11.3.1: Impedance

But why do sound waves reflect from the open end of a tube?

The resistance to the movement of a wave crossing a boundary from one medium into another is called ***impedance*** and occurs for waves on a string, sound waves in air and electronic signals in a circuit. When a wave tries to travel from a medium with one impedance to a region where the impedance is different, there will be a partial reflection. The reflection means that not all the energy of the wave is transmitted to the new medium.

There are several ways to try to avoid or minimize the effects of impedance. In general the idea is to ***match impedance*** between the two regions. For example, the speakers of a stereo system are chosen to match the impedance of the amplifier/tuner component. In electrical components impedance is measured in *ohms* (Ω) so if a speaker has an impedance of 10Ω an amplifier with 10Ω is chosen (or vice versa). If the impedance was not matched some of the energy from the amplifier would reflect back and not get to the speaker, making the system less efficient at turning electrical signals into sound. The three bones in your middle ear are responsible for matching impedance between the air outside your ear and the fluid in your cochlea as explained in this video on impedance matching in the ear.

Tube instruments have an impedance problem in that sound inside the tube will reflect off the ends, even an open end. Air inside the tube is confined by the walls of the tube but air outside is not. This difference in impedance causes some sound to reflect back into the tube at an open end and it is this reflected wave that sets up a standing wave inside the tube. Reflection is strongest if the tube diameter is less than a quarter of the wavelength of the sound wave in the tube. Open end reflection is weaker as the diameter gets bigger compared to the wavelength.

On the one hand this reflection is what causes the tube to have a fundamental frequency (resonance) but this also means less sound gets out of the instrument. Flutes are not corrected for impedance miss-match and are the softest woodwind instrument. Most other woodwinds are louder because they have bells that act as impedance matching devices between inside the instrument and outside. Brass instruments have even larger bells and so have better impedance matching and are even louder than woodwinds on average. As we will see, the bell of a wind instrument also affects the overtones present (and therefor the timbre) but the main function of a bell is to help sound waves exit the instrument by matching the impedance.

The mathematical symbol for impedance is Z, measured in ohms. In some references you will see the inverse of this number, the ***admittance*** which is defined as $Y = 1/Z$, measured in *siemens*. Here is a more complete definition of acoustical impedance. Here is a Java Applet that calculates impedance (reflected and transmitted sound energy) when sound is moving from one substance to another.