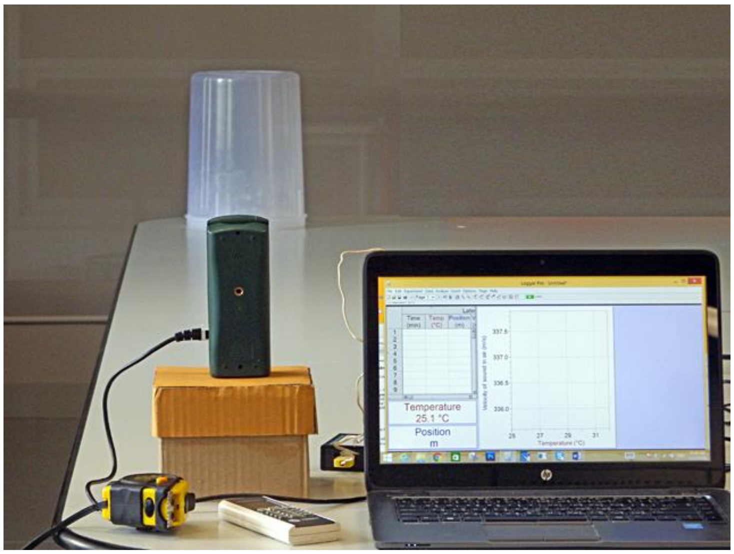
Speed of sound in air versus temperature

A Vernier position sensor and a temperature probe can be used to plot the speed of sound in a room over a small temperature range using air conditioners to control the temperature. This demonstration is particularly effective in Bangkok that has all year round tropical conditions.



Note: *air becomes stratified in layers with higher temperatures above, this demonstration must be done horizontally.*

The calibration is set for ambient temperature (in the *Set up Sensors* menu) and the distance d_o is measured with the position detector.

The apparent distance d is calculated in the computer as …

$$d = v_{20}\,\Delta t/2$$

The true distance d_o is given by …

$$d_o = v\Delta t/2$$

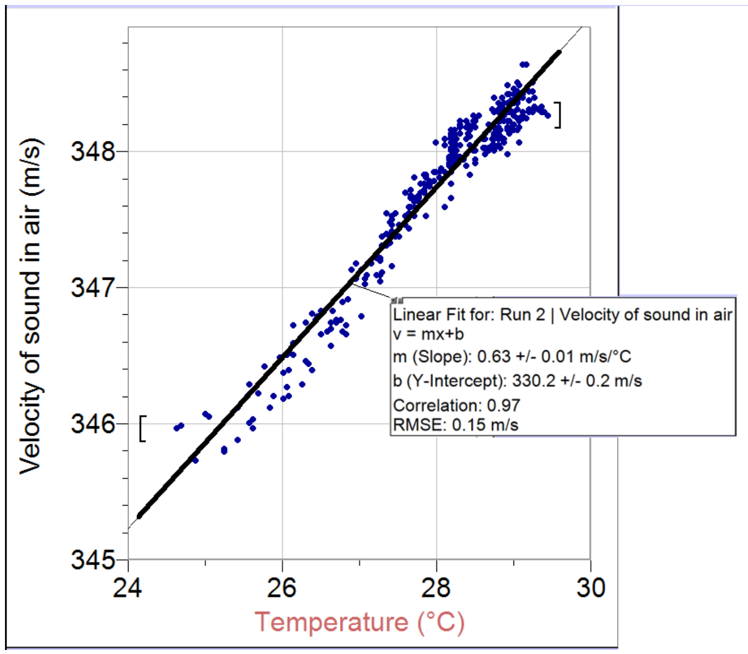
… where v is the actual speed of sound

Eliminating Δt gives ….

$$v = v_o d_o/d$$

This expression for the velocity of sound v is entered into Logger pro. The temperature calibration is now set to 20°C. The values of d_o and v_{20} = 343.2 m/s are entered into the equation and calculation of v is done in real time.

A thermocouple (at the same height above the bench) records room temperature as it slowly rises after the air conditioners have been turned off. Logger pro is set to plot sound velocity against time with one data point every ten seconds. The room is left empty for half an hour.



Fitting a straight line to the data gives an approximate expression for sound velocity as a function of temperature that agrees within 1% with that given in standard texts.

$$v = 331.5 + 0.6\,T$$ ... where T is the temperature in °C

Note: In 1816 Laplace realized that sound vibrations are very rapid. Compression in sound waves is *adiabatic*. Slight heating raises the pressure and increases the speed of sound over the expected $\sqrt{(P/\rho)}$ due to Newton.

Laplace gave the speed of sound in air as

$$v = \sqrt{(\gamma P/\rho)}$$ … where γ is the ratio of specific heats c_p/c_v

Using the ideal gas law … $P = \rho RT$ …. where T is the absolute temperature and R is the *specific gas constant* for air (287 J/K) gives the speed of sound in air as …

$$v = \sqrt{(\gamma RT)}$$ …. *in good agreement with measured values.*

The speed of sound in an ideal gas is independent of pressure and proportional to the square root of the absolute temperature. For a small room temperature range (10-40°) the approximate linear relationship is often used.