The Physics Teacher

PAPERS | SEPTEMBER 01 2023

Discovering the Laws of Gases with a Manometer Based on Arduino

Athanasios Gkourmpis

Phys. Teach. 61, 500–502 (2023)
https://doi.org/10.1119/5.0084657

Discovering the Laws of Gases with a Manometer Based on Arduino

Athanasios Gkourmpis, Hellenic Republic Ministry of Education and Religious Affairs, Athens, Greece

This paper presents a practical way to discover the laws of gases via a laboratory exercise. The instruments to be used include an Arduino UNO microcontroller board accompanied by a BMP 280 digital pressure sensor. The goal is to create a manometer of general use, one that can be achieved easily with the use of the above sensor that measures barometric pressure and a simple syringe. The students have the opportunity to learn and combine knowledge from physics and computer science in an exciting way.

Introduction

In recent years, the use of Arduino microcontrollers as measuring devices in physics labs has increased for a number of reasons. Among their advantages is their ability to make fast and precise measurements at especially low cost.[1] Arduino has a large support community that makes a large supply of relevant material, such as tutorials and examples, available. This encourages students to learn almost autonomously. The learning process is enhanced, and at the same time, the students acquire skills applicable to STEM activities, automatic control, and robotics projects.[2]

The traditional experimental teaching of the laws of gases is known to suffer from instrument unreliability, especially when using equipment with several years of continued use. Plungers with sealing problems and loss of gas compression or inaccurate gas manometers of poor quality suffering from permanent nonzero initial indications are among the most common problems. The above problems led us to seek a low-cost and perhaps more robust alternative. The digital pressure sensor BMP 280, which cooperates with Arduino microcontrollers, like the UNO board, is designed for measuring temperature and barometric pressure. There have been some attempts from researchers to use this sensor embedded in enclosed air to study the constant-temperature variation and constant-volume variation of a gas.[3,4]

The purpose of this paper is to compose a manometer of broader use to help students experiment with several gas laws (Boyle's, Gay-Lussac's, and Charles's). The main idea is the encapsulation of the BMP 280 sensor into a syringe (Fig. 1), so that its use is extended beyond its inherent ability to measure barometric pressure. The range of the measured pressure values, i.e., from 300 to 1100 hPa, is defined by the manufacturer.[5]

By connecting this "system" (the sensor in a syringe) to any enclosed quantity of air, the study of the relation of pressure (P), absolute temperature (T), and volume (V) is performed in an integrated way.

Theoretical highlights

The laws of gases[6]:

- Variation of an enclosed quantity of a gas, expansion or compression, while the temperature is kept constant, follows Boyle's law, which declares that the product of pressure and volume remains the same:

  $P \cdot V = \text{constant}.$
- Heating or cooling an enclosed gas with a definite volume obeys Gay-Lussac's law, which declares that the pressure is proportional to its absolute temperature:

  $P/T = \text{constant}.$
- Finally, the variation, heating or cooling, of an enclosed gas under the same pressure obeys Charles's law, which states that volume and temperature are proportional to each other:

  $V/T = \text{constant}.$

Pre-experimental process

Before the experimental part, the Arduino-based manometer has to be prepared. The necessary materials are the sensor BMP 280, the Arduino UNO board, four little breadboard wires (jumpers), a syringe, and an elastic tube. The four breadboard wires are passed through the plunger of the syringe, as shown in Fig. 2. The four jumpers are connected to the following sensor pins: VCC (voltage common collector) for supply, GND (ground), SDA (serial data), and SCL (serial clock). The two latter pins (SDA and SCL) enable data communication between the sensor and microcontroller Arduino UNO via

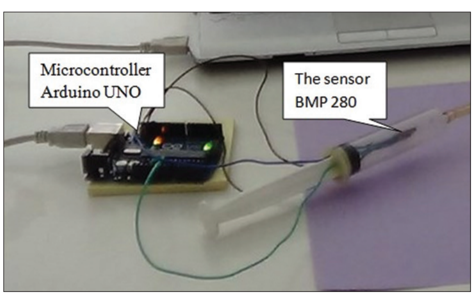

Fig. 1. The sensor is in the sealed syringe and can be used as a manometer.

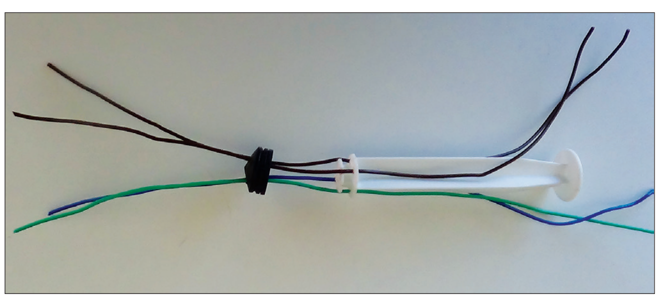

Fig. 2. Using a tiny heated metal pin, we open four little holes in the plunger of the syringe. Then we pass the jumpers through the holes.

 DOI: 10.1119/5.0084657

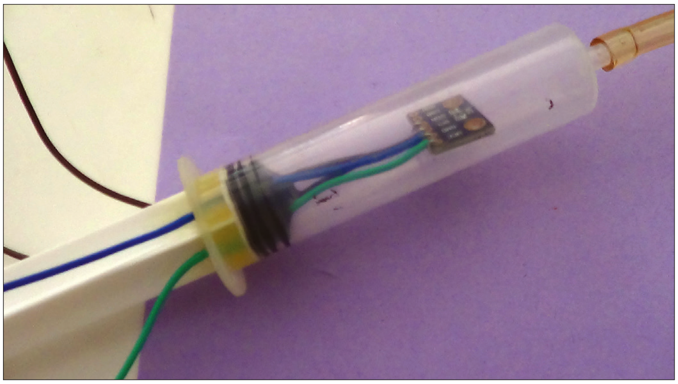

Fig. 3. The plunger of the syringe is sealed with glue.

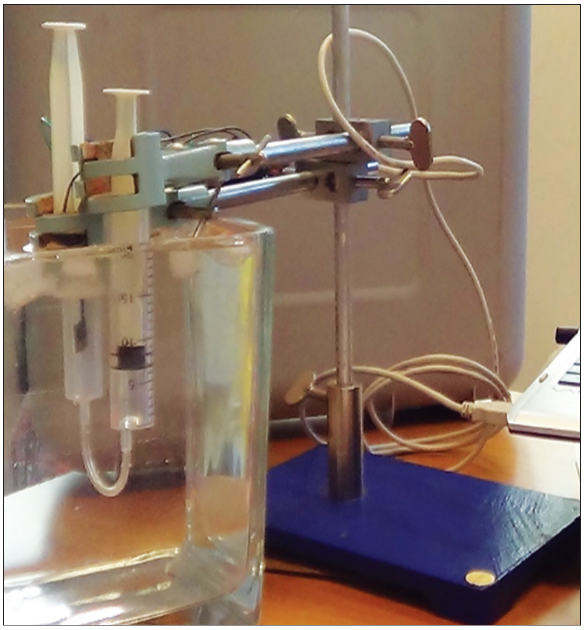

Fig. 4. The experimental setup for the isothermal variation of a gas (air) within the connected syringes.

the I^2C (inter-integrated circuit) digital interface.

The sensor is inserted into the barrel of the syringe, and the plunger is sealed with glue. Any type of glue, e.g., acrylic glue or two-component adhesive, can seal the plunger, as shown in Fig. 3.

The four wires are connected to the 3.3-V power supply, GND, SDA, and SDC pins, respectively, of the Arduino Board UNO, and the digital manometer is ready, as shown in Fig. 1.

The computer program, which collects and prints the pressure and temperature values, may be found in the Appendix[7] (with some additional comments). The program is written in the Editor of the Arduino Integrated Development Environment (IDE),[8] version 1.8.15. The pressure and temperature values are printed to the Serial Monitor, which is embedded in the Arduino IDE.

Experiment

The isothermal variation

The first part of the experiment concerns the measurement of pressure and volume of air at constant temperature, which was 289.5 K. The hub of the manometer syringe, which has a volume of 12 ml, is connected with a short elastic tube to another syringe of 8 ml of air, so the air that they both contain (approximately 20 ml) is the gas under investigation, as shown in Fig. 4. The air is initially expanded to 32 ml by pulling the plunger of the syringe. The first pressure measurement is registered by pressing ENTER on the keyboard. Then the air is being compressed in steps of 4 ml, and the computer registers the pressure at each volume when ENTER is pressed again. Thus, we measured pressure at volumes of 32, 28, 24, 20, 16, and 12 ml.

The measurements of pressure and volume for the isothermal compression described above are in agreement with Boyle's law, which states that gas pressure and volume are inversely proportional. The relative graph of the two varying variables resembles the theoretically expected hyperbola, as shown in Fig. 5. If the variation is slow, the temperature of the gas remains practically the same, and the water bath surrounding the enclosed gas could be omitted.

Variation under constant volume

We proceed to investigate the variation of an enclosed quantity of air, while the volume remains the same. This quantity of air is within our sensor–syringe system and occupies 12 ml. We have just closed the hub of the syringe to be sure that the volume will be the same throughout the experiment, which demands a water bath for varying the temperature of the air that is enclosed in the syringe. By adding water of different temperature, the temperature of the air within the syringe varies. The value of pressure for eight different temperature values and the ratio P/T, which remains practically the same, imply that for an enclosed gas of constant volume, pressure and absolute temperature are proportional. The relative P–T graph for this quantity of gas (12 ml) is shown in Fig. 6.

Isobaric variation of an enclosed gas

This procedure investigates the relation of volume of an enclosed gas to its absolute temperature, under constant pressure. The experimental setup for an isobaric variation is identical to that we used for the isothermal variation, shown in Fig. 4. The gas is heated by adding hot water in the bath around the syringes. The plunger of the one syringe is free to move, when the pressure in the gas is different from that of the atmosphere, i.e., 1.02 atm at the time and place of the experiment. When the plunger is not moving, the pressure in the gas is equal to the atmospheric pressure. We seize every such opportunity (equilibrium state) to measure the temperature and the volume of the gas. The ratio (volume)/(absolute temperature) remains roughly the same during the heating of the enclosed quantity of air under atmospheric pressure, justifying the conclusion that volume and absolute temperature are proportional. The relative V–T graph is shown in Fig. 7.

For a more precise implementation of the isobaric variation, friction should be eliminated. A lubrication film around the moving plunger could be a solution, or a syringe made of glass could be considered. The moving plunger thus becomes more responsive to pressure differences.

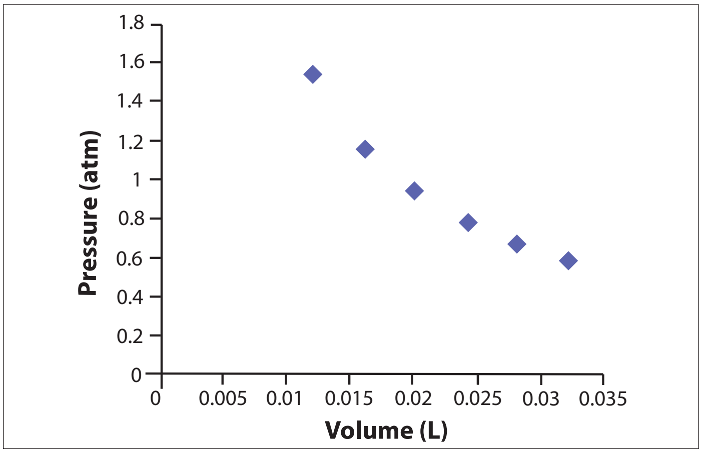

Fig. 5. ***P–V*** **graph of the isothermal compression.**

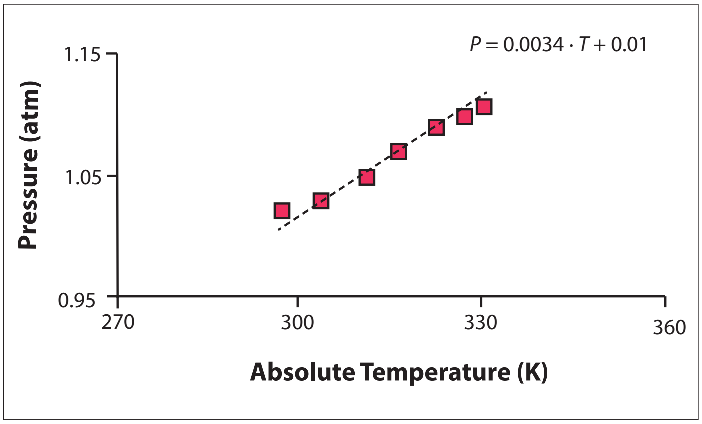

Fig. 6. The pressure vs. temperature graph is almost a straight line.

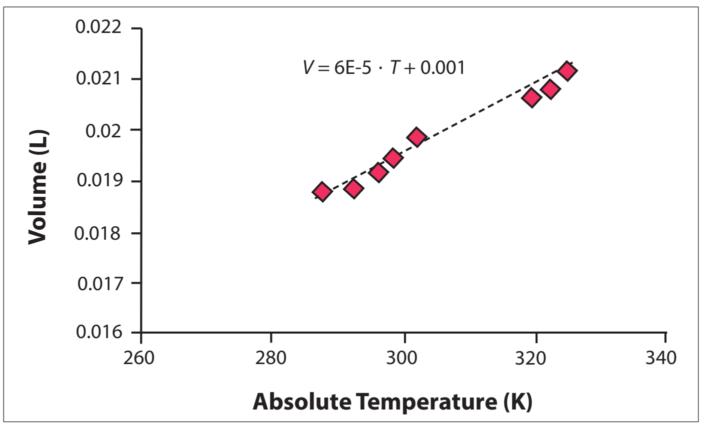

Fig. 7. The relation of volume to absolute temperature is almost linear.

Conclusion

This is an experimental exercise for discovering the laws of gases. Although the proposed arrangement was applied to measure pressure and temperature of enclosed air, examining the three laws of gases in a simple and unified way, it is by no means limited to these specific experiments. On the contrary, the device proposed in this paper may enrich any physics laboratory with a fast and precise digital manometer at a very low cost, which can help teachers and students perform numerous experiments easily and with precision. Furthermore, students are encouraged to participate in the preparation of the experimental setup, and this may be considered a case of STEM education, not only for motivational reasons, but also for learning about various topics like basic electronics and computer programming.

Acknowledgments

I am very grateful to Dr. Athanasios Alexellis for many helpful critical points. I am also thankful to referees for their helpful suggestions. I also thank the IT specialist, J. Antonakos.

References

1. Š. Kubínová and J. Šlégr, "Physics demonstrations with the Arduino board," *Phys. Educ.* **50**, 472–474 (2015).
2. Arduino Community Forum, https://forum.arduino.cc/.
3. A. A. Moya, "Studying Avogadro's law with Arduino," *Phys. Teach.* **57**, 621–623(2019).
4. R. Salar, "An Arduino-based experiment designed to investigate gas pressure," *Phys. Teach.* **59**, 202–204(2021).
5. "BMP280 Digital Pressure Sensor," https://cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf.
6. R. A. Serway and J. W. Jewett, *Physics for Scientists and Engineers with Modern Physics* (Cengage Learning, Boston, 2013).
7. Readers can access the Appendix at *TPT Online* at https://doi.org/10.1119/5.0084657, in the "Supplementary Material" section.
8. Arduino Software, https://www.arduino.cc/en/software.

Athanasios Gkourmpis *has been a high school physics teacher in southern Athens (Greece). Since 2019, he has been the director of the 1st Laboratory Centre for Physical Sciences in the southern section of secondary education in Athens (N. Smyrni). The target of the laboratory is to reinforce the experimental teaching of science disciplines at the schools of the region.*

nasosgkourmpis@gmail.com