Absolute zero: An upper-secondary acoustic levitation lab

Andreas JOHANSSON, Sebastian KILDE LÖFGREN, Jonas ENGER

Department of Physics, University of Gothenburg, Gothenburg, Sweden

Abstract. The concept of sound waves is central to our everyday experience and part of upper-secondary school physics. Acoustic levitation represents an application of standing-wave phenomena, which has seen a surge in popularity due to the introduction of cost-effective ultrasonic speakers. However, acoustic levitation by affordable speakers remains absent from upper-secondary physics education. LeviLabs is a low-cost, user-friendly, and easily reproducible acoustic levitation experiment we have developed to measure the wavelength and speed of sound. This study proposes using LeviLabs to integrate acoustic levitation into the classroom setting to measure absolute zero.

Introduction

The concepts of interference, resonance, standing waves, and their technical applications are part of the Swedish upper-secondary physics curriculum [1]. These concepts can all be experienced in an acoustic levitation experiment. Furthermore, such an experiment can offer students visual and tactile experiences of these concepts that can help develop their understanding of sound.

An acoustic levitation apparatus produces an acoustic pressure field via one or more piezo speakers. Levitation of small objects is made possible due to the acoustic forces arising as the surface of these objects interacts with the pressure field. In the acoustic field, pressure nodes and anti-nodes will arise during constructive interference. The acoustic force on the object will be directed toward the center of the closest pressure node. Within a certain range, its strength will increase with the distance to the node. The result is an acoustic force that can be strong enough to counteract the gravitational force on an object.

The advent of low-cost transducers (speakers) has accelerated the use of acoustic levitation in a variety of research areas [2]. Still, it has not yet come to any extended use in physics education, except for simple demonstrations [3-5]. The current study is guided by the following research question: How can upper-secondary school physics students investigate the relationship between the speed of sound and temperature?

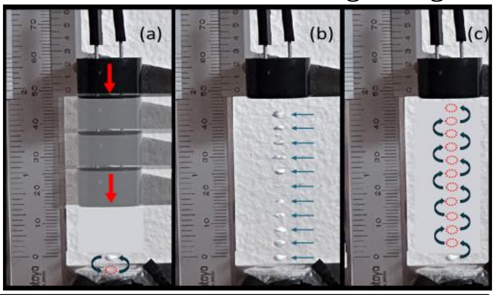

Fig. 1. Three activities to measure the wavelength of sound. LeviLab1 (a), a Styrofoam particle is placed on the bottom. The top speaker is continuously lowered, and the caliper reading is noted every time the particle “pops up” into the first node as the two signals interfere constructively. The wavelength is determined using a linear regression line fitted to the displacements versus the number of pop-ups. Levilab2 (b), several particles are levitated in the nodes. The distance between them is approximately half the wavelength. The caliper is used to determine their positions. Levilab3 (c), a single particle is moved from node to node. Its positions are used to determine the

Method

The LeviLabs experiment was designed to fit the budget, time and ease-of-use needed for an upper-secondary lab experiment to be practical. It consists of two opposite low-cost ultrasonic (40 kHz) speakers mounted on a caliper. It can be used to investigate sound concepts by measuring wavelength and speed of sound with different procedures (see Fig. 1). Each of the LeviLabs can be performed with the two speakers emitting in phase (2Ti) or out of phase (2To), or with a reflector instead of the top speaker (TR). A thermometer is used to measure the air temperature to calculate the speed of sound as a control since the speed of sound is temperature-dependent [5].

On a cold winter day (-6 °C) a small room with a door out was used. Starting at room temperature (22 °C) the door out was held open for a while and the heating of the room was turned off. The cold air from outside mixed with air in the room and lowered its temperature. The LeviLab1 (2To) procedure (see Fig. 1) was used to determine the speed of sound and the thermometer was used to measure the temperature. Speed of sound measurements were collected at decreasing temperatures. To determine absolute zero, two regressions were performed: linear and a power function with a degree of 0.5 (Fig. 2).

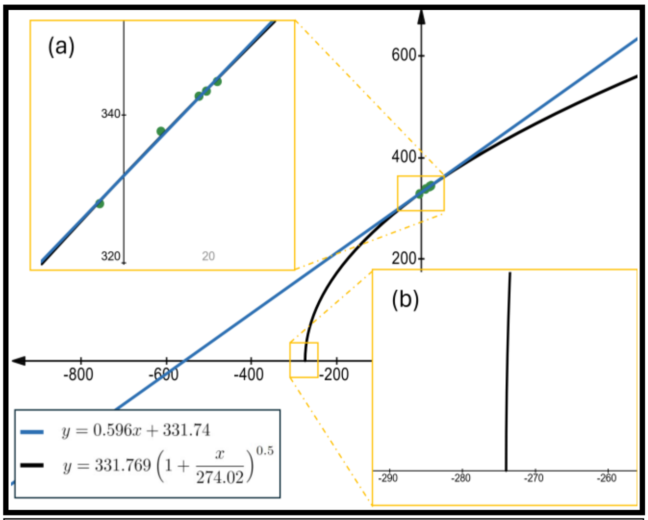

Fig. 2. Linear regression (blue) and regression with a power function (black). Inset (a) is zoom-in on datapoints. Inset (b) is zoom-in on root of power regression, the measurement of absolute zero.

Results and discussion

The calculated value for absolute zero using the linear regression was -556 °C, which is far too low compared to the theoretical value of -273.15 °C. However, the calculated value using the power regression was -274 °C, which is close to the theoretical value.

Conclusion

We found that acoustic levitation using the upper-secondary school physics experiment LeviLabs can be used to investigate the relationship between sound and temperature in a lab to determine absolute zero. We add to the very limited amount of acoustic levitation labs available for the upper-secondary level. Thereby, we increase the potential for developing students' understanding of sound and its relation to other concepts such as temperature through a visual and tactile experience of sound. Furthermore, the proposed lab offers opportunities to discuss both mathematical and physical arguments for what type of regressions to use during the analysis of experimental data.

References

[1] Swedish National Agency for Education. (2022). Physics [Subject syllabus].

[2] M. A. B. Andrade, A. Marzo, J. C. Adamowski, Acoustic levitation in mid-air: Recent advances, challenges, and future perspectives, *Applied Physics Letters* **116**(25) (2020).

[3] R. Cordaro and C. F. Cordaro, A demonstration of acoustical levitation, *The Physics Teacher* **24**(7) (1986) 416.

[4] R. S. Schappe and C. Barbosa, A simple, inexpensive acoustic levitation apparatus. *The Physics Teacher* **55**(1) (2017) 6–7.

[5] A. Lopatka, Visualizing acoustic levitation. *Physics Today* **74**(7) (021) 64.

[6] D. A. Bohn, Environmental effects on the speed of sound, *Journal of the Audio Engineering Society* **36**(4) (1988) 223–231.