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How to use a candle to study sound waves

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Abstract

This work makes use of video recording at 220 frames/s, and video analysis with Tracker to "see" the effect of air particles in motion and to conclude that infrasound waves, just like audible sound waves, are periodic. One can observe that the air particles' displacement is longitudinal, and therefore conclude that sound is a longitudinal wave. The work also shows the inverse relationship concerning the amplitude of the flame's displacement and the distance between the flame and the loudspeaker. The experimental setup provides a good opportunity to explore sound waves in a classroom, in a very original and engaging way.

Keywords: acoustic waves, oscillations, physics education, springs (mechanical), student experiments

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It is well known that sound waves in air are longitudinal waves. Although teachers use analogies, such as compressing horizontal springs, to demonstrate how longitudinal waves look like, students still present some difficulty in understanding that: (1) sound waves correspond to oscillations of air particles, and (2) there is no “air flow” (transport of particles) in sound waves [1,2]. These difficulties arise from the impossibility to actually “see” air particles moving, and from the common sense idea that free particles always have translational motion.

A simple experiment to overcome these conceptual problems can be done with a candle and a 5 W loudspeaker [1,3]. The candle is put at about 2.6 cm in front of the loudspeaker center; then a sinusoidal low frequency signal (~10 Hz, measured by using an analogic oscilloscope), produced by a wave generator, is transformed by the loudspeaker in an infrasound wave. Although the oscillatory motion of the loudspeaker membrane is clearly visible, the absence of an audible sound lets students wonder what will happen to the flame of the candle. Our experience with students is either they believe nothing happens (no sound, no wave) or they expect the flame leans away from the loudspeaker due to an invisible air pressure. The amplitude of the generated wave must be chosen to produce a visible vibration of the flame, and to avoid strong distortions of the flame’s shape (this will help the video analysis of the flame’s notion, as we will show in the following). The voltage to produce such a wave depends strongly on the characteristics of the loudspeaker. A very complete and interesting study concerning the flame motion behavior has been recently reported by Hrepic, Nettles & Bonilla [4], and is out of reach of this paper.

This experiment has a tremendous impact among students: out of nowhere, the candle’s flame “magically” starts to oscillate back and forward, in a very clear longitudinal and oscillatory motion. Such observation produces a much participated discussion among students, due to its counter-intuitive results. Immediately, they discard the idea that only audible signals perturb the air particles; secondly, the back and forward motion of the flame dismiss any (very common) conception of a constant pressure force acting away from the speaker, and the hypothesis of a periodic oscillatory motion can now be discussed in class. In order to study the physical characteristics of the wave propagating within the air particles, students need to look in detail how the flame oscillates.

The motion of the candle’s flame was recorded at 220 frames per second, with a Panasonic FZ 100 LUMIX digital camera. The video was analyzed by the freeware modeling video software *Tracker* [5,6,7].

Video data of the flame's oscillation can be collected with *Tracker* in either automatic or manual mode: automatic mode is more convenient and works better when a good contrast between the object (the flame) and the background (a black scenario) is provided; if this is not the case, then the hard and painful manual work must be done. In either case, one should attend to a particular point of the flame, that must be chosen by the user (we recommend a point at one of the extremities of the flame at its mid-height, as shown in figure 1).

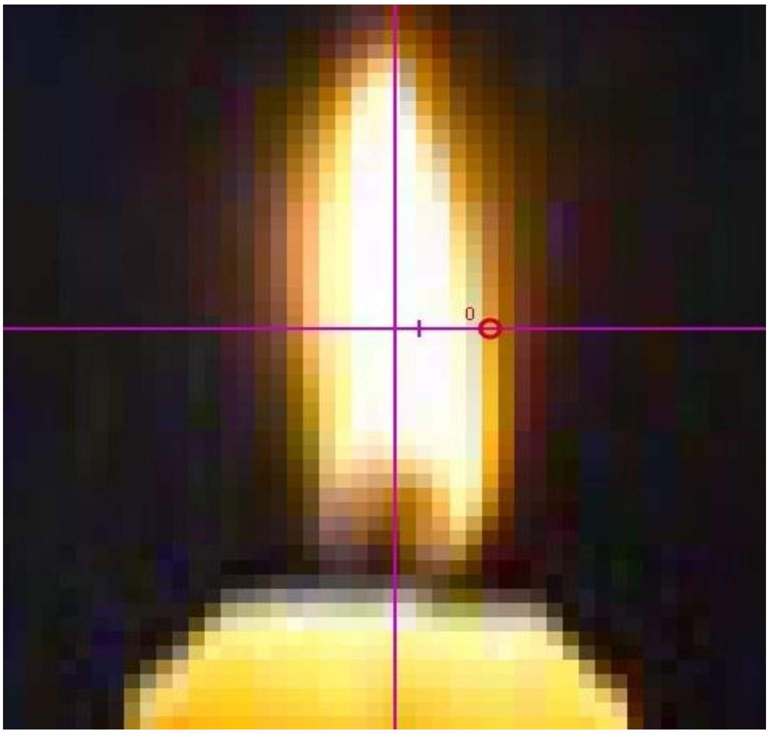

Figure 1: Initial position at the extremity of the flame (red circle). The vertical and horizontal lines represent the reference frame.

Results were then analyzed by *Data Tools* module of Tracker and show a sinusoidal-like motion of the flame (figure 2). A curve fit allows the determination of the wave frequency, which in this case is about 10.3 Hz, and also the amplitude of the displacement of the flame in the horizontal direction (approximately 0.10 cm). This experiment is, therefore, a very interesting and easy way for students understand what happens with air particles when a wave propagates in that medium. It is also useful to promote peer discussion and resolve conceptual conflicts among students, very commonly detected when teaching formal contents. In this case, we have used an infrasound sound to cause more impact in class, but sound waves can also be studied with the very same experimental procedure and recommendations described above.

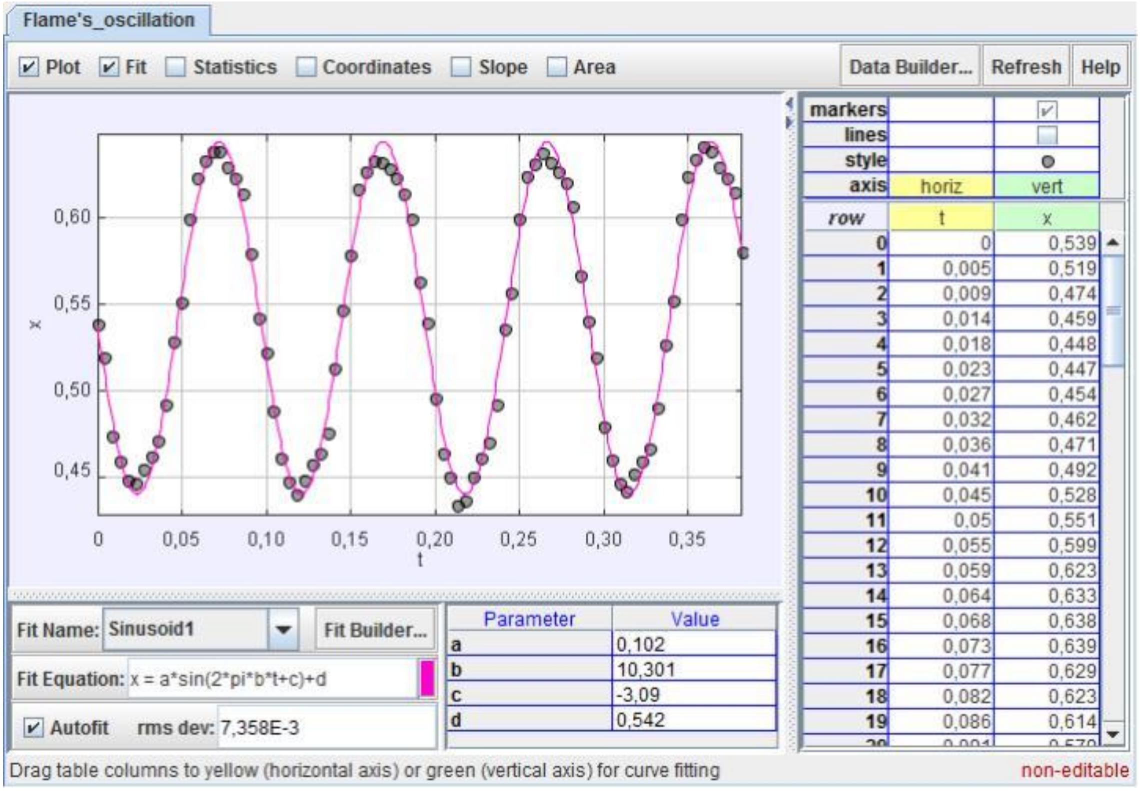

Figure 2: *Data Tools* analysis of the flame's oscillation.

We can go further with this experiment and investigate how the amplitude of the displacement (A) of the flame (i.e., the air molecules oscillation) changes with the distance (d) to the loudspeaker (the sound source). Results of this study are presented in figure 3, where we can see that the experimental values of A follow a reasonable linear fit with $1/d$.

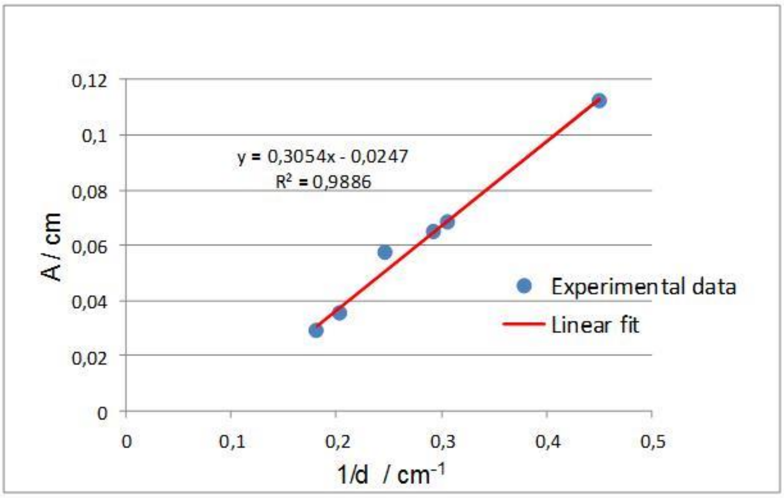

Figure 3: Experimental data of the flame's oscillation amplitude as a function of the inverse distance to the loudspeaker. The square Pearson correlation coefficient (R^2) suggests a good linear relationship.

This result can be interpreted as a consequence of the propagation of sound in a 3-D space: the physical model for sound waves predicts that the sound intensity is proportional to A^2, and decreases with $1/d^2$. [8] Therefore, the amplitude A of the flame oscillation should decrease linearly with $1/d$, which is exactly what we have obtained experimentally. The additional educational interest of this study is to provide experimental evidence of the inverse law dependence of air particles' motion amplitude, compared to the so disseminated inverse square law for sound and light intensity. This experiment helps students do understand that molecular motion has a different behavior with distance when compared to sound intensity.

Conclusion

With this simple experiment, students can: (1) "see" the effect of air particles in motion; (2) conclude that infrasound waves, like sound waves, are periodic; (3) identify that the air particles displacement is longitudinal, therefore sound is a longitudinal wave; (4) study the inverse relationship concerning the amplitude of the flame's displacement and the distance between the flame and the loudspeaker. The experimental setup provides a good opportunity to explore sound waves in classroom, in a very original and funny way.

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