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Question 1: Falling on a BMW; Question 2: Recycling Contact Lenses

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Table I. Measured values and literature values for different gases.

Gas	Frequency (Hz)	Experimental result ($m \cdot s^{-1}$)	Literature value ($m \cdot s^{-1}$, 20 °C)	Deviation (%)
CO_2	4285	288	267	8
Ar	4764	320	319	0
N_2	5338	358	349	3
He	15,217	1022	1007	1

Experimental procedure and evaluation

First the constant k is determined in a preliminary test by analyzing the tone of the whistle (Fig. 1). For the dog whistle used in the experiment, a natural frequency of 5227 Hz was obtained with breathing air (Fig. 2). With the speed of sound at a body temperature of 36 °C (351 m/s),[5] k is 14.89 m^{-1}. Afterwards, the whistle is connected to different gases (Fig. 3),[6,7] the resulting frequencies are determined, and the respective sound velocities are estimated using the previously calculated constant k. Using carbon dioxide, a frequency of 4285 Hz was obtained for the dog whistle, which gives the speed of sound as 288 m/s.

$$c_{CO_2} = \frac{f_{CO_2}}{k} = \frac{4285\,\text{Hz}}{14.89\,\text{m}^{-1}} \approx 288\,\frac{\text{m}}{\text{s}}.$$

The literature value[8] at a temperature of 20 °C is 267 m/s, so the deviation of the experimental result is 8%. For the other three gases used, the deviation was even smaller (Table I).

Why are the experimental values systematically larger than the literature values? The temperature for the exhaled air (36 °C) displayed here represents an extremum. The probable value should be lower since the breathing gas cooled down by the whistle from body temperature. Therefore, a larger k value is expected and the result would be even closer to the literature value. For example, at 30 °C, the speed of sound in the exhaled air would be 348 m/s and $k \approx 15.02\ m^{-1}$. Because of its simplicity and accuracy, the experiment is particularly suitable for teaching physics.

References

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3. S. O. Parolin and G. Pezzi, "Smartphone-aided measurements of the speed of sound in different gaseous mixtures," *Phys. Teach.* **51**, 508–509 (Nov. 2013).
4. App Schallanalysator, https://spaichinger-schallpegelmesser.de/schallanalysator.html.
5. To estimate the speed of sound in exhaled air, we weight the velocities at body temperature (36 °C)[8] of the three main gases by their proportions [nitrogen 78% (358.4 m/s), oxygen 17% (334.6 m/s), carbon dioxide 4% (358.4 m/s)] and obtain 351 m/s.
6. To achieve a temperature of about 20 °C it is necessary to use a long hose (e.g., 2 m). Then the gas cooled down during expansion from bottle pressure can approximately warm up to room temperature.
7. Kyle Forinash and Cory L. Dixon, "Helium and sulfur hexafluoride in musical instruments," *Phys. Teach.* **52**, 470–473 (Nov. 2014).
8. http://www.peacesoftware.de/einigewerte/einigewerte_e.html.

Fermi Questions

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Question 1: Falling on a BMW

A New Jersey man fell out of a 9th story window, landed on a BMW, and survived. How much force was exerted on him by the car?

Question 2: Recycling contact lenses

My eye doctor now has a special bin to recycle contact lenses. Is this worth it? How many lenses would need to be recycled to account for the dedicated bin?

Look for the answers online at tpt.aapt.org under "Browse," at the very end of the current issue.

Question suggestions are always welcome!

For more Fermi questions and answers, see *Guesstimation 2.0: Solving Today's Problems on the Back of a Napkin,* by Lawrence Weinstein (Princeton University Press, 2012).

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