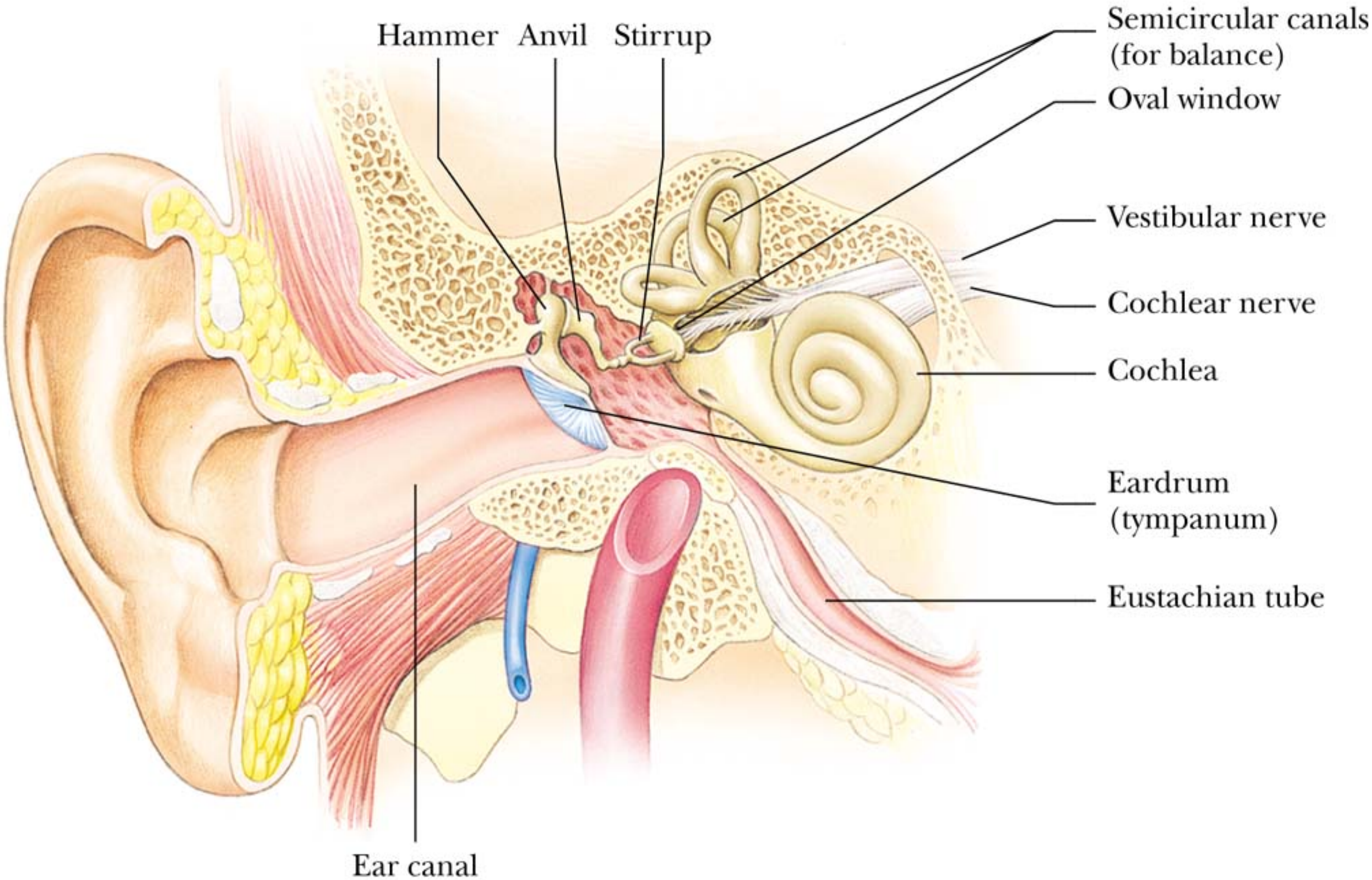
Musical Acoustics

Lecture 12

The Human Ear - II

Intensity

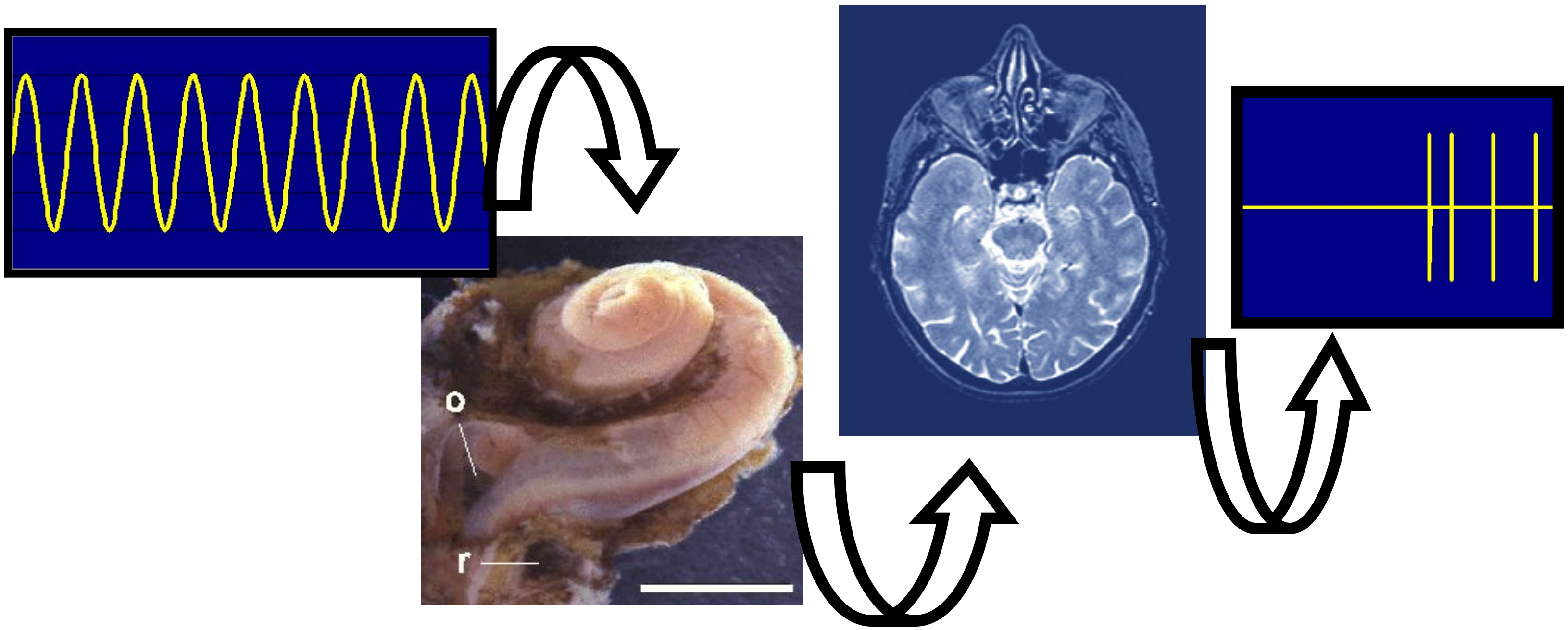


- **Faintest sound** we can hear: I ~ 1×10^{-12} W/m^2 (at 1000 Hz)
- **Loudest sound** we can stand (pain): I ~ 1 W/m^2 (at 1000 Hz)

Factor of 10^{12}? Loudness works **logarithmic**…

The Human Ear is a "non-linear Sensor"

Physics ⇨ Physiology ⇨ Perception

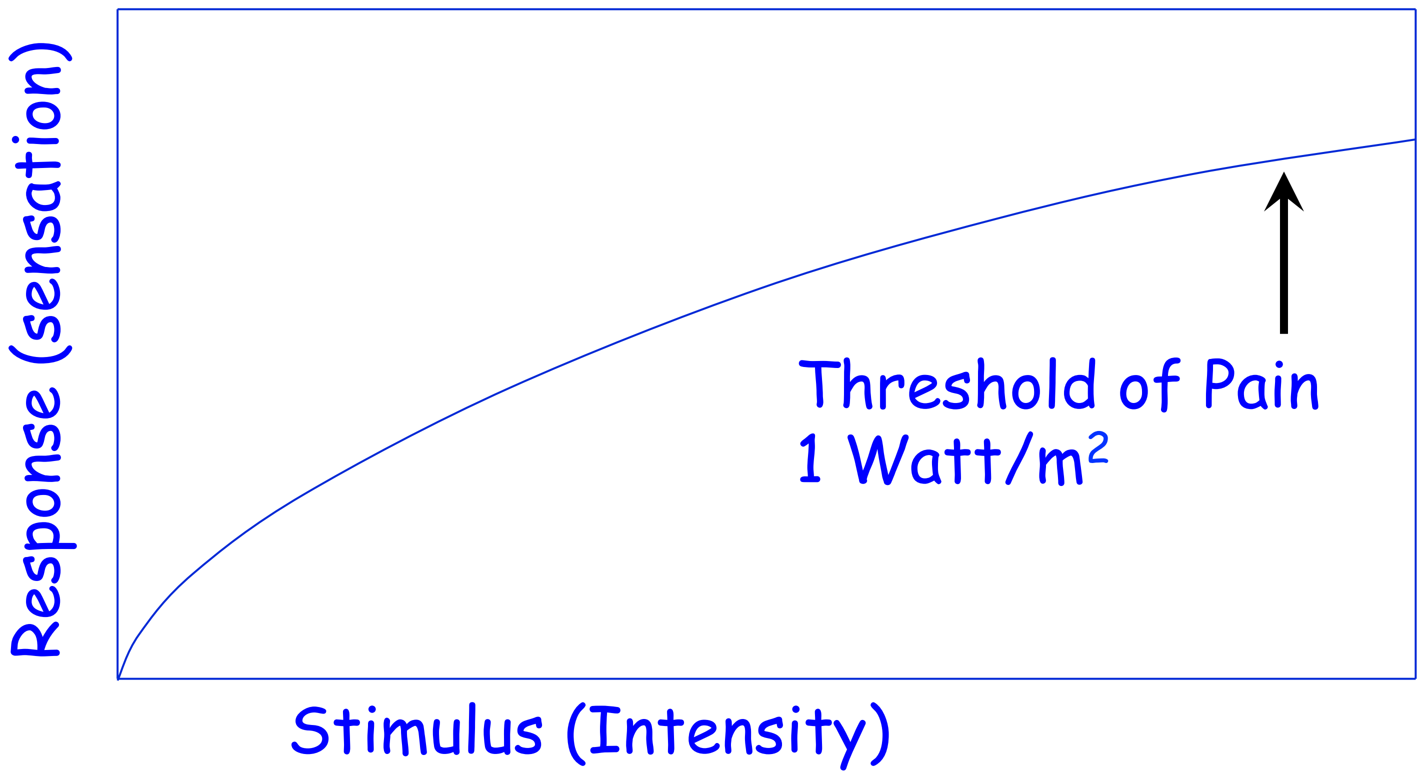


- Frequency
  Intensity ⇨ *Loudness*
  Vibration Recipe
- Intensity
  Frequency ⇨ *Pitch*
  Vibration recipe
- Intensity
  Vibration Recipe ⇨ *Timbre*
  Frequency

Loudness

• The frequency range of detectability for humans is approximately 20 Hz to 20 kHz.

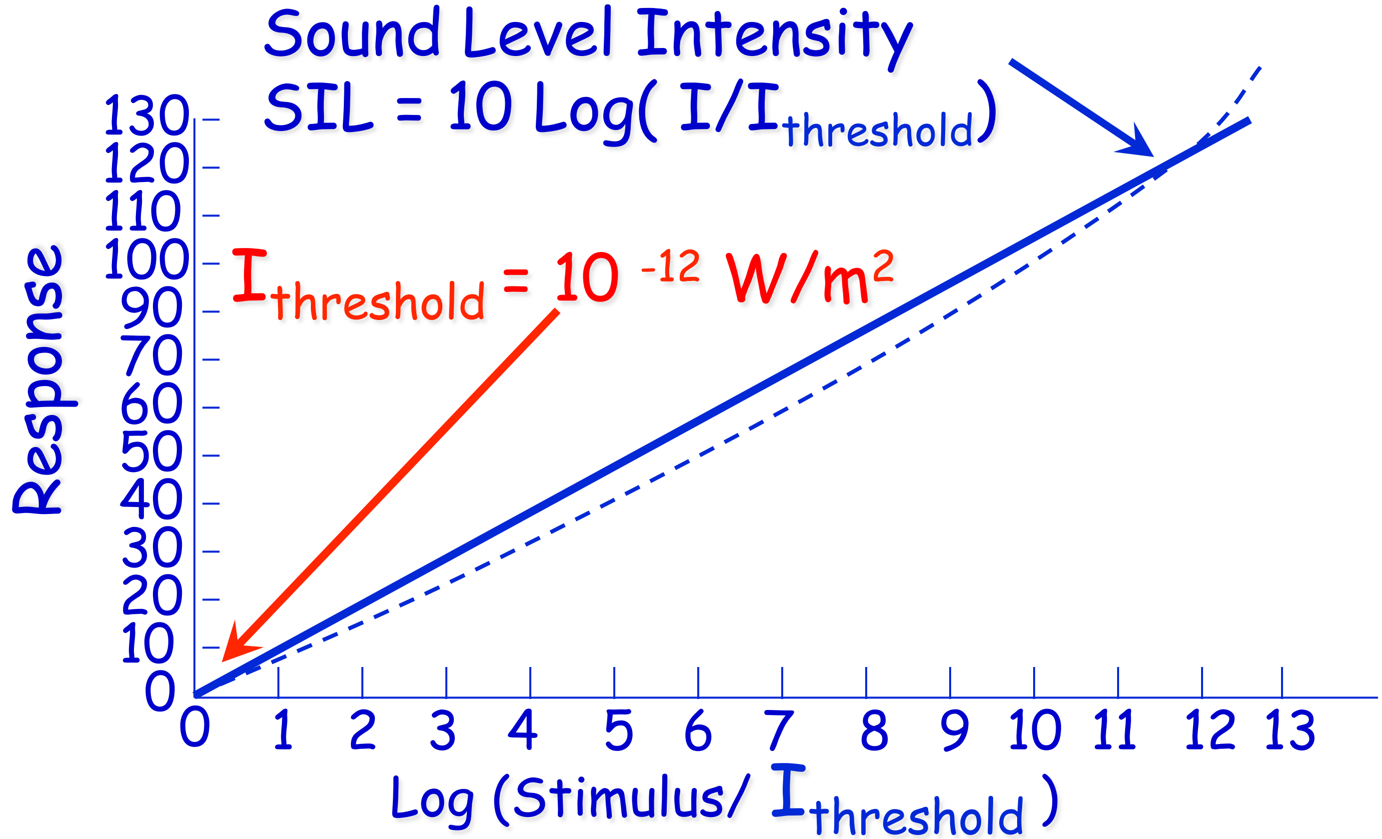
• Humans are most sensitive in the frequency range 2 kH to 5 kHz.



Decibel level β

$\beta = 10 \log(I/I_0)$ $I_0 = 10^{-12}$ W/m^2

Logarithm of Stimulus vs Response



- **Loudness** is the magnitude of the sensation produced by a sound; the "amount" of sound.

- Loudness (in **sone**) is how many times larger (or smaller) the sensation is judged to be, relative to a tone of SIL = 40 dB at 1000 Hz.

- **Loudness Level** (in **phon**) is equal to the SIL at 1000 Hz that produces the same magnitude of sensation.

Sound Pressure Level

Our ears respond to extremely small pressure p fluctuations

Intensity of a sound wave is proportional to the sound pressure squared:

$$I = p^2 / \rho v$$

$\rho v \approx 400\ m^{-2}\ t^{-1}$

ρ = density

v = speed of sound

We define sound pressure level:

$$L_p = 20 \log p/p_0$$

$p_0 = 2 \times 10^{-5}$ Pa (or N/m^2) (or **SPL**)

Decibels

$$\beta = 10 \log(I/I_0) \quad I_0 = 10^{-12}\ \text{W/m}^2$$

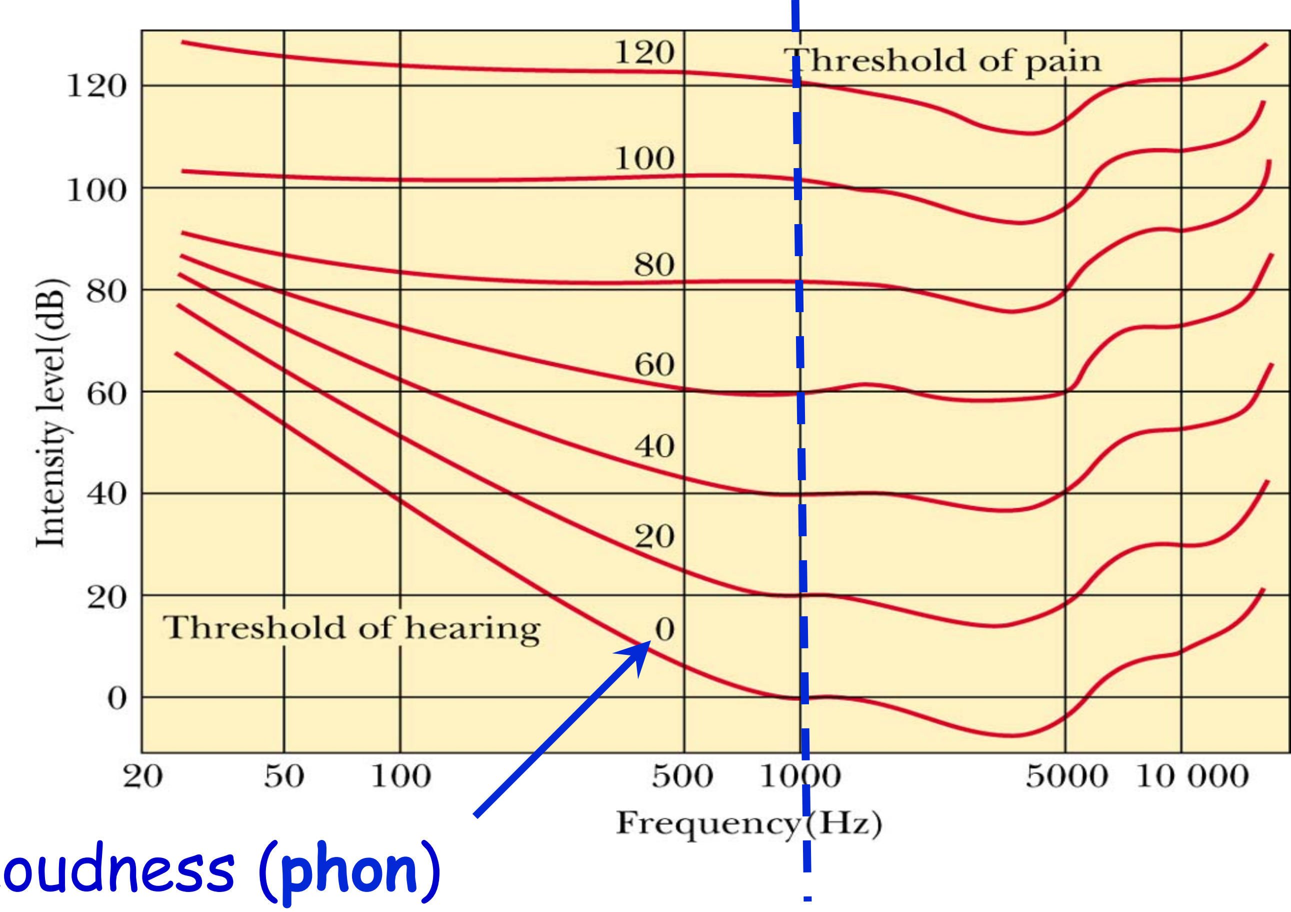
Source of Sound	β (dB)
Nearby jet airplane	150
Jackhammer, machine gun	130
Siren, rock concert	120
Subway, power mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

An increase of 10 dB: intensity of the sound is multiplied by a factor of 10.

PHONS: *Fletcher-Munson Diagram*

200 Hz—70 dB
2 kHz—70 dB
10 kHz—75 dB

Equal Loudness
(70 phon)

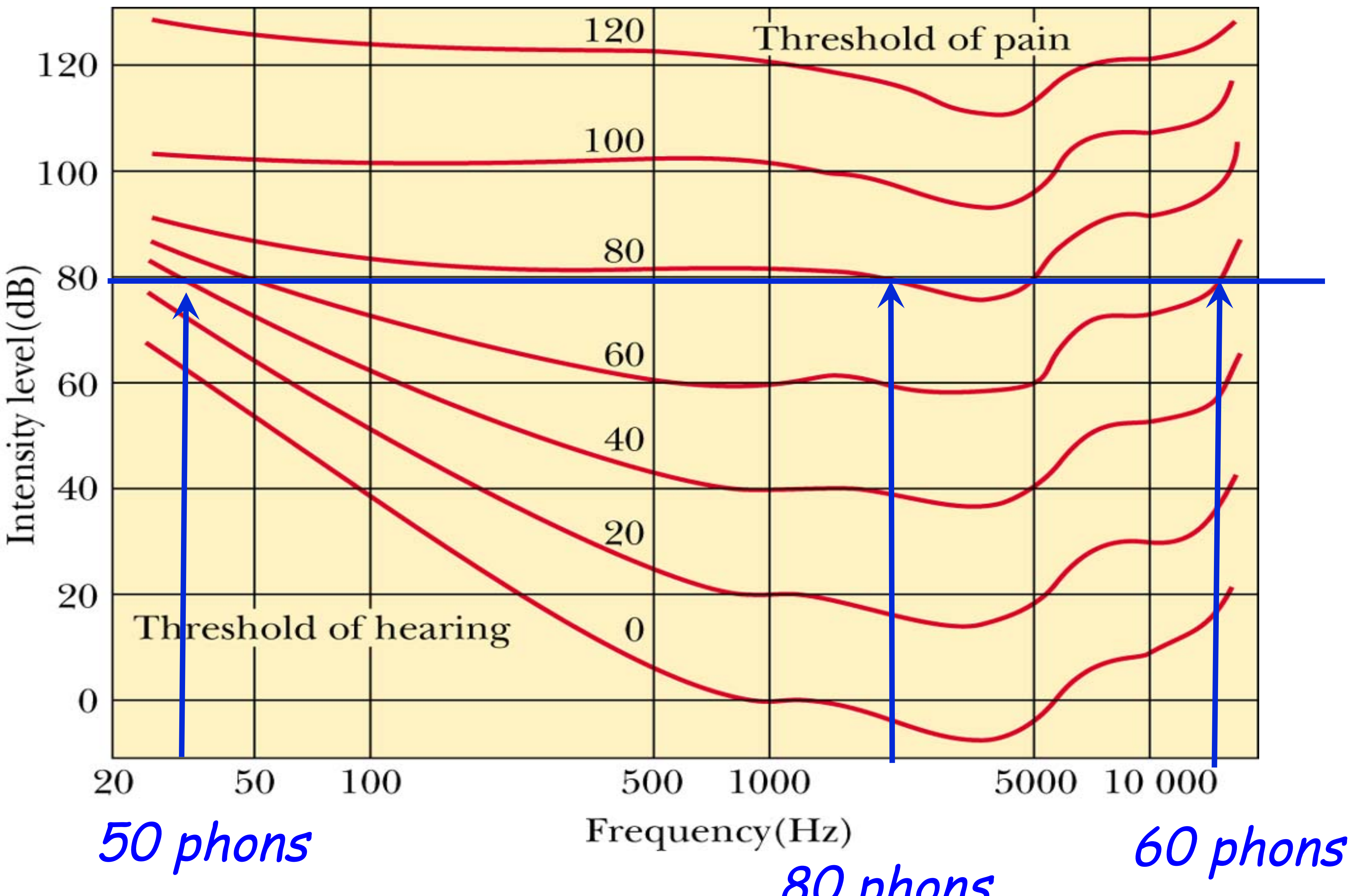


- *The Fletcher-Munson Diagram is a plot of the SIL (in dB) versus frequency for the SIL required to produce an equal sensation as that produced at 1000 Hz.*

- *The contours are of equal loudness level.*

- *The unit of loudness level is the phon. Different frequencies have different loudness for the same intensity (decibels).*

Loudness dependence with frequency



Sound level calibration

- Since the Loudness Level for a given frequency can be approximated by a linear function of the Intensity Level, Thus:

$$LL \approx A\ (SIL - SIL_{threshold}),$$

- One of the settings of a Sound Level Meter (filter switch "A") modifies the calibration of the instrument to account for the frequency dependence of human hearing.

- The Sound Level is reported then as "**dBA**."

Other loudness scales (psycophysics)

• A subjective measure of the magnitude of auditory sensation is measured in **sone**. In this system, one listens to two sounds and judges how much louder or softer a test sound is compared to the reference.

• For example, a sound of 2 sone sounds twice as loud as a tone of 1 sone.

• A loudness of 1 sone is equivalent to the loudness of a signal at 40 phons, the loudness level of a 1 kHz tone at 40 dB SPL.

• The sone and phon scales are not proportional. Rather, the loudness in sones is, at least very nearly, a power law function of the signal intensity, with an exponent of 0.3.

• With this exponent, each 10 phon increase (or 10 dB at 1 kHz) produces almost exactly a doubling of the loudness in sones.

Other loudness scales

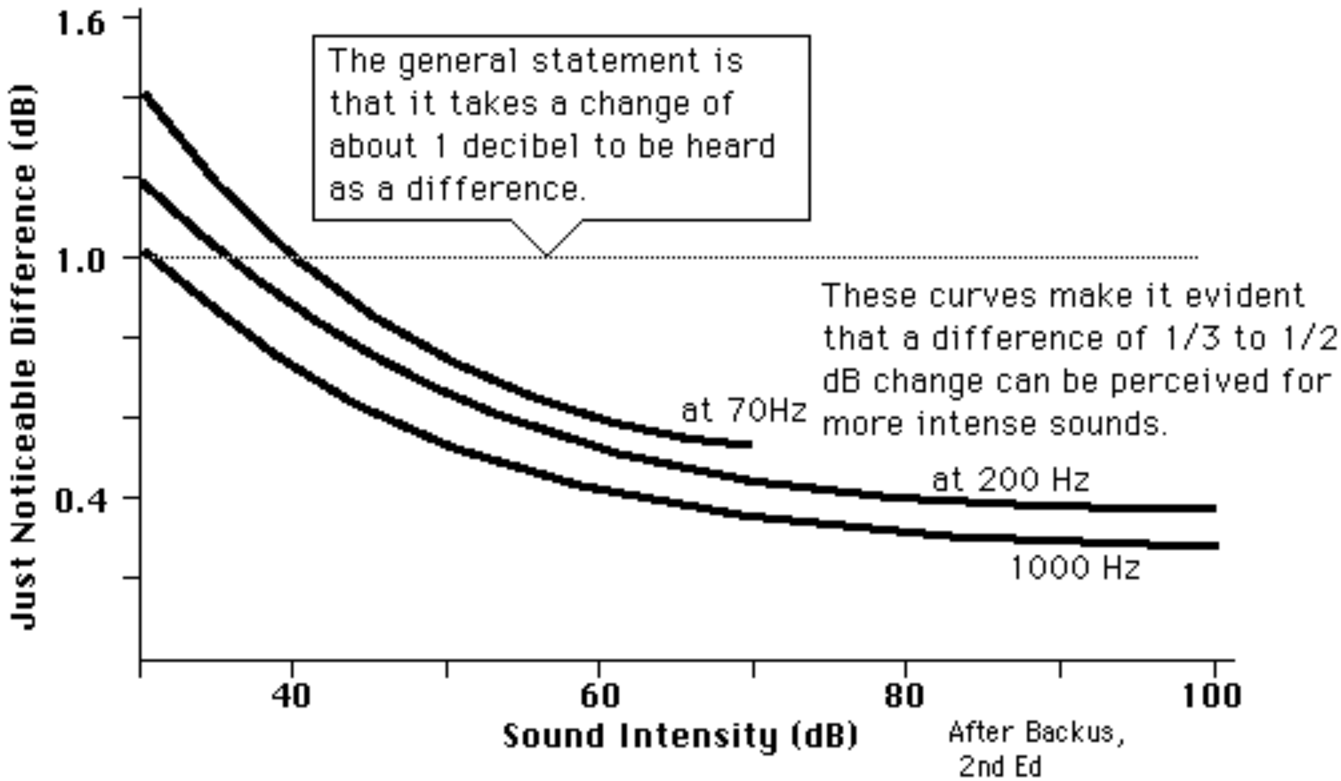
- A **Just Noticeable Difference (jnd)** is the smallest detectable difference between a starting and secondary level of a particular sensory stimulus. It is also known as the **difference limen** or the **differential threshold**.

- **Just Noticeable Difference** is the **limen** of difference that elicits 75% correct answers in a Two Alternative Forced- Choice test (2AFC test).

- Why 75%? In 2 Alternative Forced Choice:
  - 50% correct means random choice
  - 100% means can always tell the difference.
  - Thus, 75% is halfway between random and certainty.

- The limen of intensity is a ratio of about 1.26 which corresponds to a SIL difference of 1 dB. $10 \text{ Log}(1.26) = 1.0$

Just Noticeable Difference (jnd)



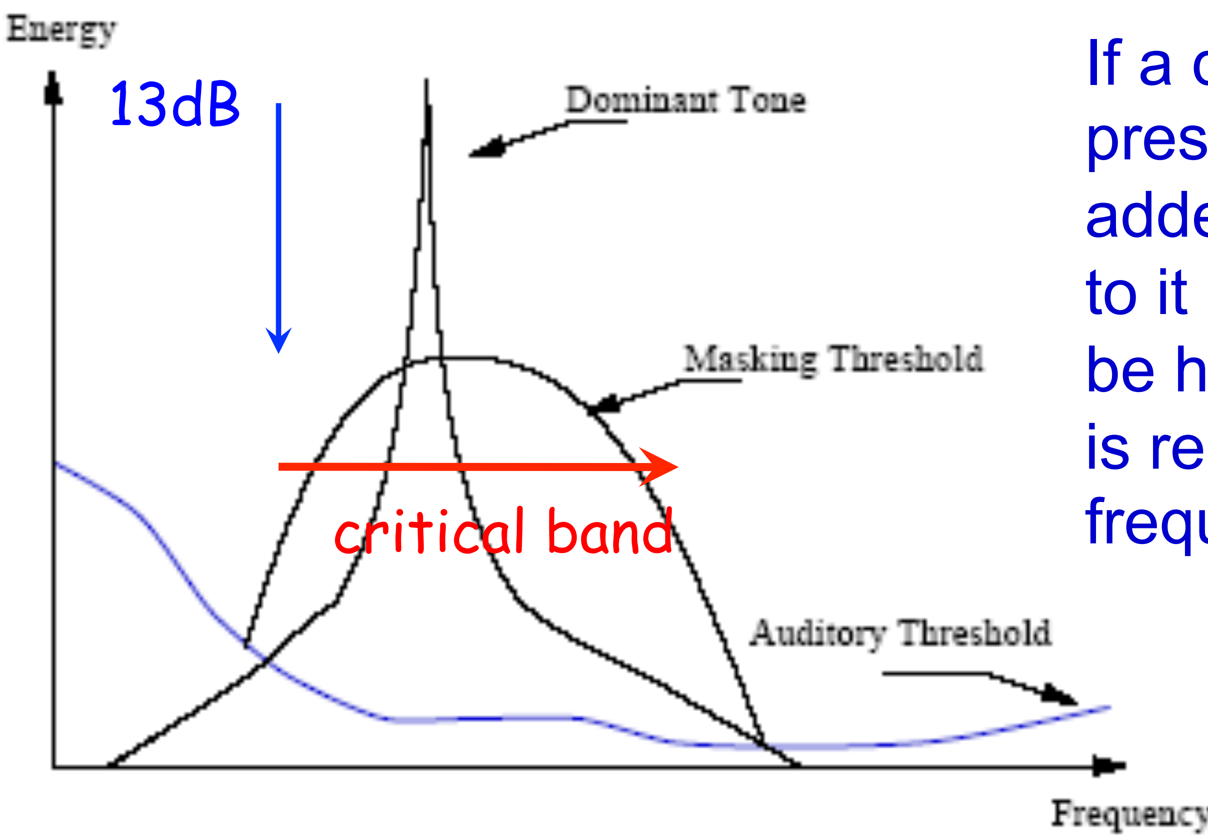
- There are some variations. The jnd is about 1 dB for soft sounds around 30-40 dB at low and midrange freqencies. It may drop to 1/3 to 1/2 a decibel for loud sounds.

- Caution must be used in applying the "one decibel" criterion. It presumes that you are increasing the <u>same sound</u> by one decibel.

Musical Loudness Scale

Pianissimo:	*pp*	very soft	50 dB
Piano:	*p*	soft	60 dB
Mezzopiano:	*mp*	medium soft	66 dB
Mezzoforte:	*mf*	medium loud	76 dB
Forte:	*f*	loud	80 dB
Fortissimo:	*ff*	very loud	90 dB
Fortississimo:	*fff*	Very, very loud	100 dB

Masking



If a dominant tone is present then noise can be added at frequencies next to it and this noise will not be heard. Less precision is required to store nearby frequencies.

- Masking is the process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound

- Masking is the amount by which the threshold is raised by the masker (in dB).