Quantitative evaluation of the „Egg in a bottle“ experiment

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An egg in a bottle or an egg in the glass is a traditional experiment that is often mentioned in textbooks, collections of experiments, entertaining online videos and amongst the layman population. Its use in physics education can be found especially in fluid mechanics – the atmospheric pressure. Various versions of its quantitative evaluation can be found. [1]
An experimental vessel with a point temperature sensor and gas pressure sensor is constructed in order to explain the causes of the known consequences of the experiment. The experiment was conducted using different heat sources: a heated water, a heated oil, a paraffin candle, a piece of paper lit aflame by a match, a cotton swab soaked in alcohol. A limited scope of this contribution allows to present only the results of the most suitable selected heat source, a 55W halogen car bulb [2].

Theoretical framework

Atmospheric pressure

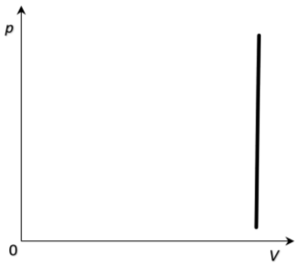
The force, caused by the Earth’s atmosphere, over a unit area in a given place is called an *atmospheric pressure*. An average atmospheric pressure is called a *barometric pressure*. A pressure higher than the barometric pressure is called an *overpressure*. A pressure lower than the barometric pressure is called a *pressure vacuum*. [3]

Isochoric process

A thermodynamic process during which the volume of the closed thermodynamic system remains constant is called and *isochoric process*. [3]

$$V = \text{const.} \tag{1}$$

An isochore is a line parallel to the *p*-axis on a *pV* diagram showing the change in pressure *p* with respect to volume *V* during isochoric process (Figure 1a). [4]



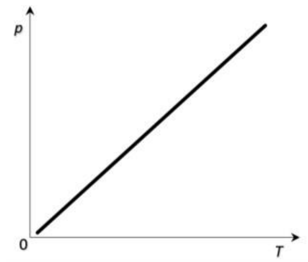


Figure 1 – (a) pV diagram of the ideal gas *(b) pT diagram of the ideal gas*

The pressure’s dependence on temperature *T* during isochoric process of the ideal gas is shown in a *pT* diagram (Figure 1b).

Charles’s law

The equation describing isochoric process is called *Charles’s law* [5]:

$$\frac{p}{T} = \text{const.} \qquad (2)$$

where p denotes a gas pressure and T stands for thermodynamic temperature.

Materials

An egg, a glass milk bottle, a paper and matches

The basis of the experiment is a hen’s egg. Quality nor price has no impact on the execution of the experiment. No limitations leading to experiment’s failure were discovered during testing. The traditional form of the experiments requires a hard-boiled peeled egg placed on top of the glass bottle neck, into which a flaming paper is tossed. We recommend a glass milk bottle, e.g. 0.75l *Bohemilk* bought in COOP Terno for 24.90 Kč (as of 12 June 2019).

Plastic food container

Principal part in measuring apparatus’s design is an airtight plastic food container with a volume $V = 1.8$ l, its dimensions are 151×108×185 mm and it is made by *Lock&Lock* (Figure 2). [6] The transparent body is made from polypropene. The lid’s rubber gasket is made from silicone, Price in the Albert chain is 129.90 Kč (26 June 2019).

Figure 2 – Lock&Lock plastic food container with volume 1.8 l

Point temperature sensor

A *Surface Temperature Sensor* STS-BTA, made by *Vernier* with a price-tag 1 485 Kč (14 June 2019) is used to measure changes in temperature. According to manufacturer’s specification is its range −25–125 °C and its sensitivity is 0,1 °C. [7]

Gas pressure sensor

A *Gas Pressure Sensor* GPS-BTA, priced at 4 980 Kč (14 June 2019) made by *Vernier* is selected to determine magnitude of the pressure. Sensor parameters are adequate to the requirements of the task. According to manufacturer’s specification is its range 0–210 kPa and its sensitivity is 0,06 kPa. [8]

Plastic extension tube for infusion

In order to connect the end of the pressure sensor to the food container, one end of the plastic extension infusion tube is used. The *Gamma* company offers *Gamaplus 1,8×450 LL V606301-ND* for 9.80 Kč (12 June 2019) [9], this tube is fitted with both male and female *Luer Lock* connectors at each end.

Datalogger

The data is recorded by a logger *LabQuest Mini*, LQ-MINI, priced at 8 195 Kč

(14 June 2019), which is connected to a computer via a USB. A software *Vernier Logger Pro* (3.15) is used to visualize and store data. The sampling frequency of the interface is up to 100 000 Hz. [10]

Car bulb

A *PX26d* car bulb by *Economy* which costs 26 Kč (17 June 2019) is used to heat the air. The bulb is designed for 12V/12W and has a H7 base. [11]

Lightbulb socket

The ceramic socket *H7 Carface* for voltages 12 V or 24 V is usually sold as a two-pack for 109 Kč (13 Jube 2019), e.g. in *Auto Kelly*. [12]

Egg hole with socket, adapter for temperature sensor, socket holder, wire holder and protective net

The parts complementing the sealable box are modelled in *SolidWorks* 3D CAD software (2018) for Microsoft Windows.

The parts are printed on a *Prusa i3 MK3S* 3D printer from PETG (PolyEthylene Terephthalate Glycol) without the need for supports, with a nozzle diameter of 0.4 mm, a layer height of 0.10 mm and a fill density of 50%.

Assembling and testing the measuring apparatus

Holes are drilled into the side of the container to accommodate a Lock Luer male thread for connecting the pressure sensor and inserting a printed adapter for the point temperature sensor. The cost of the temperature sensor is not insignificant, so it is housed in a conical-shaped adapter (Figure 3a), which is found on the Lock Luer thread as well.

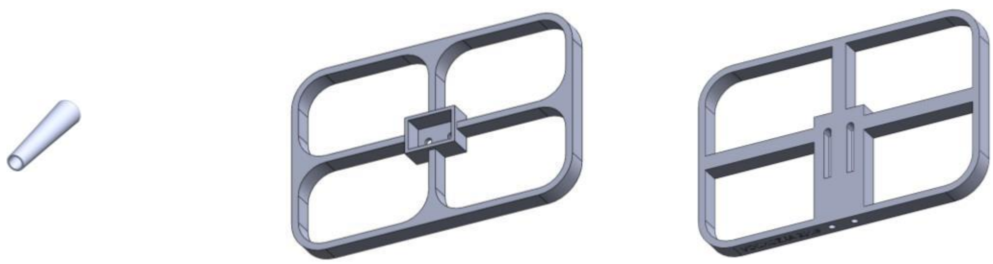


Figure 3 – (a) Adapter for a heat sensor *(b) Socket holder* *(c) Wire holder*

The sealing of the thermometer inside the adapter is ensured by a glue gun, which can be easily removed. The conical shape allows for gradual insertion to maintain airtightness. The two parts are additionally bonded with instant glue.

Holes for both wires coming out of the socket are drilled into the lid. The ceramic socket is glued to the printed socket holder (Figure 3b), which is then glued to the inside of the lid. The wires are pulled through the holes in the lid, sealed and inserted into the wire holder (Figure 3c) on the other side, which is then glued to the outside of the lid.

The bulb is placed into the socket and the container is closed with a lid. The wires are connected to a 12 V power supply. Pressure and temperature sensors are connected to the container, which are further connected via a logger to a computer.

A *Data collection* in Logger Pro is set to a *Duration* of 50 min and a *Sampling Rate* of 120 samples/min is chosen. Recording of the values begins when a *Start data collection* button is pushed. After approximately one minute, the circuit is closed, and the bulb begins to heat the volume of the container. three minutes after the start (two minutes of heating) the circuit is disconnected. The following graph sums up the values measured after 50 minutes (Figure 4).

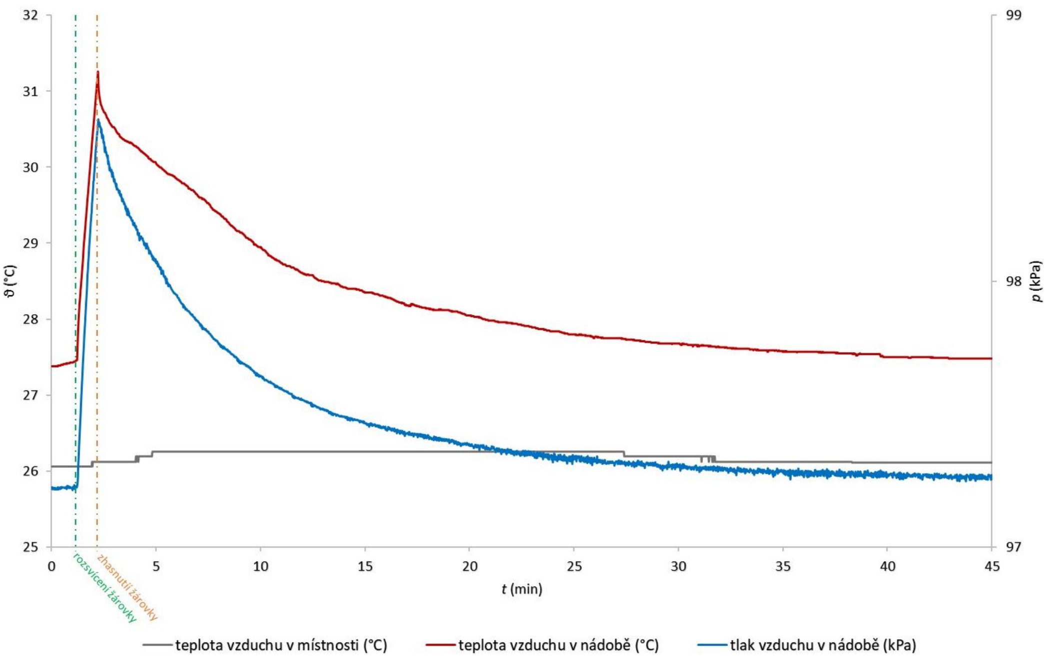


Figure 4 – Graph showing time changes in temperature of the air inside the container (red line), room temperature (grey line) and gas pressure in the container (blue line). Green dashed line – the bulb switched on, yellow dashed line – the bulb switched off.

In the graph, we can observe the minute changes in the values for all three variables from the beginning until reaching the vertical dashed line of the **bulb switched on**. The *bulb switched on* line intersects the time axis at the moment the circuit is closed. The heating of the air by the bulb proceeds until the vertical dashed line of the **bulb switched off** is reached, at which point the circuit is disconnected.

The section between the bulb-on and bulb-off lines depicts the dependence of the change in air pressure in the container on the air temperature in the container. The p-T diagram of the selected section shows a similar behaviour of the air in the container as for an ideal gas (Figure 5) in the isochoric process described by Charles's law (2).

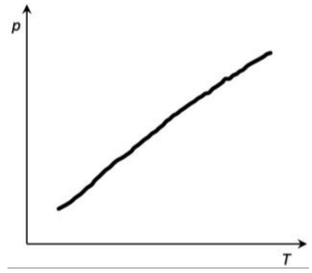


Figure 5 – pT diagram of the selected section during car bulb heating

The following part of the graph shows the changes in the measured quantities, the heat exchange between the air in the container, the container and the air in the room. As the air temperature in the container decreases, we observe a decrease in the air pressure in the container. The curve of the change of the room air temperature over time shows that the surrounding environment does not fundamentally affect the measurement.

Based on the measured results, it can be concluded that the vessel is suitable for experimentation, it is airtight, and no significant exchange of particles with the environment occurs.

Adjustments of the experimental container

The *egg opening* (Figure 6a) is the dominant component of the experiment, and it is inserted from inside the vessel into its lower base and tightened at the top with *pipe clamps* (Figure 6b).

Figure 6 – (a) egg opening *(b) Pipe clamp with screw holes* *(c) Section of the opening with the clamp*

A plastic grease is added to increase the tightness before placing on the contact surfaces. The clamps are joined together by an M4×10 bolt with an M4 nut. The assembly of the two parts is indicated by the modelled section (Figure 6c), where the empty space during assembly is occupied by the lower base of the container.

Heating by a halogen car bulb – A description

1. Hard-boiled and peeled egg was placed into the container opening.
2. *Data collection* was set for 30 min with a *Sampling rate* of 120 samples/min.
3. 130 seconds into the measurement the **bulb was turned on**, temperature and pressure changes in the container can be observed in the graph. Temperature was gradually rising. The pressure increased by approximately 6 kPa and then the change became stable. This effect was accompanied by air leakage around the egg, by the egg's lifting and subsequent sealing of the opening.
4. 445 seconds into the experiment the **bulb was turned off**. Immediately, the temperature and the pressure begun to decrease.
5. 720 seconds into the experiment the **egg was pushed** into the container.
6. When opening the container, the pressure is the same as it was at the beginning of the experiment. Temperature equilibration occurs gradually.

Measured values

The course of the described experiment can be observed in the graph (Figure 7).

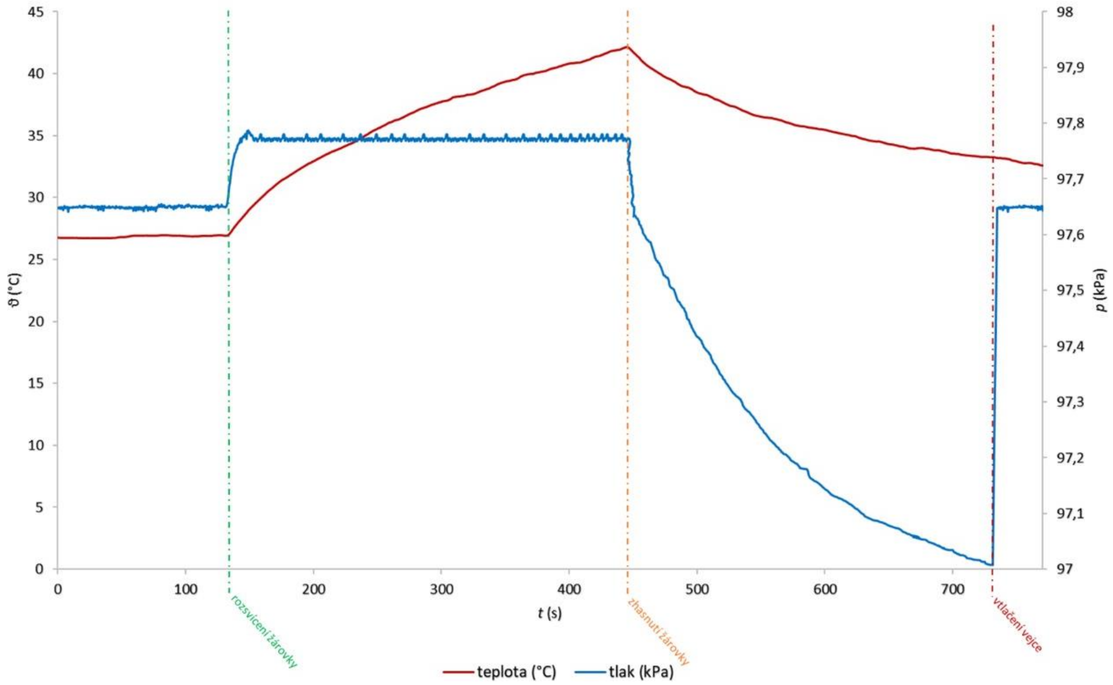


Figure 7 – Graph showing time changes in temperature of the air inside the container (red line) and gas pressure in the container (blue line).
Green dashed line – the bulb switching on, yellow dashed line – the bulb switching off, red dashed line – the egg being pushed inside.

Results

Based on the analysis of the measured values during heating with a halogen lamp, we can state that the dominant phenomenon causing the egg to be forced into the container is the cooling of the air in the enclosed space, leading to a pressure vacuum.

Conclusion

An experiment is supposed to be simple, repeatable, and understandable. The variant with a lit paper tossed into a glass vessel is ideal for a qualitative explanation. A quantitative verification requires a more complex preparation of the experiments yet exhibits behaviour similar to the one that is directly observable, and a match with measured values can be found.

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