World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

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Demonstration of gas laws in physics lessons

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World Journal of Advanced Engineering Technology and Sciences, 2025, 14(02), 099-102

Publication history: Received on 04 November 2024, revised on 08 February 2025; accepted on 11 February 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.14.2.0558

Abstract

The article describes a simple, compact device that can be used to demonstrate the validity of three gas laws in physics lessons: Boyle´s, Charles´s, and Gay-Lussac´s laws.

Keywords: Physics; Demo; Device; Gas; Laws

1. Introduction

An ideal gas is a state of matter in which the only type of interaction between its molecules is their elastic collisions which each other as a result of thermal motion. The relations between the parameters of the gas in this case is described by the so-called equation of state looks like this [1, 3]:

$$PV = nRT \quad \text{..............} \ (1)$$

where

P – gas pressure, V – volume of gas, n – number of moles of gas, R – universal gas constant, T – absolute temperature of gas.

At not too high pressure and hot too low temperature the state of a real gas is also described by this equation.

In the process of studying physics, as a rule, we talk about gas laws, which represent special cases of the equation of state (1) for a fixed mass of gas. These include, in particular, the following laws [1,2]

- Boyle´s law: at a constant temperature the product of the gas pressure and its volume is a constant value (PV = const).
- Charles´s law: at a constant pressure the volume occupied by a gas is proportional to its temperature ($V \propto T$).
- Gay-Lussac´s law: The pressure of a gas at constant volume is proportional to its temperature ($P \propto T$).

Demonstration of these gas laws usually requires the presence of fairly large-sized equipment that is not always convenient for quick demonstration. This paper describes a small-sized device that allows us to demonstrate the validity of these three laws. By using a document camera in conjunction with a projector, you can introduce these laws to a larger audience.

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2. Device structure

The device consists of an aluminium tank, which is connected at one end to a plastic medical syringe, and at the other end to a pressure-gauge. The concrete device uses a 3 ml(3cm^3) syringe and a medical manometer (sphygmomanometer) with a measurement range of 0….200 mm_{Hg}. The tube leading to the pressure-gauge is equipped with an air valve. The temperature in the aluminium tank is measured by a digital three-digit thermometer, the sensor of which is connected to the tank body. The dimensions of the entire device are approximately 20x20x7 cm. The device is equipped with stands. It is mounted on a table so that the thermometer and pressure-gauge scales, syringe and controls are located horizontally and can be projected onto the screen (see Fig.1). The gas is heated by a 12Ω 20W wire resistor, which is pressed with one side of its ceramic insulation to the aluminium tank. Voltage to the heater is supplied from a 12 DC adapter. Then the heater power is 12 W. In our device, the volume of the tank together with the tubes is 43,5 cm^3. In this way, the gas volume can be set from 43,5 cm^3 (when the syringe piston is fully moved inward) to 47,0 cm^3 (when the syringe piston is fully extended).

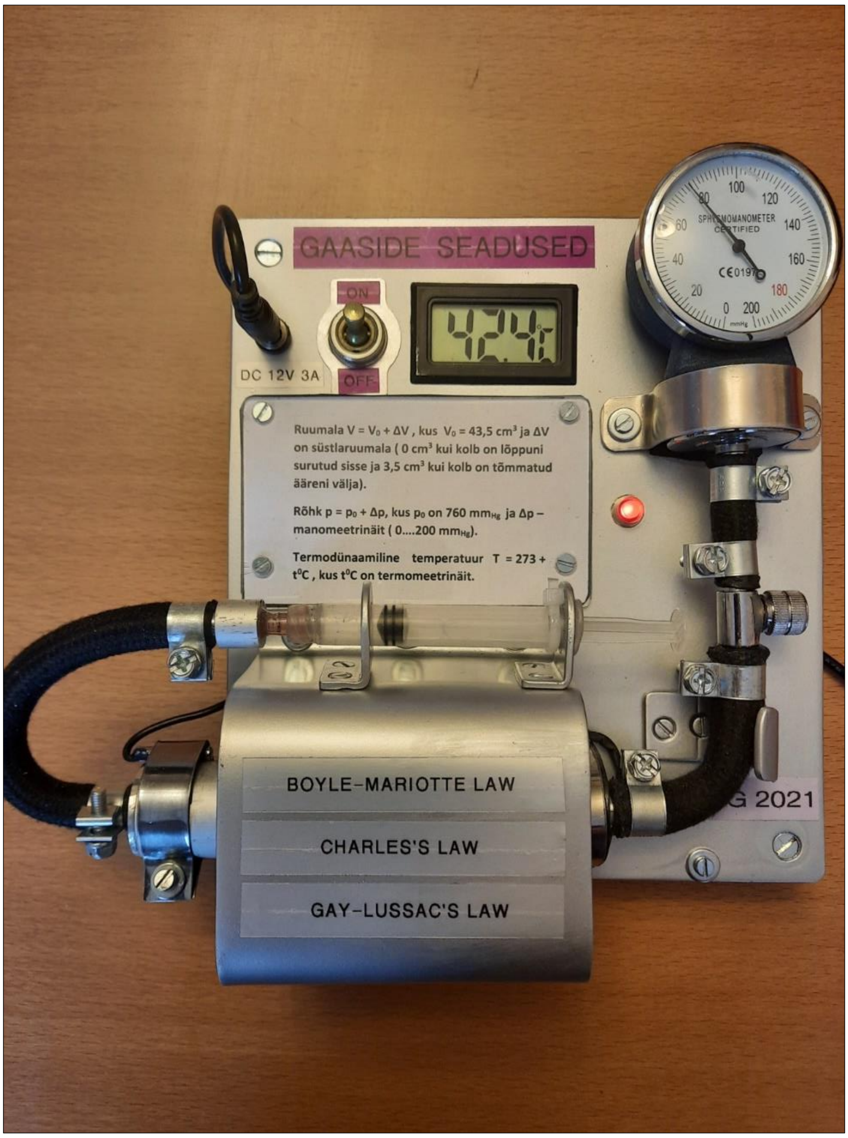

Figure 1 Appearance of the device

3. Demonstration of gas laws

3.1. Boyle´s law

According to this law:

$$P_1V_1 = P_2V_2 \quad .... \quad (2)$$

where

P_1 - gas pressure at volume V_1 and P_2 – gas pressure at volume V_2.

Measurements are taken at room temperature. Pull the syringe piston to position V_2 = 47,0 cm^3. Open the air valve (to do this, its head must be turned anticlockwise). The pressure-gauge needle should be set to zero. Close the air valve. The system is now set to atmospheric pressure $P_2 = P_0$. Slowly push the piston all the way into the syringe and after a couple of seconds record the value ΔP measured by a pressure-gauge. Now the pressure in the system is equal $P_1 = P_2 + \Delta P = P_0 + \Delta P$. The volume occupied by the gas is now equal to 43,5 cm^3. If Boile´s law is valid, then equality (2) must be satisfied.

For atmospheric pressure we take the normal pressure of 760 mm_{Hg}. Equality (2) must be satisfied with an accuracy of several percent. Even if the actual atmospheric pressure is much lower or higher than 760 mm_{Hg}, the equality must hold with an accuracy of no worse than 3%.

3.2. Charles´s law

Erom the proportionality of the volume of gas to its temperature at constant pressure, it follows that

$$V_2/V_1 = T_2/T_1 \quad .... \quad (3)$$

where

V_1 – volume of gas at temperature T_1, V_2 – volume of gas at temperature T_2.

The previous experiment ended with the syringe piston being moved inward. We open the air valve and then close it again. Turn on the device (the presence of voltage supplied to the heater is indicated dy the LED). The air in the system will begin to heat up and its pressure will begin to increase. We hold the syringe piston in this position ($V = V_1$ = 43,5 cm^3). When the pressure increase on the pressure-gauge reaches the selected value, for example, 30 mm_{Hg} , we record the temperature value t_1. The absolute temperature will be, accordingly $T_1 = t_1 + 273$. Now, while the air continues to heat up, we keep the achieved level on pressure-gauge all the time (that is, in this case ΔP = 30 mm_{Hg}). To do this, we gradually pull the piston out of the syringe, thereby increasing the volume of air in the system and, accordingly, preventing the pressure from rising. When the piston reaches the edge ($V = V_2$ = 47,0 cm^3), we record the temperature t_2 (absolute temperature $T_2 = t_2 + 273$) and turn off the device. Knowing the values of V_1, V_2, T_1 and T_2, we can check the validity of equality (3). It must be performed with an accuracy of at least 3%. This accuracy must be maintained even when the actual air pressure differs significantly from 760 mm_{Hg}.

3.3. Gay-Lussac´s law

From the proportionality of the gas pressure to its temperature at constant volume, it follows that:

$$P_2/P_1 = T_2/T_1 \quad .... \quad (4)$$

where

P_1 is the gas pressure at temperature T_1 and P_2 is its pressure at temperature T_2. We take measurements at a gas volume V = 47,0 cm^3 (the piston must be pulled out of the syringe to the end).

We open the air valve. Now the air is at atmospheric pressure $P_1 = P_0$. Now we close the air valve again. We fix the absolute temperature $T_1 = t_1 + 273$. For pressure P_1 we take the normal air pressure P_0 = 760 mm_{Hg}. Now we turn on the tank heating (the presence of voltage on the heater is indicated by the LED). The air in the system will begin to heat up and its pressure will increase accordingly. We select the pressure increment ΔP that the pressure-gauge should show (no more than 100 mm_{Hg} - for example, ΔP = 70 mm_{Hg}). We record the temperature t_2 on the thermometer at which the selected pressure increase will be achieved and calculate the corresponding absolute temperature $T_2 = t_2 + 273$. Now we know the pressure $P_2 = P_1 + \Delta P = P_0 + \Delta P$. Knowing the values of P_1, P_2 , T_1 and T_2 , we can check the validity of equality (4). It must also be performed with an accuracy of no worse than 3%. It must be performed at any real atmospheric pressure.

4. Conclusion

The fairly simple device described above has very small dimensions. Experience of its use in physics lectures shows that with its help it is easy an convenient to demonstrate to students the validity of all three gas laws. The use of a document camera in conjuction with a projector allows the device to be used in audiences with a large number of listeners.

To avoid any misunderstandings while reading this article, the following should be noted: in some countries Charles law is called Gay-Lussac`s law, and Gay-Lussac´s law is called Charles´s law [3]. This ambiquity of terminology is related to the history of the discovery of these laws.

Compliance with ethical standards

Acknowledgments

The author acknowledges the contribution of the assistent Eteri Kekelidze who prepared this manuscript for publication.

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