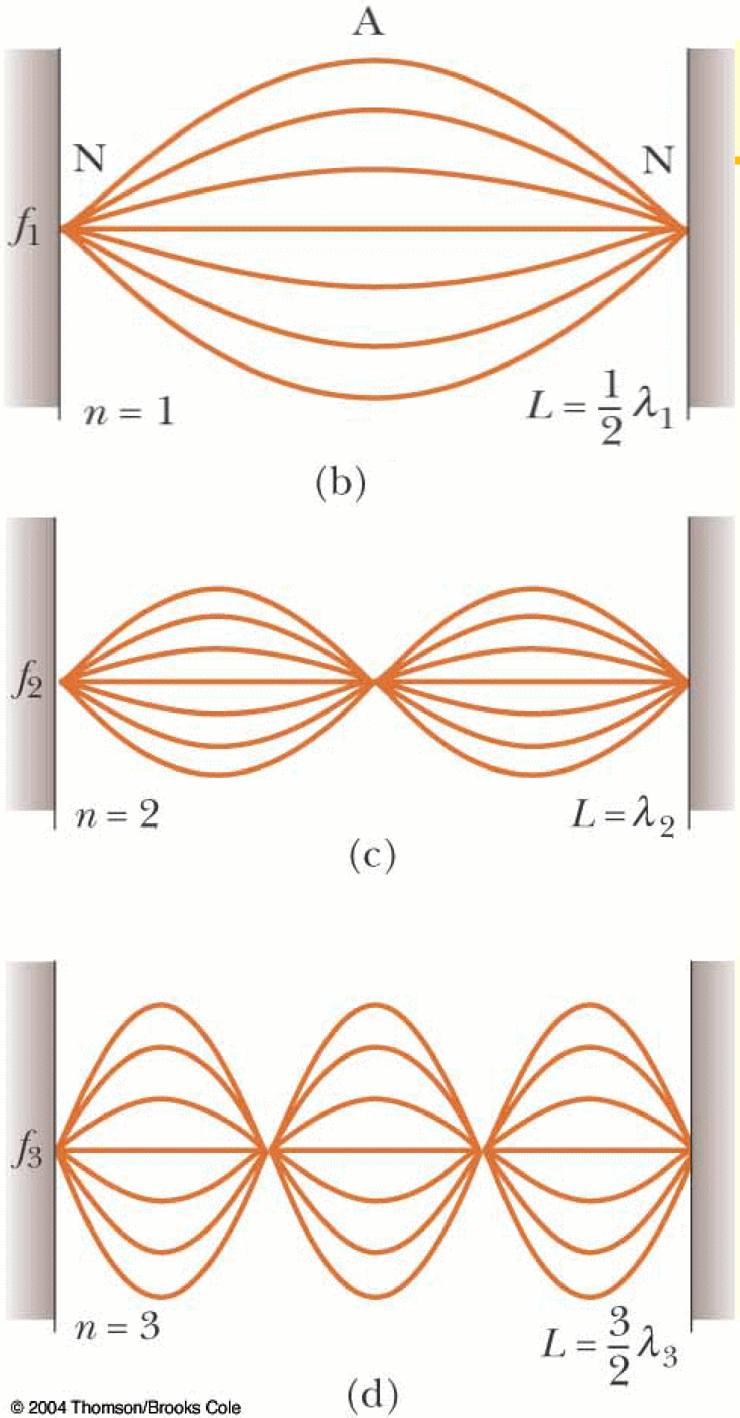
Physics 115 Lecture 9

Standing waves in an air column

February 9, 2018

String fixed at both ends

- Always a node at each end
- Harmonics
- Animated applet
- Video

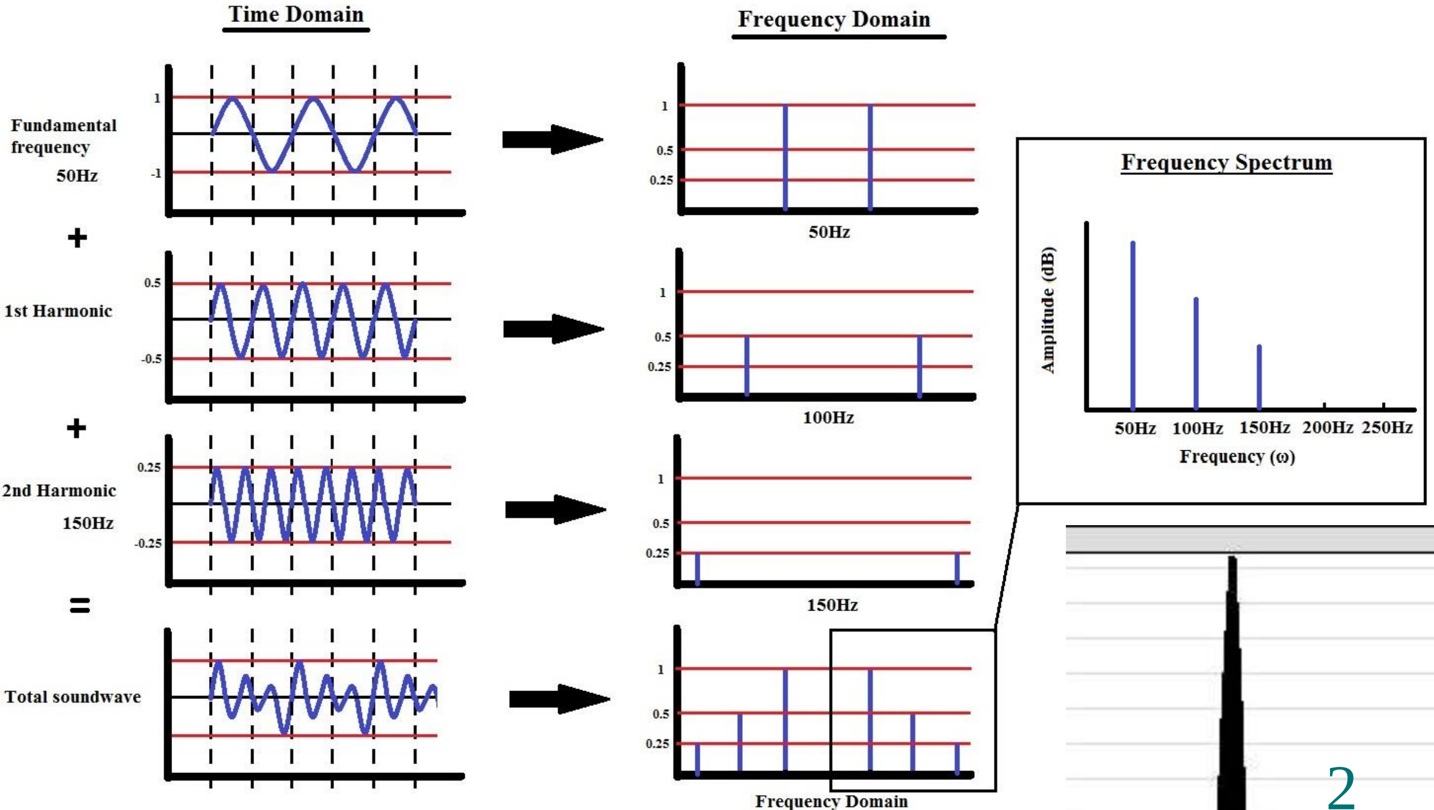


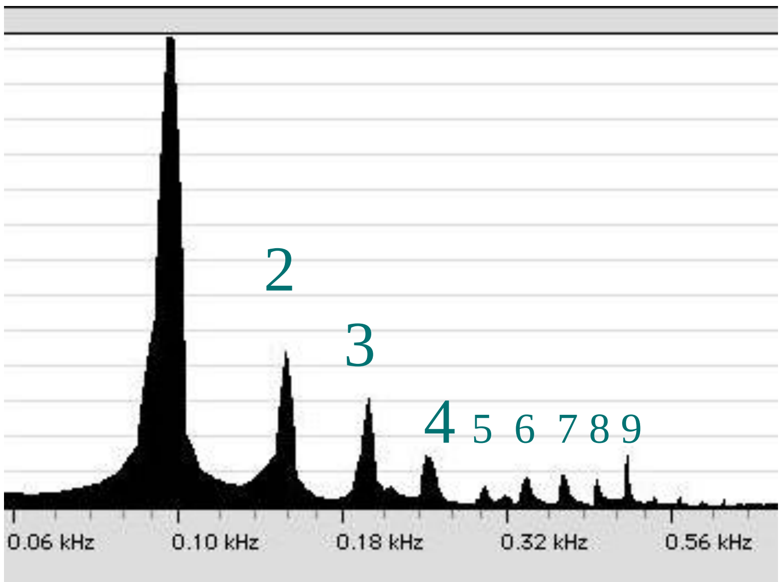
Harmonic	#antinodes	#nodes	λ	f
fundamental	1	2	$\frac{2L}{1}$	f_1
second	2	3	$\frac{2L}{2}$	$2\,f_1$
third	3	4	$\frac{2L}{3}$	$3f_1$

$$c_{\text{string}} = f\,\lambda$$

The recipe of harmonics

- The relative amplitudes (loudness) of the harmonics give a musical instrument its characteristic tone quality



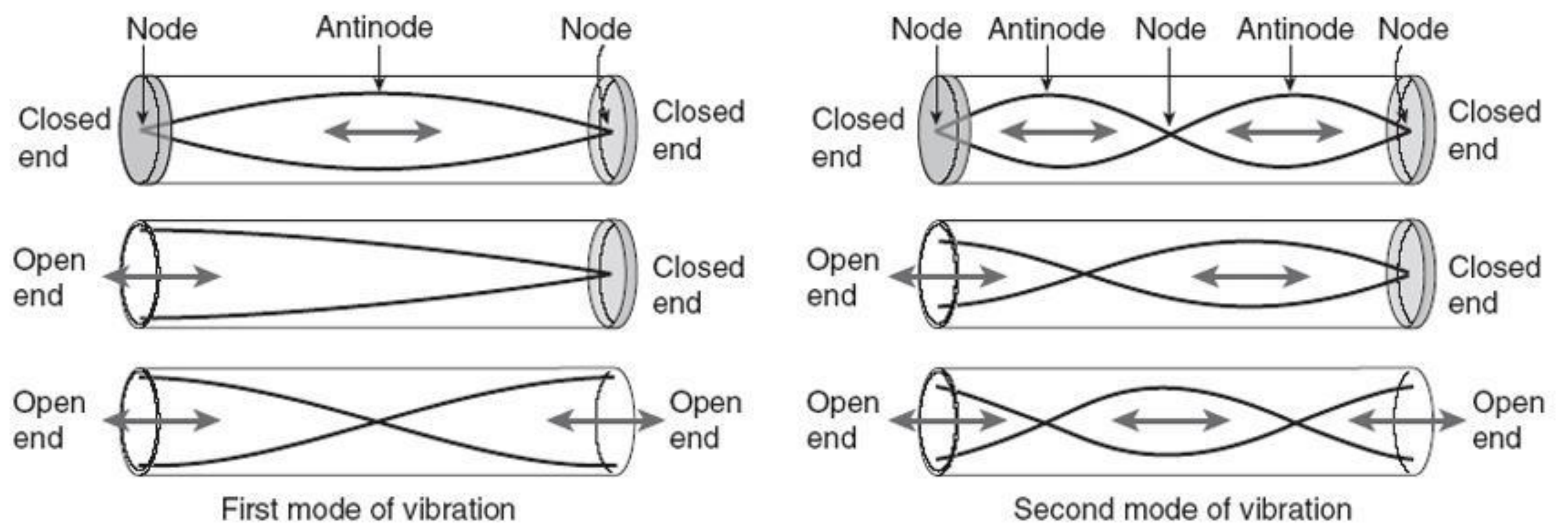


source: soundcheckucc.wordpress.com

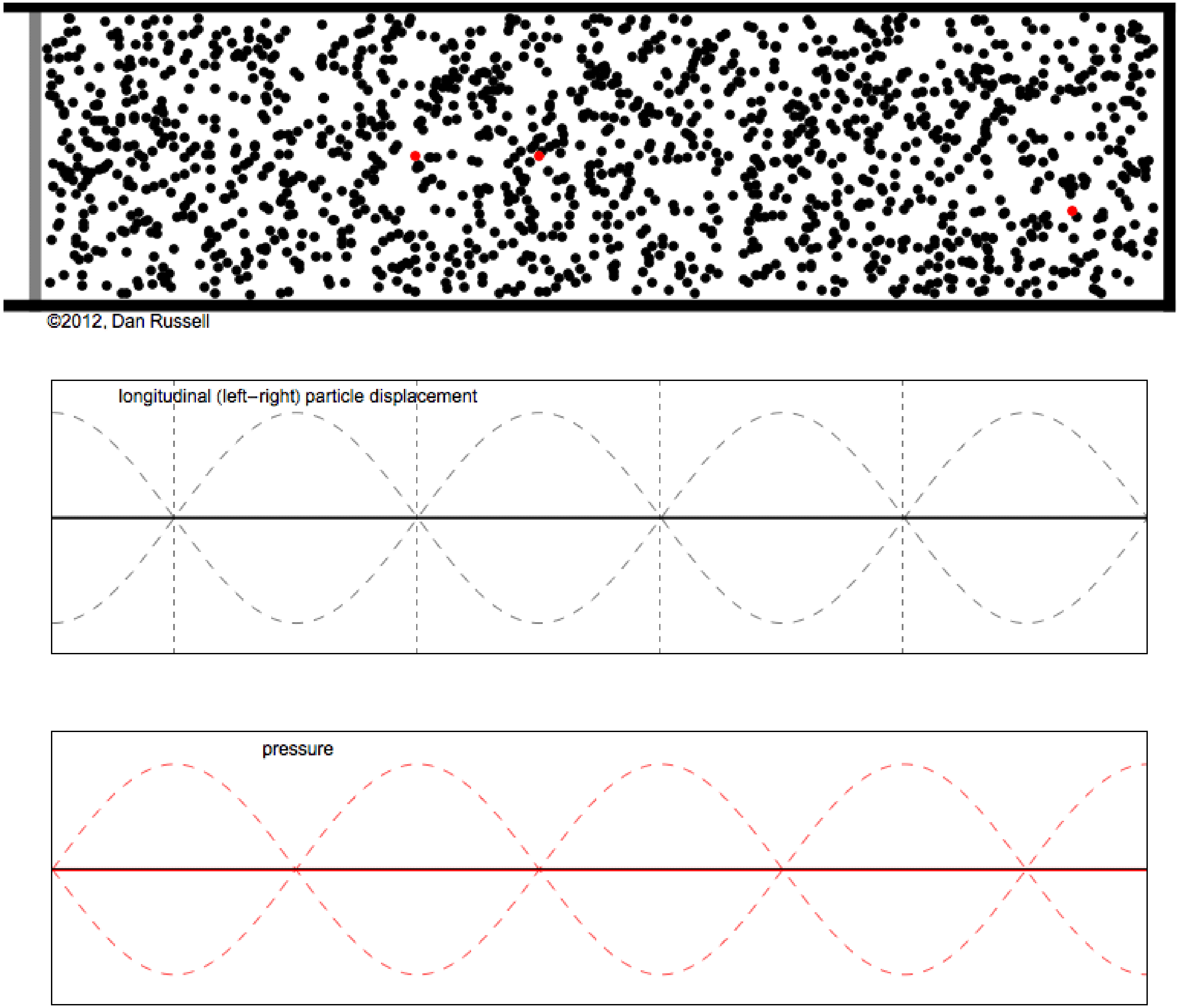
Actual guitar note spectrum (Nonlinear scale. Click on computermusicresource.com source page to hear the sound)

Wave reflection in an air column

- A typical brass or woodwind instrument creates a standing wave in an air column that is closed at one end and open at the other.
- The standard diagrams can be confusing:



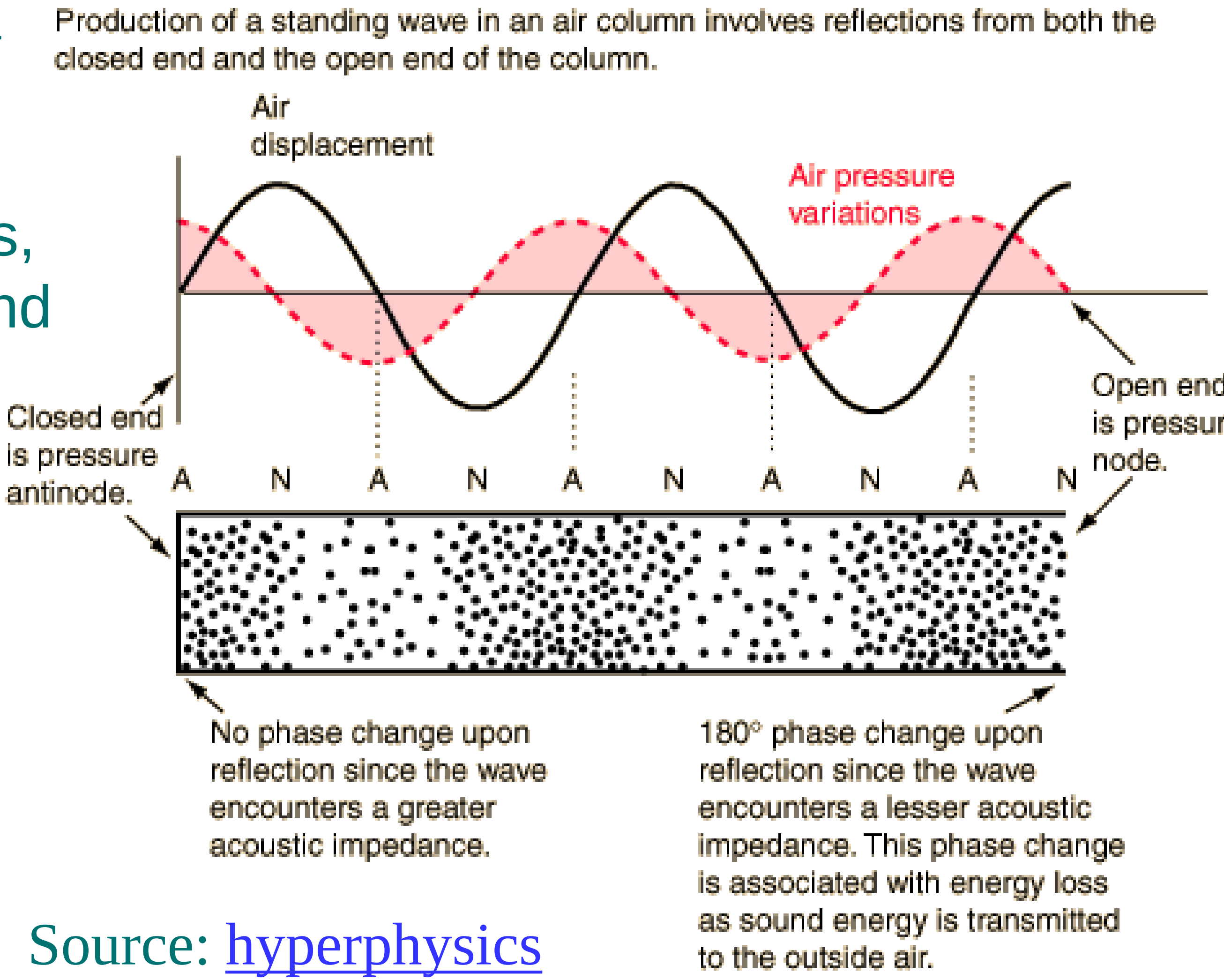
Animated longitudinal standing wave



Animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State

Why does sound reflect from the open end of a tube?

- The formation of a standing wave requires counter propagating waves, which implies sound reflection from the *open* end of the tube!



Source: [hyperphysics]

Acoustic impedance

- A sound wave reflects from the open end of an air column because of the sudden change in acoustic impedance *Z* (see link 5-09) (another tutorial)
- Specific acoustic impedance (*z*) is the opposition of a medium to wave propagation, and it depends on the properties of the medium.
- The acoustic impedance (*Z*) specifies the impedance offered by an enclosed volume of a medium of cross-sectional area *A*.

$$Z = \frac{z}{A} = \frac{\rho c}{A}$$

Acoustic impedance

$$Z = \frac{z}{A} = \frac{\rho c}{A}$$

- ρ = density of medium (kg/m^3). A denser medium offers more resistance to wave propagation.
- c = speed of sound (m/s). Faster sound speed corresponds to a stiffer medium and more resistance to wave propagation.
- A = cross-sectional area (m^2). A larger cross-sectional area offers less resistance to wave propagation. The impedance change at the end of a tube is a result of the sudden change in the cross-sectional area, and a sound wave will reflect off this boundary.

Acoustic impedance

$$Z = \frac{z}{A} = \frac{\rho c}{A}$$

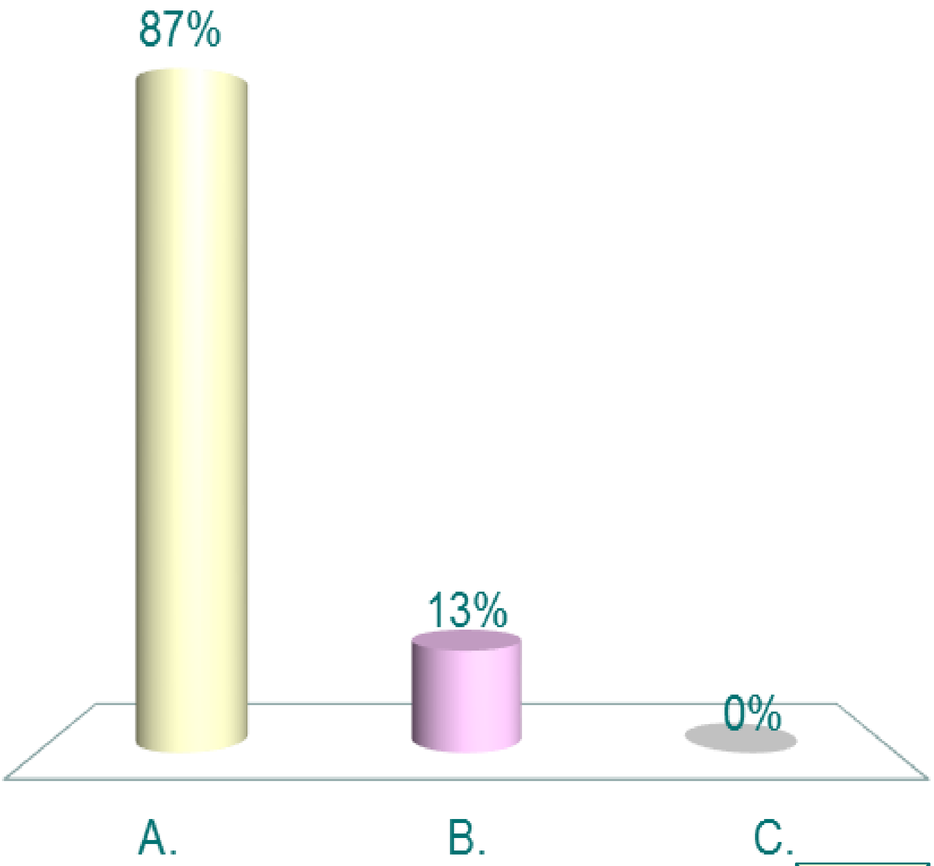
Flaring the tube end makes the impedance change more gradual, resulting in less internal reflection and a louder emitted sound

A sound wave travels through a cast iron (*c* = 3780 m/s, ρ = 7700 kg/m^3) rod and into a steel (*c* = 5100 m/s, ρ = 7700 kg/m^3) rod of the same diameter. As it does so, it encounters _____ acoustic impedance.

A. a higher

B. a lower

C. no change in the



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A sound wave travels through a cast iron (c = 3780 m/s, ρ = 7700 kg/m^3) rod and into a steel (c = 5100 m/s, ρ = 7700 kg/m^3) rod of the same diameter. As it does so, it encounters _____ acoustic impedance.

A. a higher

B. a lower

C. no change in the

$$Z = \frac{z}{A} = \frac{\rho c}{A}$$

No change in ρ or A. The higher speed of sound in steel means it is a stiffer medium that offers more resistance to wave propagation.