**A05\_Boyle's Law**

[Subheading]

How do you verify a physical law?

[Subject symbol: Ma]

Time:

10-20 minutes

Level:

From grade 3

Concepts: Boyle's Law, volume, pressure

Skills: Designing experiment setup, identifying deviations, adjusting model

[Introduction Box]

Experimentally verifying a formula might seem trivial, but when you ask students in a concrete case - such as Boyle's Law - how to do it, problems arise. What do you set, what do you measure? When do you consider results to sufficiently match theory? With Boyle's law, results often don't align. Where's the issue? In residual volume in the hose and the tip of the syringe. By incorporating that into our model, we achieve a good fit with the measured data.

[End box]

[A05\_NvV02\_Fig1\_setup; caption]

Figure 1. Setup with syringe and pressure sensor.

[A05\_NvV02\_Fig2\_measurements; caption]

Figure 2. Measurements of gas pressure against volume.

**Needed:**

Setup with a syringe, a pressure sensor, and an interface with Coach7 as a measurement and modeling program; Coach files (available on the NVON site).

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| Figuur 1. Opstelling met injectiespuit en druksensor | Figuur 2. Metingen van gasdruk tegen volume |

Figure 1. Setup with syringe and pressure sensor

Figure 2. Measurements of gas pressure against volume

**Preparation:**

Set up the apparatus as shown in Figure 1. Connect the pressure sensor to an interface and start the Coach measurement program. Choose from the standard activities (Measure, Upper Level, Physics) activity 7. Boyle's Law. Measure the volume manually and enter it into Coach. Conduct a measurement with at least 8 pressure and volume readings. Especially take measurements at higher pressures and smaller volumes since this is where issues with residual volume manifest. Save the measurement as a separate result file. (The measurement can also be done during the demonstration.)

**Execution**:

1. Draw a closed volume of gas on the board (circle or square). What happens to the pressure if we decrease the volume? Students will likely have little trouble with this.
2. But how exactly does it work? Can we encapsulate it in a formula? Boyle posited pV = constant, or for two situations: p₁V₁ = p₂V₂. What do you need to do to see if such a theoretical formula aligns with reality? How could you do that? (very brief student discussion in pairs).
3. Now the teacher shows the setup with a syringe with volume indication and a pressure sensor. What should I do now to verify Boyle's Law? Let the students think for a moment.
4. Short discussion... Outcome: set different volumes and measure the pressure to see if it matches the formula.
5. Then measure. Compare measured results with theoretical results.
6. Measured result doesn't match, what could be the reason? (brief student discussion in pairs).
7. How can we adjust our model pV = constant? (add constant term to V, the residual volume).
8. How can we determine its size? Is there a clever way to transform our graph and extract it from there? (from the deviation of the graph).

Plot the graph of 1/p against V by creating a variable 1/p in the Data Table. Show the graph of 1/p against V to the students. Ask the students why it doesn't go through the origin. Have them read the residual volume from the graph.

1. Save the measurements as a result file. Open and execute the corresponding graphical model and examine the result.
2. Import the graph of the measurements as a background graph. Have students indicate where the differences are and try to get explanations from them.

**Physical Background:**

Pressure and volume of a closed quantity of ideal gas behave according to Boyle's Law.

Due to the residual volume of the hose and the pressure sensor, the hyperbola of the measurements will deviate slightly from the volume read from the syringe. If we call the residual volume ΔV, then Boyle's Law becomes:

P.(V+ΔV)=constant(=n.R.T)

The ideal gas law assumes that the attraction between molecules is zero and that the molecules themselves are point particles that occupy no volume. Van der Waals took into account the attraction and volume of molecules. The pressure is corrected for attraction in it, and the volume of molecules is taken into account. These corrections become important at high density. The constant b is then roughly the volume of 1 mole, and the constant a depends on the attraction between molecules. These constants are determined empirically. For details, we refer to well-known textbooks such as Young & Freedman (2015). Coach models for Boyle's Law and for the Van der Waals version are available on the site.

(p+(n^2 a)/V^2 )(V-n∙b)=n∙R∙T

**Tips:**

Place the setup clearly on the lectern. Clearly show the value of the pressure sensor on the digital board. Show the students that the syringe is being depressed and explicitly mention the volume of the syringe.

[A05\_NvV02\_Fig3\_graphical model; caption]

Figure 3. Graphical model of Van der Waals gas law.

[A05\_NvV02\_Fig4\_model result; caption]

Figure 4. Comparison of model results of Boyle (orange) and Van der Waals (green).

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| Figuur 3. Grafisch model van gaswet van Van der Waals. | Figuur 4. Modelvergelijking Boyle (oranje) versus Van der Waals (groen). |

Figure 3. Graphical model of Van der Waals gas law. Figure 4. Model comparison Boyle (orange) versus Van der Waals (green).

**Further Research:**

What influence does a lower or higher temperature have on gas pressure measurements?

The graphical model also shows the Van der Waals gas model. Plot this graph alongside Boyle's law and ask students to explain how the differences arise. At what pressures does Boyle's law deviate from Van der Waals' gas law?

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Associated Coach files on the site:

[A05\_NvV02\_1BoyleExperiment.cma7]

[A05\_NvV02\_2BoyleModel.cma7]

[A05\_NvV02\_3Van der Waals Model.cma7]

[A05\_NvV02\_4Boyle Van der Waals Model Comparison.cmr7]

Literature:

Young, H.D. & Freedman, R.A. (2015). University Physics 14th edition, Pearson, chapter 17 Heat and Temperature.