An Investigation of Resonance

A polystyrene gong

The expanded polystyrene ball in figure 1 is 10 cm in diameter and enclosed in a 20 cm plastic globe with a 7.5 cm circular opening and a 2 cm cylindrical neck.

Fig 1 – a polystyrene ball is enclosed in a plastic globe.

A peculiar distinctive sound like that of a drum or a gong is produced when the ball is made to bounce in the opening by shaking the globe vertically or by tapping the ball with a finger. An investigation of the source of the sound and its amplification begins with a series of questions.

Helmholtz resonance

A spherical cavity with a short cylindrical neck is a Helmholtz resonator. A single low frequency resonance is produced by the simple harmonic motion of a mass of air in (and close to) the opening. The restoring force is provided pressure oscillations in the air inside the cavity. The wavelength of this resonance is many times the diameter of the cavity. The frequency of a Helmholtz resonance is given by …

$$f = v/2\pi\,[A_x/VL]^{1/2}$$

… where v is the velocity of sound in air, A_x is the cross sectional area of the opening, V is the volume of air enclosed, and L is the effective length of the neck, which in one case [pdf] has been found to be close to the diameter of the neck for all neck lengths.

i Estimate the Helmholtz frequency with and without the enclosed ball.

Consider the following FFT plots

Hitting the ball by bouncing it on the hand in an open room produces a band of what might be called pink noise. The dull thud when the ball is hit persists for less than 0.005 seconds. An FFT plot with an inset showing the duration of the sound is shown below.

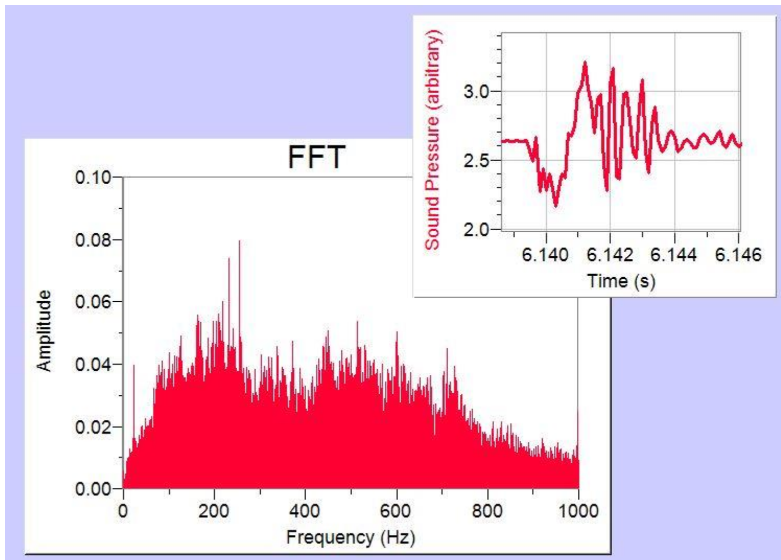


Fig 2 – the frequency spectrum of the dull thud produced by hitting the ball with a hand.

The sound produced by the ball bouncing on the inner rim of the neck of the cavity is louder, persists for much longer and is confined to a narrower frequency range. Data plots are shown below when the neck length was 2 cm (figure 1).

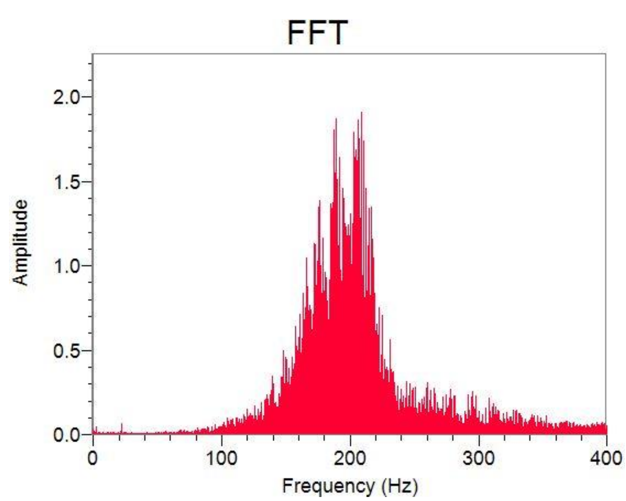


Fig 3 – the frequency spectrum of the ball in the cavity: neck length 2 cm.

An amplitude/time plot of the sound when the ball bounces above the 2 cm neck is shown below. A single dominant resonance persists for ~ 0.1 seconds.

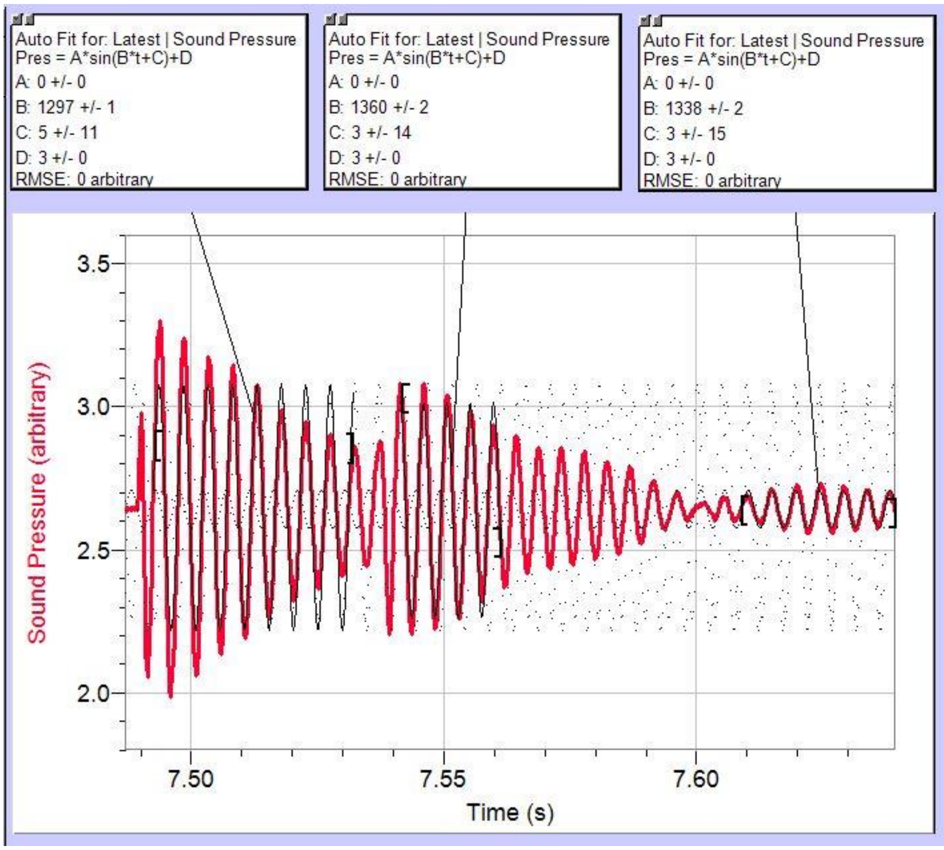


Fig 4 – a sound pressure/time plot for the ball in the cavity: neck length 2 cm.

Sine wave fits to sections of the graph in figure 4 show that the dominant resonant frequency changes in wavelength (pitch) over time intervals of less than one tenth of a second.

ii Using the data from figure four, write down an average frequency of resonance and state the likely variation as something more than half the range.

iii Write a brief account of what you consider to be the source of the sound and its amplification taking into consideration the data in figures 1-4 and your estimate of the resonant frequency of the cavity. Can you account in any way for the apparent variations in frequency shown in figure 4?

iv How would you go about testing your ideas? What additional items would you need to purchase and what measurements would you make?

Please consider drafting and answer before you the next section.

Varying the neck length

The neck length was increased in steps by adding sections cut from a water bottle. FFT and amplitude/time plots are shown below.

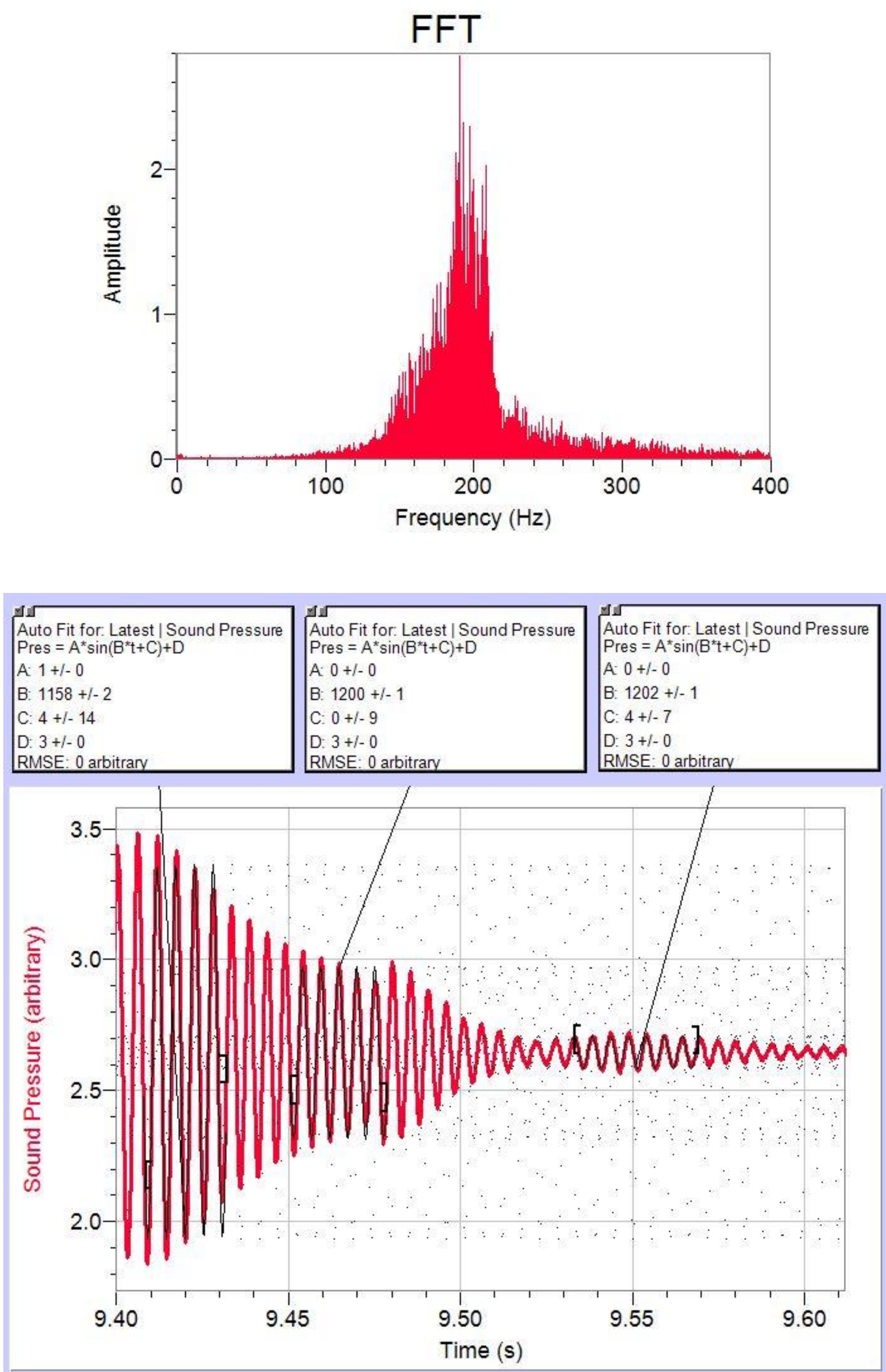


Fig 5 – FFT and amplitude/time plots for a neck length of 4 cm

Extending the neck to 9 cm again reduces the frequency of the resonance band and also reduces the loudness of the sound.

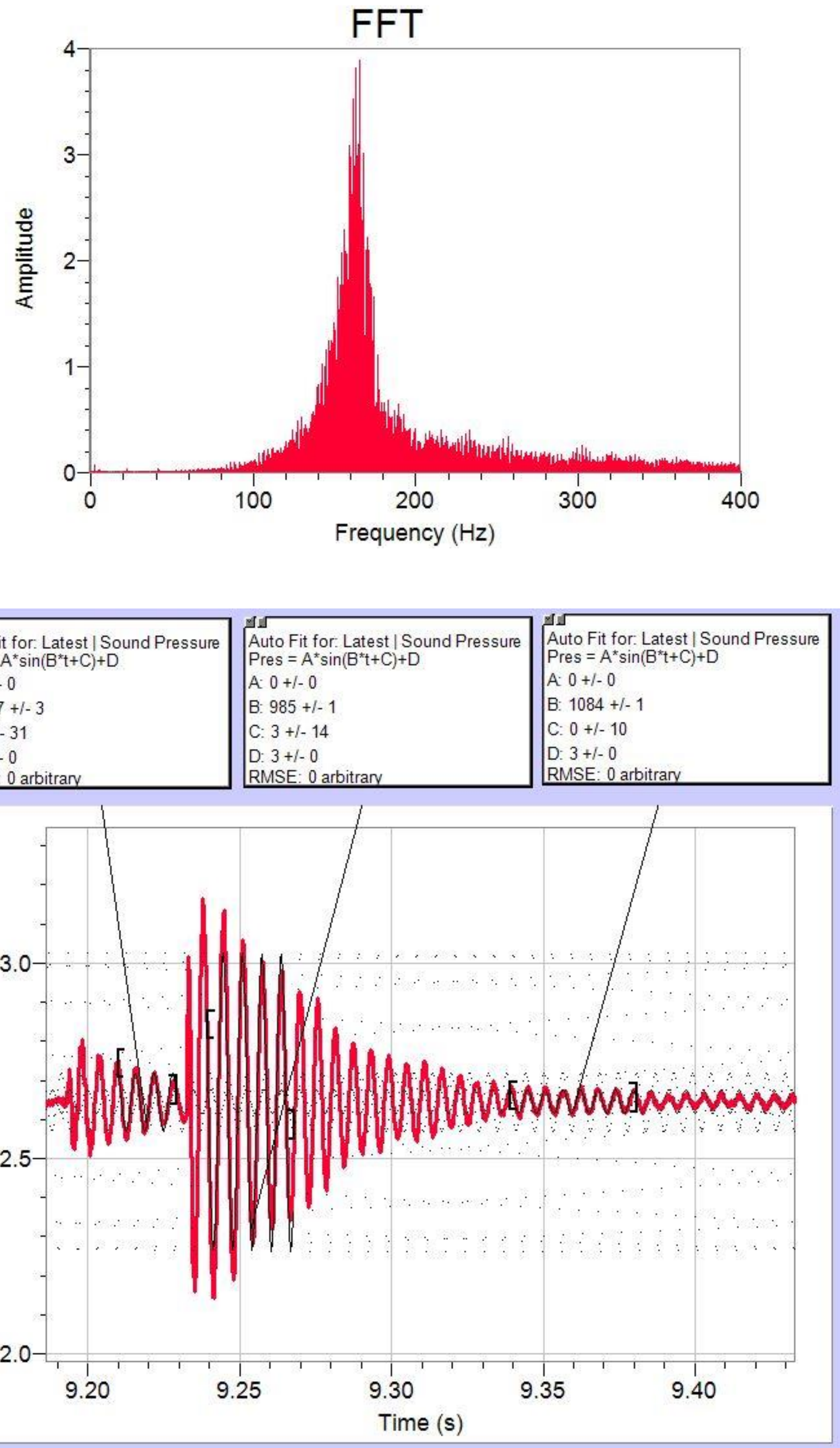
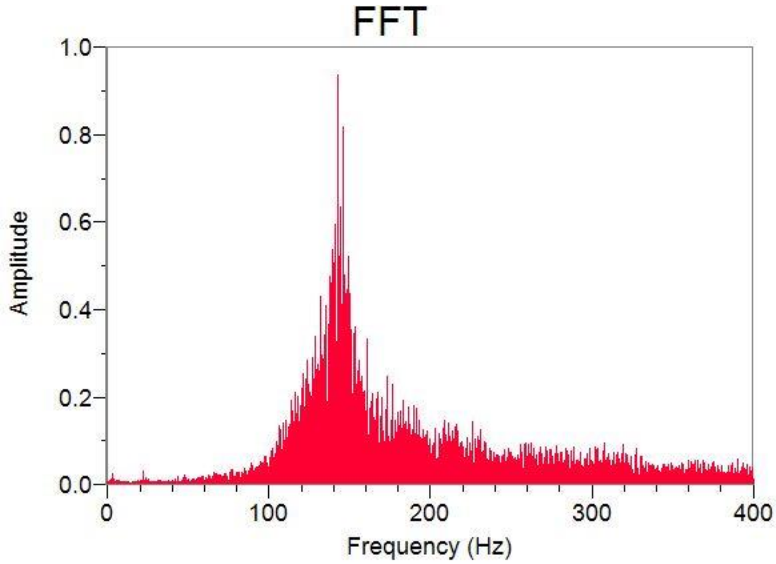


Fig 6 – FFT and amplitude/time plots for a neck length of 9 cm.

Doubling the neck length further reduces the loudness and pitch of the sound



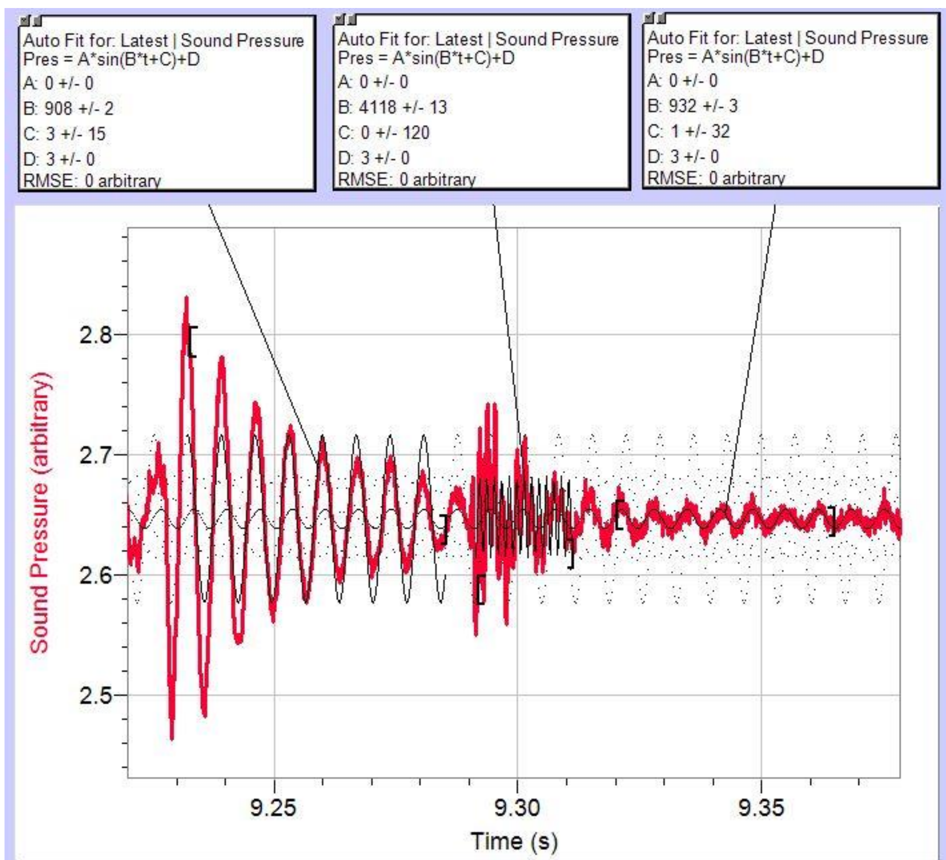


Fig 7 – FFT and amplitude/time plots for a neck length of 21 cm.

v Revise/extend your plans for an investigation based on the data in figures 5-7.