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An experiment to observe Stevin's law with an Arduino

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Abstract

Using an Arduino board, a distance and a pressure sensor, we propose in this paper an experiment to verify Stevin's law. We measure pressure as a function of liquid depth and show that both parameters have a linear relationship. We did this for water and, by the linear relationship between both parameters, we calculate its density.

S Supplementary material for this article is available online

1. Introduction

Stevin's law states that the pressure at any point within a fluid at rest is only proportional to the depth of that point, i.e. the pressure inside a fluid increases with the depth.

$$P = P_0 + \varrho g h \tag{1}$$

where P_0 is the atmospheric pressure, ϱ is the fluid density, g is the gravity acceleration, and h is the depth.

Measuring pressure due to a liquid column is a traditional practice in physics laboratories. It can be done, for example, measuring the mass of the liquid inside a graduated cylinder as a function of the height of the liquid. Knowing the weight of the liquid and the area of the cylinder we can measure the pressure. Another way to measure the pressure as a function of depth is to connect one side of a rigid tube to a U-shaped manometer. The other side can be immersed in the liquid and it is possible to measure the liquid height difference in a manometer for each depth. Macchia [1] presents a simple way to measure the pressure at a point inside a liquid using a smartphone but this proposal is restricted to the use of high-end devices that comes with a barometer. Because of the low cost and easy access, the Arduino board can be used to measure pressure and height data. Here we present an experimental setup to measure the cited parameters. With the data collected for tap water, we verify Stevin's law and calculate the density of the liquid.

2. Experimental setup

In this experiment, we use a pressure sensor (MPX5010DP) to measure the pressure at the bottom of a 7 cm diameter and 40 cm tall graduated cylinder. We fix the pressure sensor on top of the graduated cylinder. A small diameter tube (internal diameter 6 mm), connected to the sensor, was fitted to the graduated cylinder is such a way that the end of it stays at the bottom of the

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cylinder. We also fix an ultrasonic sensor (HC-SR04) to the top of the cylinder. The ultrasonic sensor is responsible to measure the height of the liquid column. Both sensors are connected to an Arduino board that sends to a serial port the values of pressure and height of the column liquid when we fill the cylinder with the liquid (we use water and soy oil). A scheme of the experimental apparatus and a picture of ours is shown in figure 1.

The MPX5010DP is a differential pressure sensor, which means that the pressure is measured is based on a reference pressure. In our case, atmospheric pressure is used as a reference, keeping one of the duct doors open to the air and the other is connected to the tube that goes inside the graduated cylinder. The output signal of the sensor is an analog voltage (V_{out}) that varies depending on the pressure (P). We used the calibration equation given by the datasheet. The relationship between the analog signal and pressure is given by:

$$V_{\text{out}} = V_s \times (0.09 \times P + 0.04) \quad (2)$$

where V_S is the source voltage (5 V). Figure 2 shows the circuit sketch where the HC-SR04 and MPX5010DP are connected to the Arduino board. To prevent noise, we add a capacitor filter circuit as proposed at the MPX5010DP datasheet [2].

We built the source code is such a way that it sends it to the Arduino IDE Serial Monitor the values of the liquid height and relative pressure (in the base of the cylinder). We present our proposed source code in the supplementary material (stacks.iop.org/PED/55/033004/mmedia). In that code, the height is calculated from the distance of the liquid surface, measured by the sensor, minus the height of the sensor relative to the base of the graduated cylinder. Once the Arduino begins, it asks for a command to start the measurements and another to stop them. The values are collected after a second and presented in the Serial Monitor.

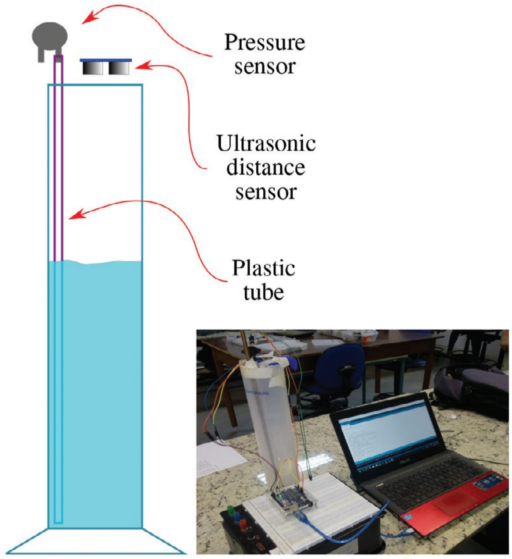

Figure 1. Scheme of the experimental apparatus. The inset shows a picture of our apparatus mounted in the physics lab.

3. Results and discussion

Figure 3 shows the results of pressure as a function of liquid column height for water. As mentioned before, we filled the cylinder with the liquid, and during this procedure, the Arduino collected the data for each second. When we finished filling, we copy the data and plotted it (figure 3). As expected, a linear behavior can be observed in accordance with the theory (equation (1)). Because we measured the relative pressure ($\Delta P = P - P_0$), when the cylinder was empty the relative pressure is zero.

From a linear fit, we get the slope of $(10.3 \pm 0.2)\,\text{kPa m}^{-1}$. Considering the gravitational acceleration $g = (9.8 \pm 0.1)\,\text{m s}^{-2}$, we calculated the density of water that is equal to $\varrho_{\text{water}} = (1.05 \pm 0.02)\,\text{g cm}^{-3}$. This result is close to the density of water, it is higher than expected because we used tap water instead of pure water.

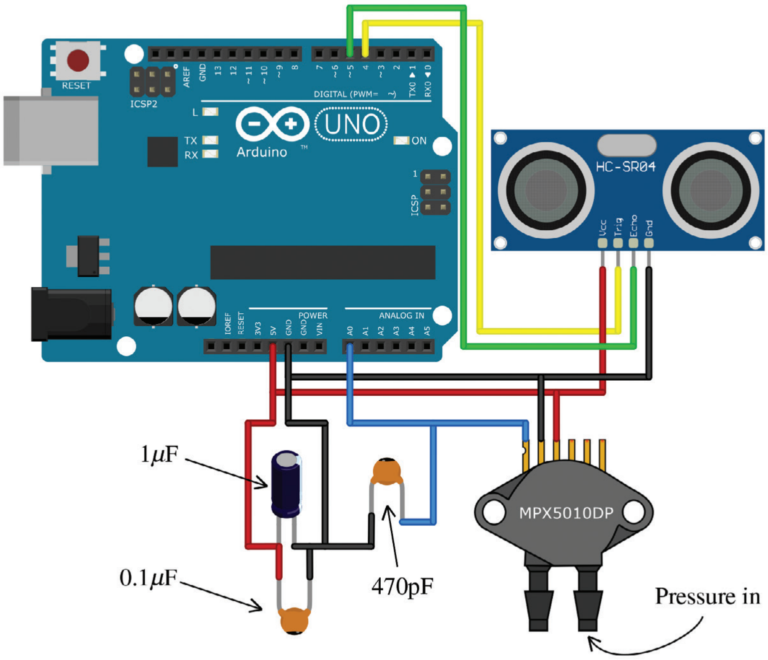

Figure 2. Sketch of the circuit with Arduino [3].

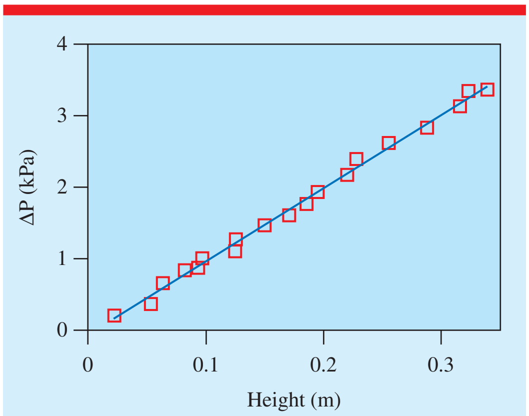

Figure 3. Graph of relative pressure as a function of the water column height.

4. Conclusion

Here we present an experimental apparatus that uses an Arduino to verify Stevin's law and calculate the density of a liquid. Filling the graduated tube with tap water we observed the linear behavior of relative pressure with the liquid column height as established by Stevin's law. The tap water density was calculated as $\varrho_{\text{water}} = (1.05 \pm 0.02)\ \text{g cm}^{-3}$.

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[2] MPX5010DP datasheet (www.nxp.com/docs/en/data-sheet/MPX5010.pdf)
[3] Image made with Fritzing (http://fritzing.org/home/)

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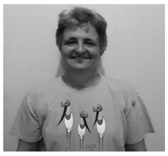

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