

- * Auditory/ear canal is $L \sim 3 \text{ cm}$ long, closed at the inner ear at the eardrum – a membrane. Auditory canal = organ pipe ($L \sim 3 \text{ cm}$ long), with one end open and one end closed (Thus, there will be standing-wave resonances in the ear canal at: $f_n \sim nv/4L$, $n = 1, 3, 5, 7, \dots$)
 \Rightarrow Boosts our hearing sensitivity in the $f \sim 2\text{-}5 \text{ KHz}$ frequency range!!!).

The Middle Ear:

- * Ossicular chain – hammer, anvil, stirrup – transmit sound vibrations on ear drum to oval window of cochlea. Ossicles are a lever system, w/ $\sim 1.3\times$ mechanical advantage.
- * Eardrum is $\sim 20\times$ bigger area than oval window – gives overall amplification factor of $\sim 26\times$!
- * Performs important function of impedance-matching, efficiently transferring the mechanical vibrations of the ear drum/tympanium/tympanic membrane (\sim low mechanical impedance) to the oval window ($\sim 20\times$ higher mechanical impedance) and into cochlear fluid.
 $Z_{mech}(f) \equiv F(f)/v(f)$, mechanical force $F(f)$ (Newtons) = $p(f) \times A$ = pressure \times area.
- * The specific longitudinal acoustic impedance of cochlear fluid \sim that of sea water:
 $Z_{ac}^{sw} \sim 1.5 \times 10^6 \text{ Pa}\cdot\text{s}/\text{m} (= \text{N}\cdot\text{s}/\text{m}^3)$. Note: $Z_{mech} \equiv F/v (\text{N}\cdot\text{s}/\text{m}) = Z_{ac} (\text{N}\cdot\text{s}/\text{m}^3) \times A_{\perp} (\text{m}^2)$
- * Ossicles also protect the inner ear from very loud noises – via the so-called acoustic reflex – which triggers two sets of muscles – one tightens the eardrum, another pulls the stirrup away from the oval window!
- * Also has a “safety valve” – the eustachian tube - for pressure equalization and fluid drainage.

The Inner Ear:

- * Cochlea – coiled/rolled up ($\sim 2 \frac{3}{4}$ turns), filled with perilymph fluid.
- * Cochlea is divided down its length by a soft partition known as the basilar membrane, forming 2 long chambers connected together by an opening at the far end called the helicotrema.
- * ~ 15000 hair cells (connected to $\sim 30,000$ nerve fibers embedded in the basilar membrane) sense acoustic disturbances in perilymph fluid; transmit information to brain via the auditory nerve.
- * Amplitude of sound waves in perilymph fluid reaches a maximum at a particular point along the cochlea, for a particular frequency! (see graph(s) below...)
- * Sense of pitch (human perception of frequency) depends (in part) on location along the cochlea.
- * Additionally, 3 semi-circular canal(s) attached to cochlea = 3-axis (x, y, z) accelerometers (!) used for balance/orientation determination/sensing – *i.e.* an inertial guidance system!