7.3 The Speed of Sound

In this section, the speed of sound in air is developed through an activity as well as an investigation. The value is then applied to calculations involving the effects of temperature and the type of medium.

Achievement Chart Categories	Assessment Opportunities/Specific Expectation Addressed	Assessment Tools
Knowledge/Understanding	Practice Questions Understanding Concepts, q. 1–4 WS1.01, WS1.02, WS1.03 Section 7.3 Questions Understanding Concepts, q. 1–8 WS1.01, WS1.02, WS1.03	Rubric1: Knowledge/Understanding
Inquiry	Activity 7.3.1 Investigation 7.3.1 WS1.02, WS1.03, WS2.02	Rubric 2: Inquiry Skills
Making Connections	Section 7.3 Questions Making Connections, q. 9 WS1.02	Rubric 4: Making Connections

Expectations Addressed

Overall Expectations—WSV.01, WSV.02
Overall Skills Expectations—SIS.01, SIS.02, SIS.03, SIS.07
Specific Expectations:

- WS1.01 define and describe the concepts and units related to mechanical waves (e.g., longitudinal wave, transverse wave, cycle, period, frequency, amplitude, phase, wavelength, velocity, superposition, constructive and destructive interference, standing waves, resonance)
- WS1.02 describe and illustrate the properties of transverse and longitudinal waves in different media, and analyze the velocity of waves travelling in those media in quantitative terms
- WS1.03 compare the speed of sound in different media, and describe the effect of temperature on the speed of sound
- WS2.02 design and conduct an experiment to determine the speed of waves in a medium, compare theoretical and empirical values, and account for discrepancies

BACKGROUND INFORMATION

For your reference only, the speed of sound in air varies as the square root of the temperature in kelvin—that is, $\sqrt{T(°\text{C}) + 273°\text{C}}$. This is approximately a linear relationship in the region of room temperature.

The speed of sound in the materials is related to the elastic modulus (one dimension) or bulk modulus (three dimensions) and density of the materials in the following ways:

$$v \propto \sqrt{\frac{\text{elastic modulus}}{\text{density}}}$$

$$v \propto \sqrt{\frac{\text{bulk modulus}}{\text{density}}}$$

Temperature is the only variable discussed here that affects the speed of sound in air.

Other factors—for example, atmospheric conditions and elevation above sea level—affect the speed only slightly.

The equation used to calculate the speed of sound in air at various temperatures (page 243) is approximate and applies best to temperatures relatively close to 0°C.

In general, the speed of sound in gases is less than that in liquids or solids. The elastic properties of molecules vary; these properties will affect the transfer of sound energy from one molecule to the next. This makes for exceptions to the above rule. For example, the speed of sound through lead and hydrogen is similar. Another example is solid rubber, in which the speed of sound is less than it is in most gases.

The speed of sound in air increases with the temperature, but the speed of sound in water decreases if the temperature increases.

The apparent loudness of a sound underwater has very little to do with increased speed. In air, the energy loss is largely due to the conversion of sound energy to thermal energy, whereas in water the loss is less per metre of transmission.

ADDRESSING ALTERNATIVE CONCEPTIONS

It is a common misconception that the speed of sound decreases at higher altitudes because of decreased air pressure. Decreased air pressure is a minor factor—the main cause is that the lower temperatures at higher altitudes result in lower values for the speed of sound.

Related Background Resources

Nelson Web site:
www.science.nelson.com
for specific Web links

PLANNING

Suggested Time

Narrative/Practice—10 to 20 minutes
Activity 7.3.1—15 to 20 minutes
Investigation 7.3.1—20 to 25 minutes
Section Questions—20 to 30 minutes

Core Instructional Resources

- Solutions Manual
- Reference to the Appendixes: Appendix A5, pages 565–7, has information about percentage difference and sources of error

Supplemental Resources

- Lab and Study Blackline Masters

TEACHING SUGGESTIONS

- The activity and investigation should be done first, followed by development and practice of the speed/temperature relationship.
- The equations involving uniform motion $\left(v = \frac{\Delta d}{\Delta t},\ \Delta d = v\Delta t,\ \Delta t = \frac{\Delta d}{v}\right)$ are required here. If the students have not studied these equations recently (i.e., if units 1 and 2 have not been completed), they should be reviewed.
- If possible, obtain some helium gas. Fill a balloon with helium and inhale one full breath only. When you speak, your voice will be dramatically higher in pitch. This is because the velocity of sound is higher in helium than it is in air. Your vocal cords vibrate at the same frequencies, but the resonant frequency of the column formed by the windpipe, mouth, and so on is higher because it consists of helium, not air (see section 8.6).
- Helium is harmless to the body (it is an inert gas). Nevertheless, this demonstration should be done with caution because the body needs oxygen. Dizziness and fainting can occur if you are not careful. Take several breaths of air between breaths of helium. *Do not allow students* to do this demonstration, no matter how persistent their requests.
- You may want to defer this demonstration and discussion until section 8.6, where resonance and the human voice are discussed.

Activity 7.3.1

- Weather will be a factor in this activity, since the whole class will go outside.
- The results are not as important as understanding the concept of measuring the speed of sound using echoes.
- As seen in the laboratory manual, the results can be quite good—that is, less than the 8% error, but this will depend on the timing device used.
- The results will be much better if a computer, rather than a stopwatch or digital timer, is used.
- Wind can produce errors.
- It is suggested that the computer be reserved for Investigation 7.3.1.

ACTIVITY 7.3.1

Measuring the Speed of Sound Outside

- This activity, although primitive compared with measuring short time intervals with a computer, permits students to measure time with a simple but effective technique.

BEFORE

Teacher Preparation

- This activity could be done by individual students, but time may be a factor, since groups of four would have to do it separately. The activity could be done as a class, sharing common results.

Time: *15 to 20 minutes*

Materials and Equipment:

For the class demonstration or for each group you will need
2 pieces of wooden board (hardwood)
a stopwatch
a thermometer

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Safety and Disposal:

- No safety precautions are necessary.

Assessment:

Students can be assessed on their inquiry skills.

Student Preparation

Students need to know how to apply the equation for the average speed of motion, $v = \frac{\Delta d}{\Delta t}$.

DURING

Assuming you are doing this as a class activity, have at least three different groups perform one trial each.

AFTER

- Compare the results of the various trials.

The speed of sound is determined in this activity by setting up a rhythmic clap between two boards and listening for the echo between claps. For the purposes of this investigation it is assumed that the distance between the source of sound and the reflecting wall is 150.0 m. Students time how long 20 "clap intervals" take and then find the average interval between claps. The sound has travelled four times the distance between observer and wall (600.0 m) in this interval. The speed of sound is calculated and compared with the expected speed when the temperature is taken into account.

Assuming the temperature is 20°C, the expected speed of sound will be

$$\begin{aligned} v &= 332\text{m/s} + \left(0.59\frac{\text{m/s}}{^{\circ}\text{C}}\right)t \\ &= 332\text{ m/s} + \left(0.59\frac{\text{m/s}}{^{\circ}\text{C}}\right)(20^{\circ}\text{C}) \\ v &= 343.8\text{ m/s} \end{aligned}$$

If the average "clap interval" is found to be 1.75 s, this would result in a calculated speed of

$$\begin{aligned} v &= \frac{d}{t} \\ &= \frac{600.0\text{ m}}{1.75\text{ s}} \\ v &= 342.9\text{ m/s} \end{aligned}$$

The percentage error associated with this value is then calculated as

$$\begin{aligned} \%\text{ error} &= \frac{|\text{experimental} - \text{accepted}|}{\text{accepted}} \times 100\% \\ &= \frac{|342.9\text{ m/s} - 343.8\text{ m/s}|}{343.8\text{ m/s}} \times 100\% \\ &= 0.262\%\text{ (three significant digits allowed)} \end{aligned}$$

INVESTIGATION 7.3.1

Measuring the Speed of Sound in the Classroom

- In this investigation, students use high-tech apparatus to determine the speed of sound in air in the classroom.

BEFORE

Teacher Preparation

Time: *20 to 25 minutes*

Materials and Equipment:

Each group of two or three students will need
cardboard mailing tube (closed at one end)
thermometer
button microphone
tape measure
oscilloscope and amplifier, or computer interface

Safety and Disposal:

- No safety precautions are necessary.

Assessment:

- Students can be assessed on their inquiry skills.

Student Preparation

- Students need to know how to apply the equation for the average speed of motion, $v = \frac{\Delta d}{\Delta t}$.

DURING

- If only one setup is available, have student groups take turns taking the measurements.

AFTER

- Discuss with the students how the measurements in this investigation compare with those in Activity 7.3.1.

Extensions/Modifications:

- See the suggestions in questions (g) and (h).