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The Speed of Sound in an Iron Rod

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The speed of sound in a solid has traditionally been measured by inducing resonance in a long rod, sometimes by magnetostriction, sometimes by electrostatic attraction (!), more often by a mechanical driver. Examples of these can be found in A.B. Wood's *A Textbook of Sound*,[1] as well as in other books and in several papers that have appeared in the physics teaching literature.[2-7]

A very agreeable method is found as experiment 7.5 in Whittle and Yarwood's *Experimental Physics for Students*.[8] A metal rod is dropped onto an iron plate. The rod's contact with the plate completes a circuit that drives current through a ballistic galvanometer.

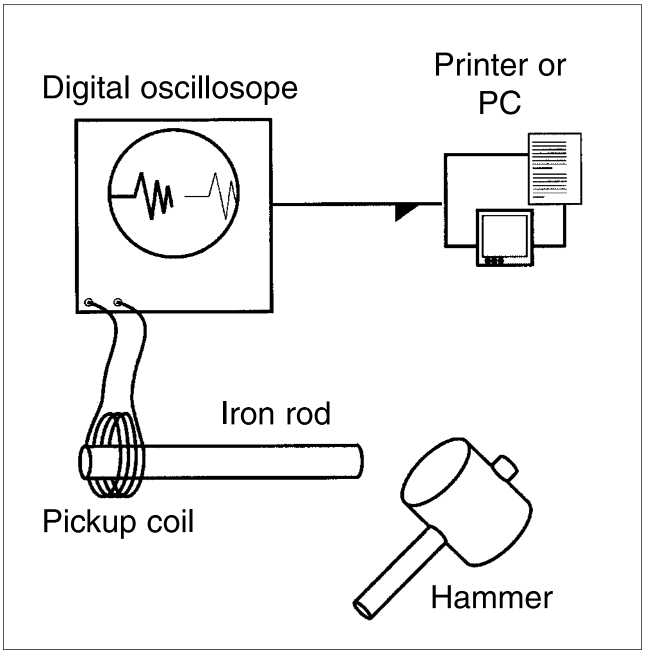

Fig. 1. The pulse generated by the hammer blow travels back and forth in the rod, inducing voltage pulses in the pickup coil.

The rod will bounce when the sound wave set up by the impact returns, breaking the circuit. The rod is caught in the hand, and the charge that has flowed onto a ballistic galvanometer is measured. The idea is very nice pedagogically. The realization that the rod bounces because the sound wave pushes it off is guaranteed to get students' interest. Of course, ballistic galvanometers are not common now and are a little troublesome to use. Also, the plate must be massive and rigid, so as not to contribute its own time delay in pushing the rod off. An obvious improvement is to use the connection made when the rod is in contact with the plate to gate open an interval counter. One does need a counter with a time base of 10 MHz or better to get an adequate resolution. The contact is not very clean, however, and one still needs the massive, rigid plate below. I've used an I-beam section.

A still better way, pedagogically, is to show the sound wave as it travels back and forth in the rod using an oscilloscope that will capture pulses. The method described here requires that a ferromagnetic rod be used. If an end of the rod is struck with a hammer, then a compression wave will propagate down the rod at the speed of sound, reflecting back and forth between the ends. If the rod is slightly magnetized (as it is in the Earth's magnetic field), the increased density at the compression maximum will be accompanied by an enhanced magnetization. When this region of higher magnetic field passes through a pickup coil placed around the rod (see Fig. 1), an emf will be induced. The signal, consisting of a series of pulses, may be fed directly into an oscilloscope. A digital oscilloscope can capture the image and allow the measurements to be saved and measured at leisure, and perhaps printed. Many digital scopes allow a direct dump to a printer or plotter, which requires only the scope and printer. If the scope has a GPIB or serial output, one can interface it directly with a computer using Labview or Igor, which has many advantages. And of course, add-on oscilloscope modules for desktop computers with a high enough band pass for this purpose are starting to become reasonably priced.

I use an iron rod (½-in diameter) and a pickup coil having about 2500 turns. The resulting emfs vary from about 5 V to 40 V, depending on the hammer blow and the geometry of the coil. Achieving even the higher voltage does not require a mighty hammer blow. If desired, a coil carrying dc current may be placed around the rod to supplement the magnetizing field of the Earth. This results in still higher amplitude pulses that are even more easily detected.[9] My pickup coil is the primary winding of an output transformer from an old vacuum-tube radio. However, coils with appropriate dimensions and a sufficient number of turns may be purchased from scientific equipment companies.[10] Figure 2 shows a typical oscilloscope trace. The peaks are about 0.47 ms apart. With an effective rod length of 1.2 m, the speed of sound comes out to be 5.1×10^3 m/s, in excellent agreement with the known value for iron.

I have found that seeing a representation of a sound wave actually bouncing back and forth is very appealing to students. This experiment is one of the most liked in my introductory-level physics course.

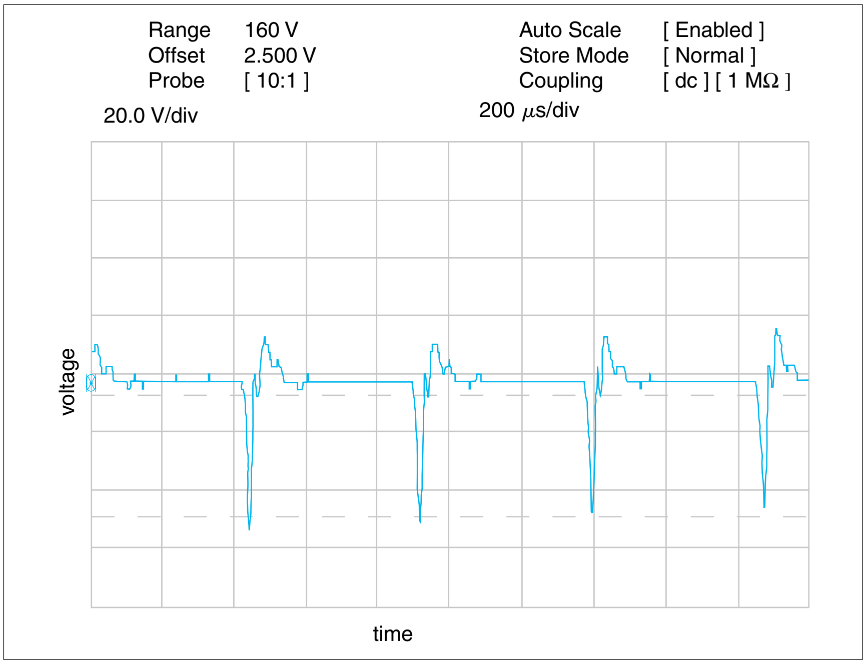

Fig. 2. Digital oscilloscope trace showing pulses detected by pickup coil.

References

1. A.B. Wood, *A Textbook of Sound* (Macmillan, New York, 1941).
2. See, for example, Charles R. Rhyner, "Measurement of the speed of sound in metal rods," *Am. J. Phys.* **38**, 1152–1153 (Sept. 1970).
3. Gerald P. Hart, "Measurement of the speed of sound in metal rods using the microcomputer," *Phys. Teach*. **24**, 89 (Feb. 1986).
4. Oakes Ames, "A direct measurement of the speed of sound in rods," *Am. J. Phys.* **38**, 1151–1152 (Sept. 1970).
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6. R.C. Nicklin, "Measuring the velocity of sound in a metal rod," *Am. J. Phys.* **41**, 734–735 (May 1973).
7. Michael T. Frank and Edward Kluk, "Velocity of sound in solids," *Phys. Teach.* **29**, 246–251 (April 1991).
8. R.M. Whittle and J. Yarwood, *Experimental Physics for Students* (Chapman and Hall, London, 1973).
9. I am grateful to an anonymous reviewer for this suggestion.
10. For example, PASCO model numbers SF-8612 and SF-8613.