Popular Explanations of Physical Phenomena: Broken Ruler, Oxygen in the Air and Water Attracted by Electric Charges

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Abstract
The inquiry-based approach to learning has proven to be quite effective, since Socrates, but it is difficult to found good questions to induce reasoning. Many sources explain wrongly some experimental results, which can be used as discrepant events. Some use the breaking of a ruler with a newspaper to "show" that the atmospheric pressure is powerful or "measure" the oxygen in the air using a burning candle or "explain" that electric charge attracts the water because the dipolar properties of the water molecule. Those are seemingly reasonable explanations but they are not true. Those demonstrations can be used to promote discussion and understanding from very simple reasoning.
Keywords: Demonstration, discrepant event, atmospheric pressure, oxygen in the air, water attracted

Introduction

Using demonstrations in the class room it is a good way to present some discrepant events, trying to induce reasoning on the students. Another approach includes use physics mistakes on popular movies. A few examples are: some movies use the sound of the explosions in the battles between space ships, forgetting that the sound needs the air to propagate. The laser beams are quite visible on those battles, but in the vacuum there are not particles to disperse the laser beam allowing it to be seen. The invisible man should be blind because its eyes are no focusing the light in its retina. To see something we used the reflected light, we see transparent objects when its refractive index is different from that of the air.

Can a newspaper sheet break a ruler?

To answer experimentally this question let us place a 0.30 m the ruler on the edge of a table, with a portion of approximately 0.05 m protruding out of the table. Then let us place a newspaper sheet on the portion of the ruler that lies on the table (taking care that no air pockets are left between the paper and the table). Then, let us apply a sudden blow to the protruding edge of the ruler. In this way the opposite end of the ruler should move about 5 times faster than our hand, and we would expect that the paper would be cut. Surprisingly for most of the audience, if we follow this procedure the ruler is broken. A word of advice: it is necessary to practice this demonstration before showing it in public, because if you are not fast enough, the rule will drag the newspaper, and ¡it will flow away from the table! You can use your hand to do it, if you are fast enough. Otherwise you may use a hammer to apply the blow.

Many authors (Leeming, 1954; Herbert, 1965; Vivian, 1967; Mandell, 1968; de Vries, 1974; Perelman, 1975; Amery, 1978, Spangler, 2012, SciencesFunFunFun, 2008 and

Questacon, 2012) explain this experiment claiming that the atmospheric pressure applied over the paper sheet (around 10 newton/cm^2 applied over 25x20 = 500 cm^2) produces a force stronger than that needed to break the ruler. It is claimed that because the paper sheet is touching the table, if we try to lift the paper, a vacuum between the paper and the table would be produced. It is a seemingly *reasonable explanation* for the breaking of the ruler. According to it, if we separate the paper sheet from the table, the ruler should drag the paper sheet.

Using three rulers and a paper sheet, and using almost the same setup, we can try again the experiment. In this case, however, we place to each side of the protruding ruler (approximately at 0.1 m of it), another ruler completely over the table (not protruding). With this arrangement the paper is not in contact with the table, there is a separation of the order of the thickness of the ruler in between (*i.*e., there is air above and below the paper sheet). If we now apply a sudden blow to the protruding edge of the ruler, *the ruler is broken again!*

Fig. 1. *Left side: 3 ruler and paper before the blow. Right side after the blow. Photos taken from a video in my page in thumb Divulgation.*

Consequently, *the reasonable explanation* is not true. The breaking of the ruler is due to the *mass* of the paper sheet, which is added to the ruler's mass (and not to any vacuum produced between the sheet and the table). To prove this we can place again the ruler on the table (with one end protruding out of it), and place a little portion of plasticine (weighting 10g, which is the weight of the paper sheet) on the opposite end of the ruler. This time the paper sheet is not used. If we now strike the protruding end of the ruler: *it breaks again* (and the plasticize ¡hits the ceiling!). With the help of a hammer, it is possible to break the ruler without any added weight; its own mass is enough.

If you try many times this demonstration you will notice that the faster the blow, less energy is provided to the broken ruler, it is almost motionless after a really fast blow. If we use a wood ruler we can make the same experiments, but we need a longer ruler or more speed, and/or the help of a hammer. The inquiry approach produces more questions as a result, promoting more experiments. Using a motion detector we can measure the speed of the hand and relate it to the ruler movement. Using a standard blow, we can find the minimum torque needed to broke the ruler, with a faster video camera.

How much oxygen is in the air?

Rahi (2012) in an Internet site and two children books (De Vries, 1974;Vivian, 1967) uses a lit candle in a dish with water. The candle is covered with a milk bottle. The water level rises inside the bottle because the flame consumes the oxygen in the air, and the water occupied the missing volume. Montoya (2011) has a video in YouTube using burning alcohol in a cotton ball, trapping the air with a large cylindrical glass. He says that the oxygen disappears producing a vacuum enough to allow him to move the water recipient and the glass together. The atmospheric pressure keeps them together. Tilting the glass, the water level in the glass goes to about 50% of its volume. He mentions that if glass is full with oxygen the water level should full the glass. He knows that the oxygen in the air is about 20%, without making the connection with the 50% of the water level. Internet can be wrong.

The first time I made the experiment, the water level rises about 20%, in excellent agreement with the expected value of 20.95%. The problem with this explanation is that they forget about the gases produced in the combustion. Knill (2006) on the WEB takes into account the CO_2 and H_2O produced in the combustion, using $CnH2n_{+2}$ as the formula for the paraffin. For n = 21 the combustion equation is:

$$33O_2 + C_{21}H_{44} \text{----}\rightarrow 21\ CO_2 + 22H_2O$$

So 33 molecules of oxygen disappears from the air and only 21 Carbon Dioxide appears, so we should measure 1/3 only reduction in the oxygen volume (about 7% total air volume. The water molecules condense and the liberated heat is neglected. At the end of the chemical reaction some CO should be produced, occupying twice the volume of oxygen, and is also neglected.

Knill (2006) says, "After some time, the candle dims and goes out. Just before the candle dies, the water level rises to almost 1/10th of pitcher height." But really the water level rises slowly when the candle is burning and increases sharply when the candle goes out, not before. On all my experiments the water raises something near 20% of the trapped volume. You can see that on my video ¿Oxigeno en el aire? In the thumb Divulgacion in Riveros (2010). Trying to use this procedure to measure the oxygen in the air requires measuring the air temperature as function of time, calculate the instantaneous density and integrate the new volume after cooling. Besides the measurement of the Carbon Monoxide that will increase the volume. The initial idea is to take out the oxygen from the enclosed volume, neglecting the heat liberated in the combustion and the gases produced. If we can absorb the Oxygen in a slow oxidation with a solid as a product, we can really neglect the heating and the oxide solid volume.

The main problem with the candle measurement is that the combustion heat is liberated so fast that the air temperatures are near 800 °C in the flame and cooling as they move by convection. Using Iron wool in the bottom of an inverted bottle, it oxidizes slowly so the temperature is almost constant, and the solid oxide formed has a negligible volume compared with the oxygen gas. The oxidation takes between 8 to 24 hours, so the water level rises occupying all the oxygen volume (Riveros et al, 2000).

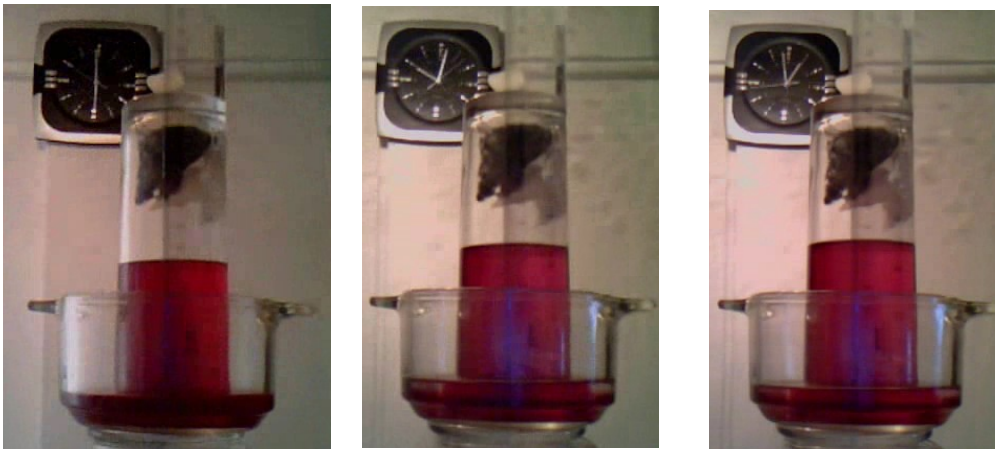

Fig. 2. *Absorption of Oxygen by Iron wool in the air trapped by the colored water*

There is a video made with a photograph every 10 seconds, the cylindrical glass with 149 mm length, trapping 78 mm of air with colored water. Two grams of Iron wool degreased with soap absorbed the Oxygen in the trapped air. After 13 hours the air length decreases to 62 mm. That gives 20.5% of Oxygen, neglecting the 0.25 cm^3 of the Iron volume. The radius vase is 2.5 cm. The video is on my page under the name "ExpEdu Medir oxigeno en el aire.

Why is water attracted by an electric charge?

This is a very popular experiment (Perelman, 1975; Pople, 1997; and in Helmentine, 2012). It is explained by Hewitt (1994) and three Internet sites (Sadler, 2012, SkySkull. 2008, Chiaverina, 2012)) as a result of the polar character of the water molecule. Those sites appear on the first page of a search "Water attracted by electric charge", surely there are many more.

To demonstrate this attraction we need a falling water stream and a charged object. In home, we may use an almost closed water faucet, a rubber balloon and a plastic bag. Rubbing together the balloon and the plastic bag, we get two charged objects with opposite charges. The photograph shows a charged balloon attracting a thin water stream. Hewitt (1994) uses this fact to find preconcepts in students, asking them what happened if we changed the sign of the electric charge near the water stream. To get the answer in a short time, he gives 3 options:

- *a) The stream is repelled*
- *b) The stream is attracted*
- *c) No force on the stream*

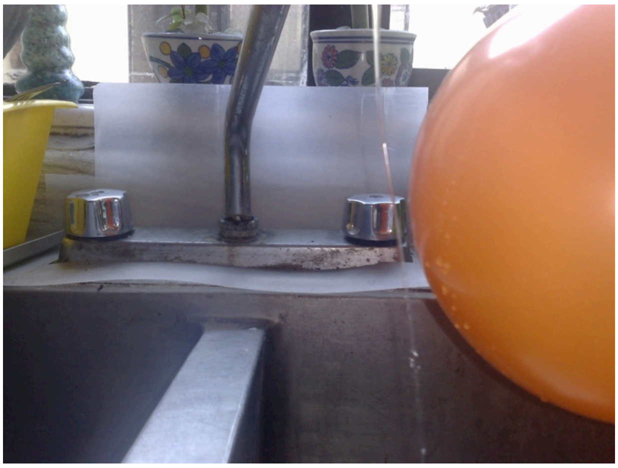

Fig. 3. Water is attracted by an electrically charged balloon

If they say the water should be repelled then they believe the water is charged. The water from a faucet is at ground voltage, it is not charged. If they say there is no force, we need to ask them why they believe that. If they say there is attraction again, we need to ask them why. Hewitt (1995) believe it is because the water molecule is an electric dipole, the two hydrogen atoms form an angle of 107°; so the center of positive charge it different from the center of negative charges. The CO_2 is different; the two oxygen atoms form a 180° angle, so the molecule has not dipole moment. So when the external charge is positive, the water molecules oriented themselves with the negative oxygen near the charge. If the external charge is negative, the hydrogen atoms are near the external charges producing again an attraction.

This is a reasonable and beautiful explanation, but it is wrong because it forgets than the water is a conductor with free ions inside. The ions may come from impurities or from the H^+ and OH^- always present. The theoretical resistivity of water is 21 Mohms.cm. When we put an electric charge near a conductor, the free charges inside move to the surface until the internal electric field is null. Then there is not internal field to move the internal electric dipoles. The force comes from the force on the charges on the water surface, and that is always an attraction, the charges are always of opposite sign to the external charge.

If the external charge is near the point where the water stream forms droplets, then the drops are charged electrically and may be used in a Kelvin Generator. According with the dipole model the drops are never charged. You can see a short video in my page, in the thumb Divulgacion under the name Water-attracted.

Conclusion

Many of the sites in Internet are sponsored by Universities, but even they can be wrong. So we need to be careful about books, articles and materials appearing in the WEB. In the References appear ten sites with mistakes and some of them allow sending messages with suggestions. The sites mentioned are a few appearing in a very short search. The authors are free to accept or reject the suggestions. Wikipedia allows improving the materials, so the new version about breaking the ruler with the air pressure mentions the inertia of the paper as the reason (Wikipedia, 2012). There is always the opportunity of reasoning, before understanding. Understanding produces pleasure, the best didactic tool I know.

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