreased by the pressure ρhg, where h is the height of the water column around the egg and ρ is the density of the liquid. If we consider the egg to be a cylinder with S being the base area and H the height, the resulting condition for the egg flowing up is written as $\rho_k \cdot g \cdot H \cdot S \le \rho \cdot g \cdot h \cdot S$, where ρ_k is the average density of the egg. Assuming the H is equal to h, the side walls of the egg are fully immersed in the liquid; as long as the r_k is smaller than r, which is fulfilled in our case. As a consequence, the egg flows up in the liquid.

The egg turning upside-down

The two-coloured kinder egg is perforated on the both sides and hung on an iron wire which is threaded in the middle. Keeping the wire in the hand, we examine carefully which side of the egg is upward in the air. After deflecting the egg from the balanced position, it stabilizes in the same position as before. Immersing the egg in a liquid afterwards, the water penetrates inside which leads to turning the egg upside down - the side of different colour is up now. After picking the egg out from the liquid, the water starts to flow away and egg returns to its equilibrium position finally. What causes such behaviour in the kinder egg?

Fig. 2

Fig. 3

The egg is in the equilibrium position in the air so its centre of gravity is placed under the axis of rotation, passing through the pivot. Thus when deflecting the egg from its equilibrium position the moment of the gravitational force with respect to the rotational axis causes it to return to the original position. If we want to move the egg's centre of gravity it is necessary to hang some object in the upper part of the egg. Immersing the egg in a liquid, it starts to be filled with water (the escaping bubbles of air prove that) which causes the equilibrium position to become unbalanced and the egg turns on its side. Putting the egg into the water, the lift force starts to act at the centre of gravity of the immersed part. Thus to turn the egg, the working point of the lift force has to be under the axis of rotation and additionally, the moment of rotation arising from this force has to be higher than the momentum of rotation caused by the gravitational force. Because of that we have to hang some object into the lower part of the egg whose average density is smaller than the density of water, such as a piece of polystyrene. If this piece is moving in the liquid, it prevents the egg from turning around.

How to measure the weight of some candy or some home-made hydrostatic weights?

We will ask students to determine somehow the mass of some candy, using the following instruments: a vessel with the scale appropriate for the volume, and another vessel which can be put into the first one to let the pack of candies float inside. We give them a hint by demonstrating one possible method. Put the vessel into the childish plastic bottle with the scale. As a vessel, we can use a tube for pills into which one can put the sweets. How can we measure the mass of one candy using this system?

The tube which is immersed in the bottle is floating, thus the gravitational force is compensated by the lift force equal to

$$M \cdot g = \rho \cdot V_0 \cdot g \, ,$$

where M is the mass of the tube, V is the volume of immersed part and r is the density of the liquid. Putting the n sweets inside the tube, mass of each one is labelled as m, so the following criterion has to be fulfilled:

$$(M + n \cdot m) \cdot g = \rho \cdot (V_0 + \Delta V) \cdot g \, ,$$

where ΔV is the difference in volume of the immersed part of the tube or the difference between the volumes of water measured by the volumetric flask when the tube is empty and when it is filled with candies. The mass of one candy could be written as

$$m = \frac{\rho \cdot \Delta V}{n} \, .$$

Fig. 4

Together with the students, we can discuss the error of the volume measurement which influences the accuracy of the result and also possible ways to increase the precision of measurements that are done by this method.

Miraculous glass

Holding the glass in your hand, start to fill it with water stored in a second glass of the same volume. We observe that the water does not flow away for a long time. It starts to flow away at the moment at which we fill the glass with almost the whole volume of water from the second glass. After water stops flowing, we can see that the glass is almost empty which can be proved by pouring the little amount of water. What is inside the glass?

Obr. 5

There is a very easy system inside, called the siphon- curved pipe with two arms of different size. One arm is mounted on the hole at the bottom of the glass; the second one is placed at a small distance above the lower one. When we start to pour the water inside the glass, it starts to fill the pipe. When the level of the water reaches the bend of the pipe, water starts to flow continuously away the glass until the water level falls below the lower side of the pipe. The difference of the pressures on both sides of the hole (there is atmospheric pressure acting on the one side and atmospheric plus hydrostatic pressure on the other) causes the continuous flow of the water outside the glass.

What is inside the envelope?

There is a secret message hidden in the closed envelope. How can we read it without opening the envelope? Drip wax on the envelope (from a burning candle) and wipe it off carefully. After removing the wax, the text of the message is legible. How is it possible?

The fact that we cannot see anything looking through the paper could be explained with geometrical optics in the following way: when the light passes through the paper, the rays of light impact the interfaces between the cellulose and the air. Both reflection and refraction occur at the boundaries, and these effects are more significant the greater the difference between the indices of refraction and the higher the angle of incidence. Besides that, total reflection occurs at the cellulose-air interface. The cellulose's fibres are thin so the angles of incidence significantly differ from zero. The result is multiple reflections and refractions at the boundaries, and a lot of rays neither pass through nor create a readable image. Liquid wax fills the pores between the fibres; its index of refraction is approximately equal to 1.48, almost the same as that of cellulose (1.46). As a consequence of filing the pores between the fib-

res with the wax, the paper changes to a homogeneous thin layer. This layer does not refract the rays of light and the objects placed behind are visible very clearly.

Is the glass transparent?

Spill some shattered glass into a burette, which becomes opaque. Stick the colour image on its back side. We cannot see anything looking through the burette filled with the glass. Start to pour glycerine inside. We observe that the image starts to become visible until we see it all.

The explanation is the same as in the previous experiment. We note that the indices of refraction of glass and glycerine are almost the same.

Switching off the bulb

A small pocket flashlight's bulb and a big table-lamp's one are connected in series and plugged into a source of voltage. The small bulb lights up. When coming closer to the filament of the bigger bulb with the burning match; the smaller bulb switches off. Repeat the experiment blowing at the filament of the big bulb now. We notice that the brightness of the small bulb increases. How can we explain the switching off of the bulb and the increase of the brightness?

Both bulbs are connected in series so the total resistance is proportional to R=Rs+Rz where the Rs is the resistance of the big bulb and Rz is the resistance of the small bulb. The current flowing through the small bulb is expressed as I=U/(Rs+Rz). The filament of the large bulb is made of tungsten and after heating it above the fire of the match, its resistance increases rapidly which leads to the decrease of the current flowing through the small bulb. The power belonging to the current flowing through the small bulb is equal to $P = I^2 \cdot R_ž$. *Considering this equation, a decrease of the current leads to a decrease of the heat emitted by the bulb, which is switched off at the end. Blowing on the filament causes its cooling, resulting in a decrease of the resistance of the tungsten filament and an increase of the current flowing in the network; thus the bulb lights up.*

Boiling water in a pipette

Fill the pipette with cold water at first. After picking it up from the bottle of water, it does not flow away. On the contrary, when filling the pipette with boiling water, one observes that the bubbles of air go up in periodic intervals and the water flows away proportionally. How can we explain the different behavior of cold and hot water?

If we pick the pipette out from the cold water, the pressure on the water-air boundary is proportional to $p_1=p_0+\rho hg$, *where* p_0 *is the pressure of the gas on the upper part of the pipette,* ρ *is the density of water and* h_c *is the high of the water column. Label the pressure acting on the lower part of the boundary as* p_2. *This pressure is equal to the atmospheric pressure (the contribution of the capillary pressure is negligible). Because water is not flowing away, the pressures on both sides of the interface have to fulfill the equation* $p_1=p_2$ *or* $p_a=p_0+\rho hg$ *(1). Water can flow off the pipette only if the pressure* p_0 *is increased. Placing the boiling water into the pipette, the situation* *changes because the upper part of the pipette is filled with saturated vapour. If the balance is established, the equation (1) is fulfilled and the water does not flow away. As time passes both the water and the vapour begin to cool down. Since the pressure of the saturated vapour depends on the temperature,* p_0 *is decreased and the equilibrium described by eq. (1) is overcome. The pressure of the gas at the lower side is higher, the interface between the air and water begins to elevate and the bubbles of air get inside, followed by the cool air that is heated up by passing through the hot water. As the bubble is moving up, the pressure in the upper part is increased and a little water outflow follows. As the gas in the upper part is still being cooled down, the pressure is decreasing and another air bubble is sucked up.*

Conclusion

The presented ideas document that a lot of interesting experiments are easy to do and I believe that teachers will use them not only as a diversification of their class-works, but also as the inspiration for the improvement of their own experiments.

References

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