Fun with physics – hands on experiments in physics teaching

MICHAEL VOLLMER
University of Applied Sciences Brandenburg / Germany
Email: vollmer@fh-brandenburg.de

A number of hands-on experimented are described, some of them well-known, others maybe less known, which may be used in physics teaching. As most of the content has already been published, only a brief summary is given for each demo, followed by a short description with a selection of relevant references.

1) Stroop effect

The Stroop effect [1] describes a very old and well known phenomenon of interference in perception (see [2]). In detail, Stroop examined the effect of interfering color stimuli upon reading names of colors serially aloud. An experiment can easily be prepared by using a number of colors and the respective words and have them appear sequentially in a presentation. The audience/volunteer is asked to say aloud the name of the color of the words which themselves describe different colors (e.g. Fig. 1). You may be surprised how difficult this seemingly easy task is in practice – and this may be used to teach students never to completely trust their eyes and brains but to use objective measurement apparatus.

Fig. 1. A snapshot of a Stroop effect sequence in a presentation.

2) Karate for beginners

A wooden rod lies on two easily breakable objects, e.g. on two glasses, or two raw eggs. Hitting the rod in the middle very hard leads to breaking of the rod. Subsequently, the two parts fall down without damaging the supports. Fig. 2 shows a snapshot, recorded with a high speed camera [3] (more details, see [4, 5]).

Fig. 2. Snapshot of a high speed video sequence: a wooden rod is hit by a fast moving hand at its center. While breaking, the ends move upward such that the supports are not damaged.

3) The magic cork in the bottle

An example for another really surprising experiment uses a wine bottle (with cork) and a piece of very thin and light cloth, e.g. of silk. Whereas the empty bottle, which should be dry inside, and the cork are needed, the wine is not essential for the experiment. The cork is pushed inside the bottle and the task is to remove the cork from the inside of the bottle without destroying bottle or cork. The only equipment allowed is the silk cloth.

Fig. 3 depicts the set up for solving the problem. The silk scarf is pushed into the bottle with part of it still being outside (to be able to exert a force from outside). Then the bottle is moved to place the cork onto the silk such that tearing from the outside will result in the silk totally surrounding the cork. Then one just needs to tear the silk scarf outside, at the same time removing the cork (more details, see [5]).

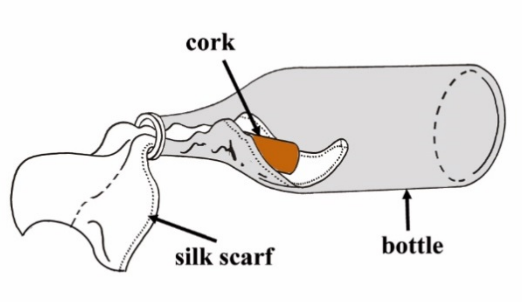
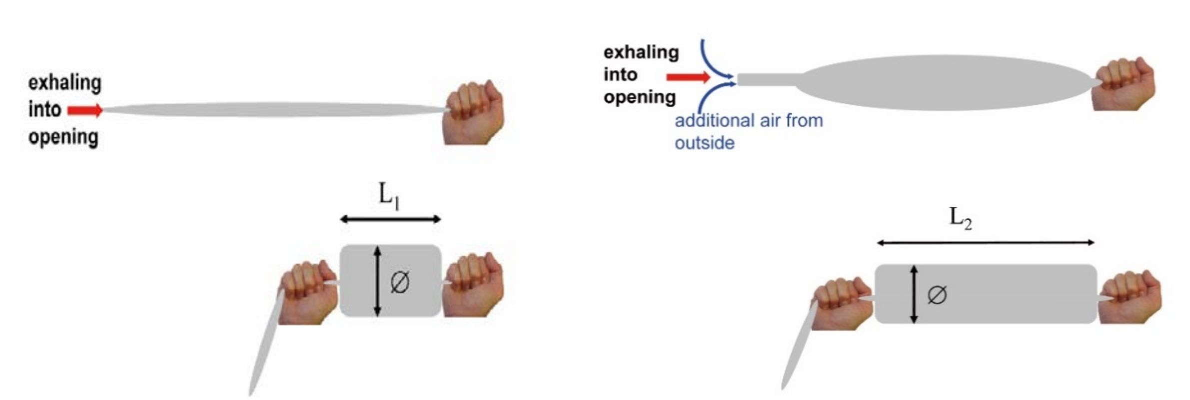


Fig. 3. Set up to remove a cork from an empty bottle.

4) The roasting wrap: lung volume and how to win a respective competition

Roasting wraps are used to improve the cooking of food. The food is placed in an enclosure of plastic such as a plastic wrap in cylindrical form which may be closed at both ends. On the one hand one may study the thermodynamics within such plastic wraps, here we just use the cylindrical plastic wrap for some experiments with gases. A competition is done in a two-step way. A volunteer is asked to have his lung volume tested. The empty cylindrical wrap is closed from one side by holding its ends together tightly with a hand (Fig. 4a). The other opening is held in the hand of the volunteer such that an entrance opening is formed into which the volunteer may exhale. He is then asked to take deep breaths of air and exhale five times into the opening – closing the opening in between each time. After exhaling the end is closed and the volume within the wrap is measured by sliding the hand along the axis of the wrap towards the other end while taking care to keep the wrap tightly closed. As a result, a length of inflated wrap can be measured with a ruler and from the known diameter of the wrap the lung volume can be computed.

In a second step, the teacher may say that he will be able to produce an even larger volume with just one time exhaling – instead of the five times from the volunteer (Fig. 4). He may indeed succeed if – while exhaling – the mouth is not completely covering the opening (as should have been the case for the volunteer). The reason is that additional air is streaming in. From a microscopic point of view, the rapidly moving exhaled breath molecules are colliding with adjacent molecules of the room air. The transferred momentum leads to the air flow into the wrap. This means that the viscosity of the air is important. One may also be tempted to explain the outcome qualitatively with the Bernoulli equation (without friction, i.e. not considering viscosity). The dynamic pressure is large where the exhaled air streams into the opening. Therefore the static pressure must be small, which leads to the additional air streaming in.



(a) (b)

Fig. 4. (a) Wrap volume after lung test and (b) after letting additional air move into it while exhaling.

5) Measuring reaction times

Reaction times can be easily tested by students. Just hold a ruler and ask a volunteer to make a gap between his thumb and index finger with the ruler inside. The volunteer is asked to react and close the gap between the fingers as soon as the ruler is released. The falling distance is related to the total reaction time, i.e., the real reaction time until the brain has send information to the muscles and the following time needed to close the gap. Similarly, reaction times of feet may be measured by having a gap between foot and a wall and letting the ruler fall (more details, see [5]).

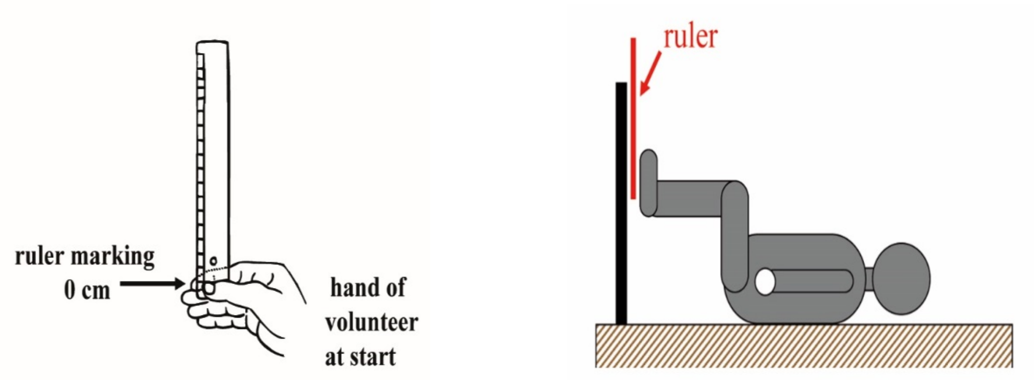


Fig. 5. Measuring reaction times with hand or feet (after [5]).

6) Drinking from a height

It is surprising that humans can easily create a vacuum of about 500 hPa using their mouth (details, see e.g. [6, 7]). A five meter long transparent plastic tube with inner diameter of a few mm is prepared such that its lower end is in a container, e.g. with orange juice whereas the upper end is held in 5 m height by a person standing on a ladder. Sucking at the upper tube end leads to a rising liquid level of orange juice within the tube with – having some luck – will ultimately reach the mouth.

Fig. 6. Example of a person standing on a ladder and sucking orange juice to several meters height due to vacuum created with the mouth.

7) Strange behavior of superballs

Superballs are popular toys, partly also due to their special properties upon reflection (see Fig. 7). Due to their material properties a ball colliding with a wall will gain angular momentum, i.e. it rotates (see [4, 5] and refs. therein). Therefore, when such a ball is thrown at an angle towards the floor such that it can hit a table from below (Fig. 7), it will change angular momentum i.e. spin, twice and will be reflected back to where it came from.

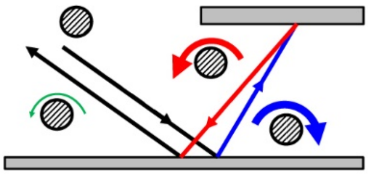


Fig. 7. Schematic trajectories of a superball, thrown onto the floor and hitting a table from below.

8) The Christmas present

A nice way to present particularly expensive Christmas presents to the loved ones use the following physics magic. Attach the present, e.g. a bottle of Champagne, to one end of a string of around 2 to 3 meters length and a much smaller weight, e.g. a piece of soap to the other end. Ask two tall people to hold a slightly roughened metal or wooden rod above their heads with outstretched arms such that it is horizontal. Place the string above the middle of the rod such that the champagne is close to the rod and held the small object (the soap) at the end of the horizontal string (Fig. 8). Then let the soap go and observe what happens. The bottle should not hit the ground, i.e. will not be destroyed if the underlying physics works correctly. This experiment is useful when discussing accelerated linear and rotational motion as well as the exponentially increasing frictional forces of strings (ropes) if wound around rods.

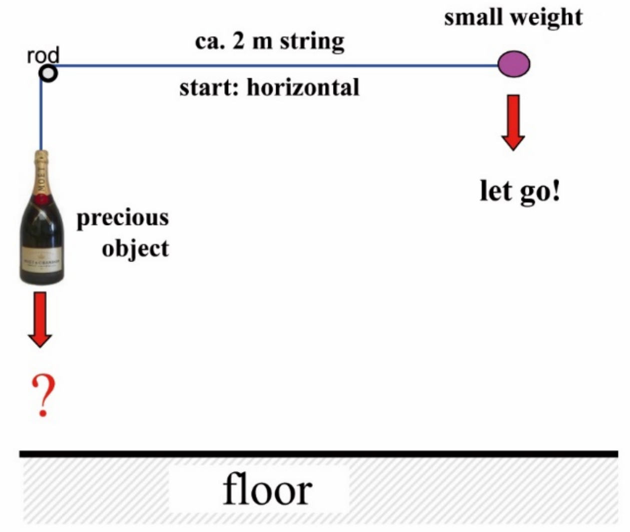


Fig. 8. Set up for the falling Christmas present experiment.

9) The magic of time

The effects of the Lorentz force on cylindrical magnets falling in the vicinity of non-ferromagnetic metal tubes have already been described quite often (e.g. [8, 9]). The effect is more pronounced if an identically looking non-magnetic cylinder is used a second object: it falls much more rapidly through the tube, approximately following the laws of free fall without friction in air.

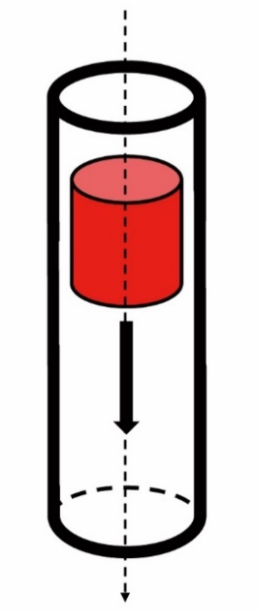


Fig. 9. A magnet (inner red cylinder) is falling in a non-ferromagnetic metallic tube.

10) Conductivity of a human chain

The resistance of dry skin can be very high (order 100 kΩ). As a consequence, tiny, yet detectable currents (order of micro-amps) will flow through the body when applying voltages of the order of several Volts (see e.g. [10]). Using sensitive instruments, even a chain of several people will easily transmit a detectable current (Fig. 10). This simple set up can be modified in a number of ways to include available electronic gadgets ([11]).

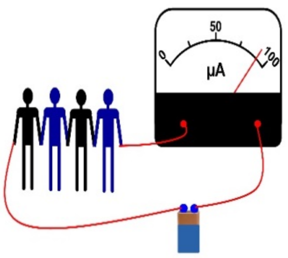


Fig. 10. Typical arrangement to demonstrate the conductivity of human skin

11) Observing phenomena in the near infrared spectral range

Human perception is limited to the visible spectral range between wavelengths of λ = 380 nm and λ = 780 nm. In contrast, Si-based sensors in cameras and camcorders have sensitivities extending to about 1100 nm. Using slightly modified regular digital cameras with Si-based detector chips one may perform several rather simple experiments for teaching the fascinating physics phenomena occurring at NIR wavelengths ([12, 13] and refs. therein). Fig. 11 depicts one example, demonstrating that water and red wine look much alike in the NIR.

Fig. 11. Water and red wine look alike in the near Infrared.

12) He voice

Inhaling helium gas and then speaking is an always exciting demonstration which – unfortunately – is not very simple to explain (e.g. [14, 15, 16]). The perceived pitch of the voice increases giving rise to a so called Mickey mouse voice. The explanation assumes that the frequencies of sound are produced by the larynx. What we perceive then depends on how this frequency spectrum is altered by the filtering due to the vocal tract. The filtering is described by so called formants. Their frequencies depend on geometry of the vocal tract. In brief, since geometry is unchanged, the wavelengths stay more or less the same when inhaling another gas. However the speed of sound changes which leads to an increase of the formant frequencies (Fig. 12).

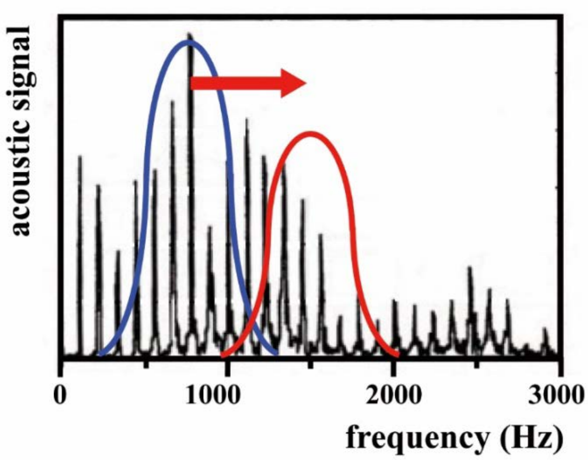


Fig. 12. The formants (roughly indicated as colored bell shaped curves) governing the frequency spectrum of human voices change with inhaled gas. For Helium it increases (from blue to red), after ([14]).

13) Ring in chain

A nice example of physics magic involves a metal ring and a metal chain. The set up (see Fig. 13) is the following: the two ends of a chain of typical length one meter are connected such that it forms a loop which is placed over a hand. The ring is lifted outside of the chain ends and also held by the same or the other hand. One then needs to let the ring fall, such that it does not fall to the ground but stays within the chain. Details of the experiment including videos for download are described elsewhere [5, 17].

Fig. 13. Set up for the ring in chain magic.

Acknowledgment

I want to thank my colleague Klaus-Peter Möllmann from Brandenburg University of Applied Sciences. Most of these experiments were developed and performed together with him.

References

[1] Studies of interference in serial verbal reactions, J.R. Stroop, Journal of Experimental Psychology, IS, 643-662 (1935)

[2] Half a Century of Research on the Stroop Effect: An Integrative Review, C.M. MacLeod, Psychological Bulletin Vol. 109, No. 2,163-203 (1991)

[3] High speed—slow motion: technology of modern high speed cameras, M.Vollmer, K.-P. Möllmann, Physics Education 46/2, 191-202 (2011)

[4] Exploding balloons, deformed balls, strange reflections and breaking rods: slow motion analysis of selected hands-on experiments, M. Vollmer and K.-P. Möllmann, Phys. Ed. 46/4, 472-485 (2011)

[5] Low cost hands-on experiments for Physics teaching, M. Vollmer, K.-P. Möllmann, Lat. Am. J. Phys. Educ. Vol. 6, Suppl. I, pp. 3-9 (2012). http://www.lajpe.org

[6] Vakuumphysik im Alltag: Physikalische Freihand- und Low-cost-Experimente , M. Vollmer, PhyDid 1/1, (2002) S. 19-32 , see www.phydid.de

[7] For the love of physics, from the end of the rainbow to the edge of time – a journey through the wonders of physics, p. 75 ff, W. Lewin, W. Goldstein, Free Press / New York (2011)

[8] Lenz's Law Magic Trick, M.J. Ruiz, The Physics Teacher 44, 96 (2006)

[9] Lenz's Law Demonstration Using an Ultrasound Position Sensor, P.S. Fodor, T. Peppard, The Physics Teacher 50, 344 (2012)

[10] Ch. Chiaverina, People Demos: Kinesthetic Physics Activities, p.78 in Z. Drozd (ed.) Veletrh Napadu Ucitelu Fyziky 15, Praha (2010)

[11] Music through the skin, M.Vollmer, K.-P. Möllmann, in preparation

[12] The Physics of Near-Infrared Photography, K. Mangold, J.A. Shaw, M. Vollmer, Eur. J. Phys. 34/6, S51-71 (2013)

[13] The optics and physics of near infrared imaging, M. Vollmer, K.-P. Möllmann, J.A. Shaw, in Education and Training in Optics and Photonics (ETOP) 2015, edited by Eric Cormier, Laurent Sarger, Proc. of SPIE Vol. 9793, 97930Z

[14] Physik des menschlichen Stimmapparats…, A.L. Moser, V. Nordmeier, H.J. Schlichting, Tagungsband Vorträge Didaktik der Physik, DPG-Tagung 1997, Berlin, p 486ff

[15] Helium Speech: An Application of Standing Waves, C.D. Wentworth, The Physics Teacher 49, 212 (2011)

[16] Helium and Sulfur Hexafluoride in Musical Instruments, K. Forinash, C.L. Dixon, The Physics Teacher 52, 470 (2014)

[17] Ring falling into a chain: no magic – just physics, M.Vollmer, K.-P. Möllmann, The Physics Teacher 49, 335-337 (2011)