Signals, systems, acoustics and the ear

Week 1

Laboratory session: Measuring thresholds

What's the most commonly used piece of electronic equipment in the audiological clinic?

And what is its purpose?

To determine the lowest intensity sounds that people can hear

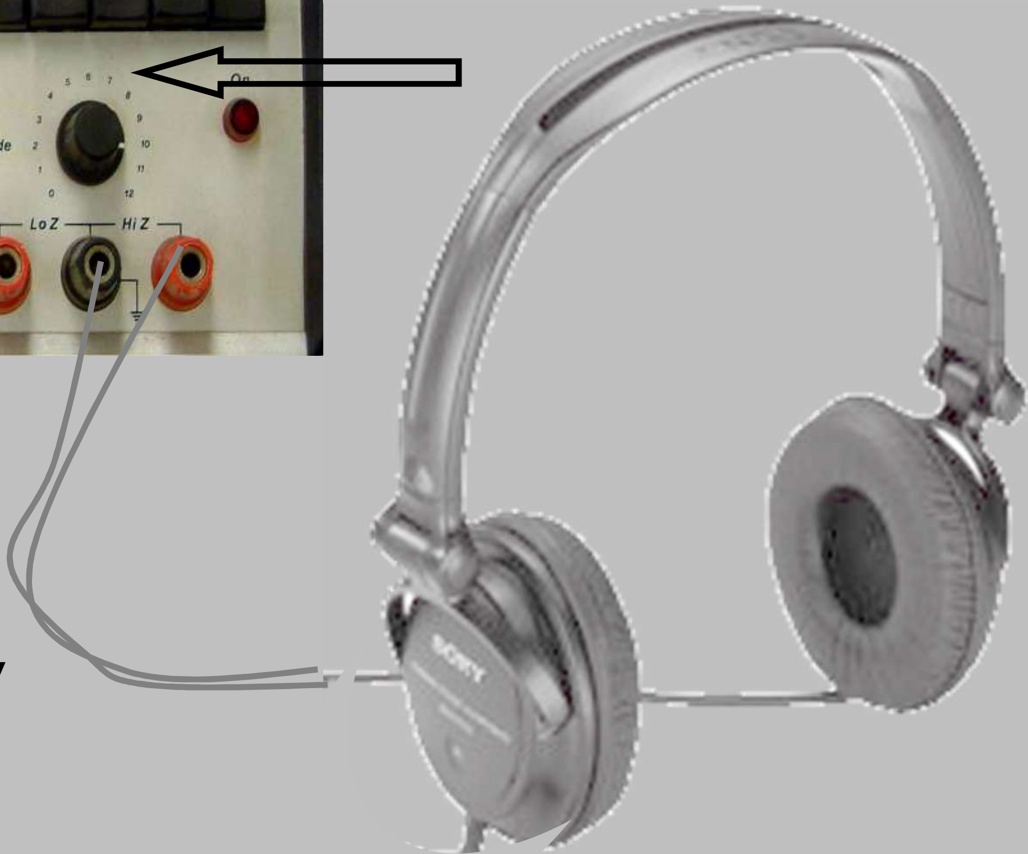
(for pure tones as a function of their frequency)

The minimalist audiometer needs …

- An oscillator to *generate* an electrical sinusoidal wave at the desired frequencies
- A calibrated volume control to *adjust* the intensity of the sound
- A headphone to convert the electrical wave to an acoustic one, so it can be presented to the listener

The minimal audiometer

change amplitude
(2 ways)

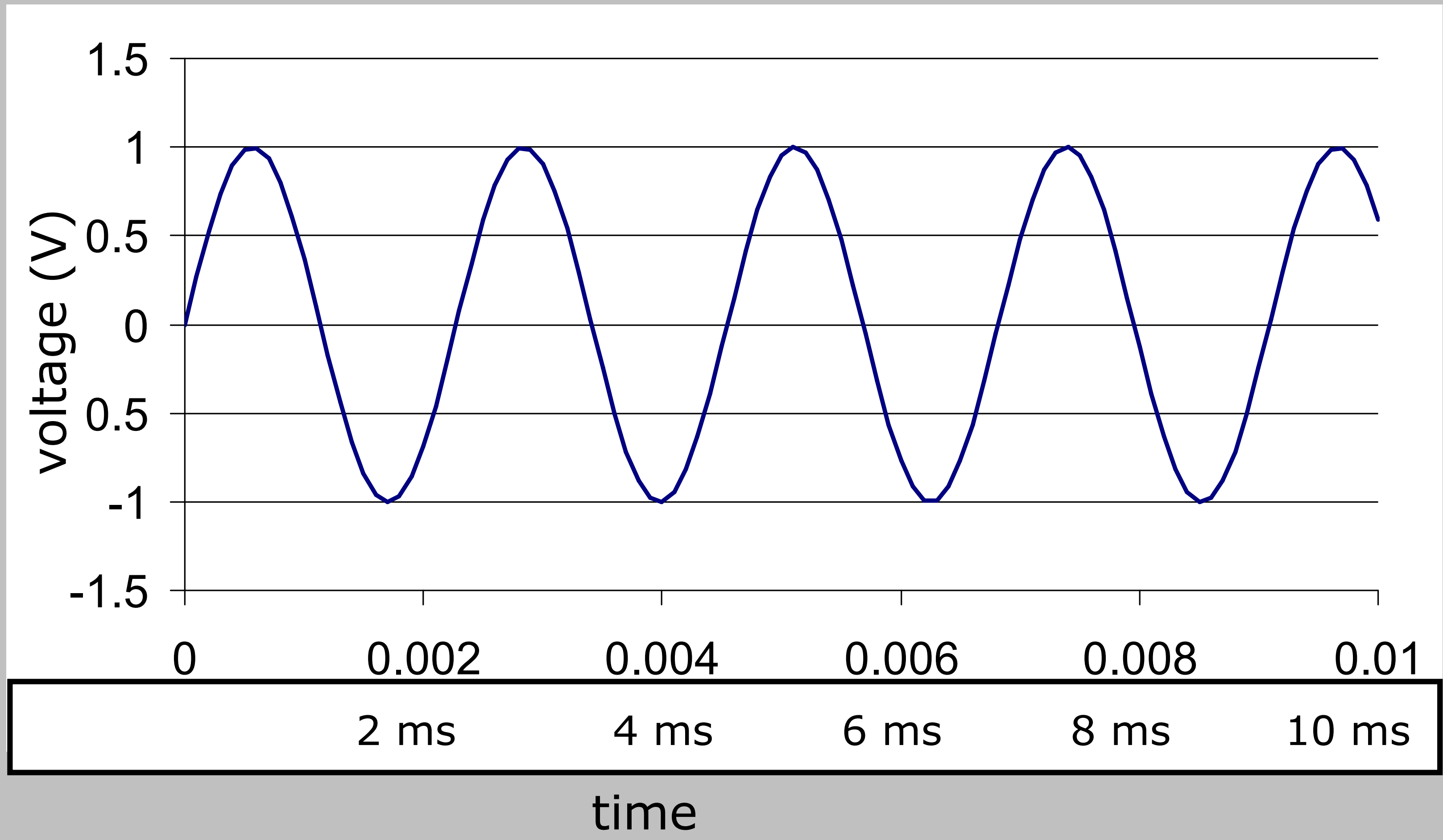


change frequency

What comes out of the oscillator?

- Electrical wave (to be graphed as a *waveform*)
  - A graph of the *instantaneous* value of the voltage (or current), across time
- Crucial for every waveform …
  - x-axis is always *time* (s, ms, μs)
  - y-axis always a *linear instantaneous* amplitude measure (V, mV, μV)
- But oscillators usually give a very special waveform, a *sinusoid*, also known as a *pure tone* (at least in reference to sounds)

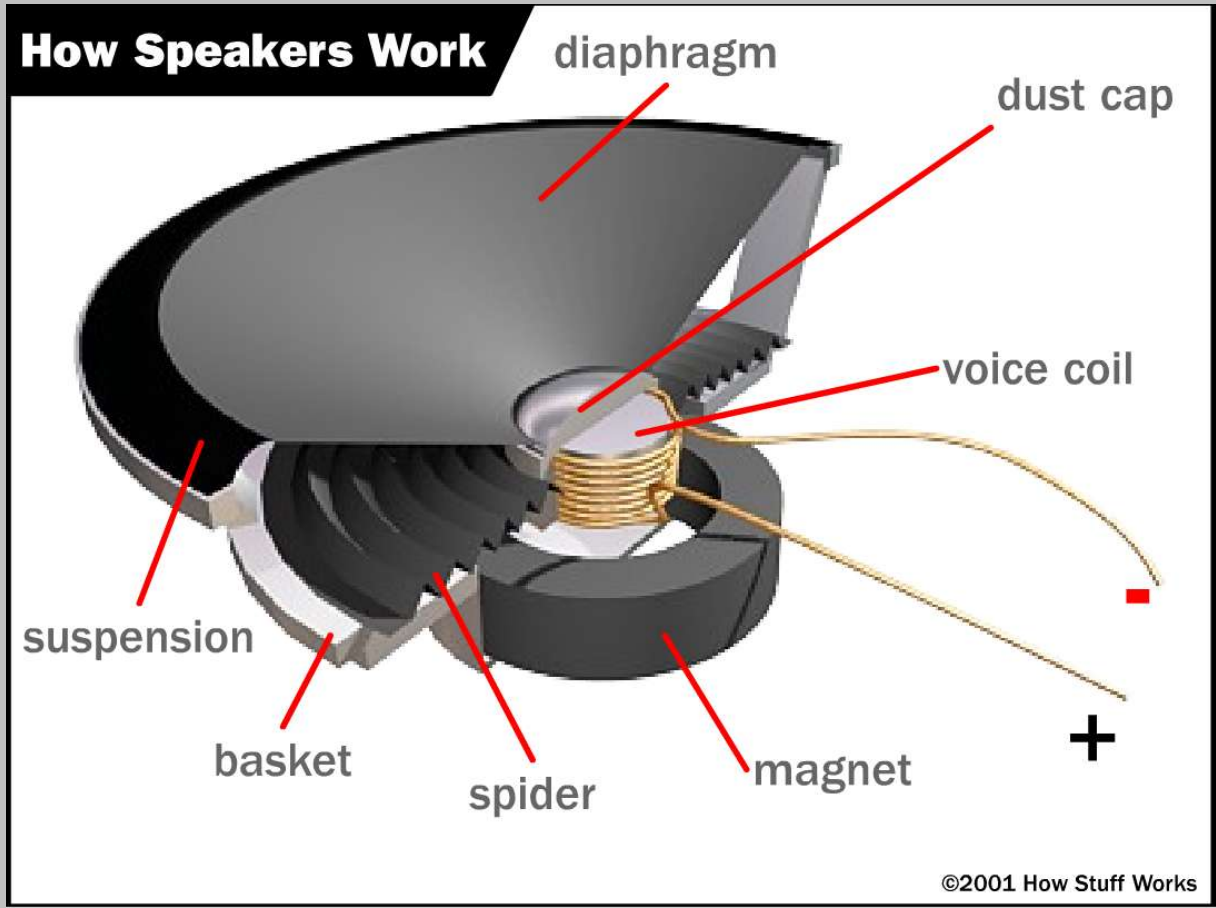
An electrical sinusoidal waveform from an oscillator



Transducing an electrical wave to an acoustic one

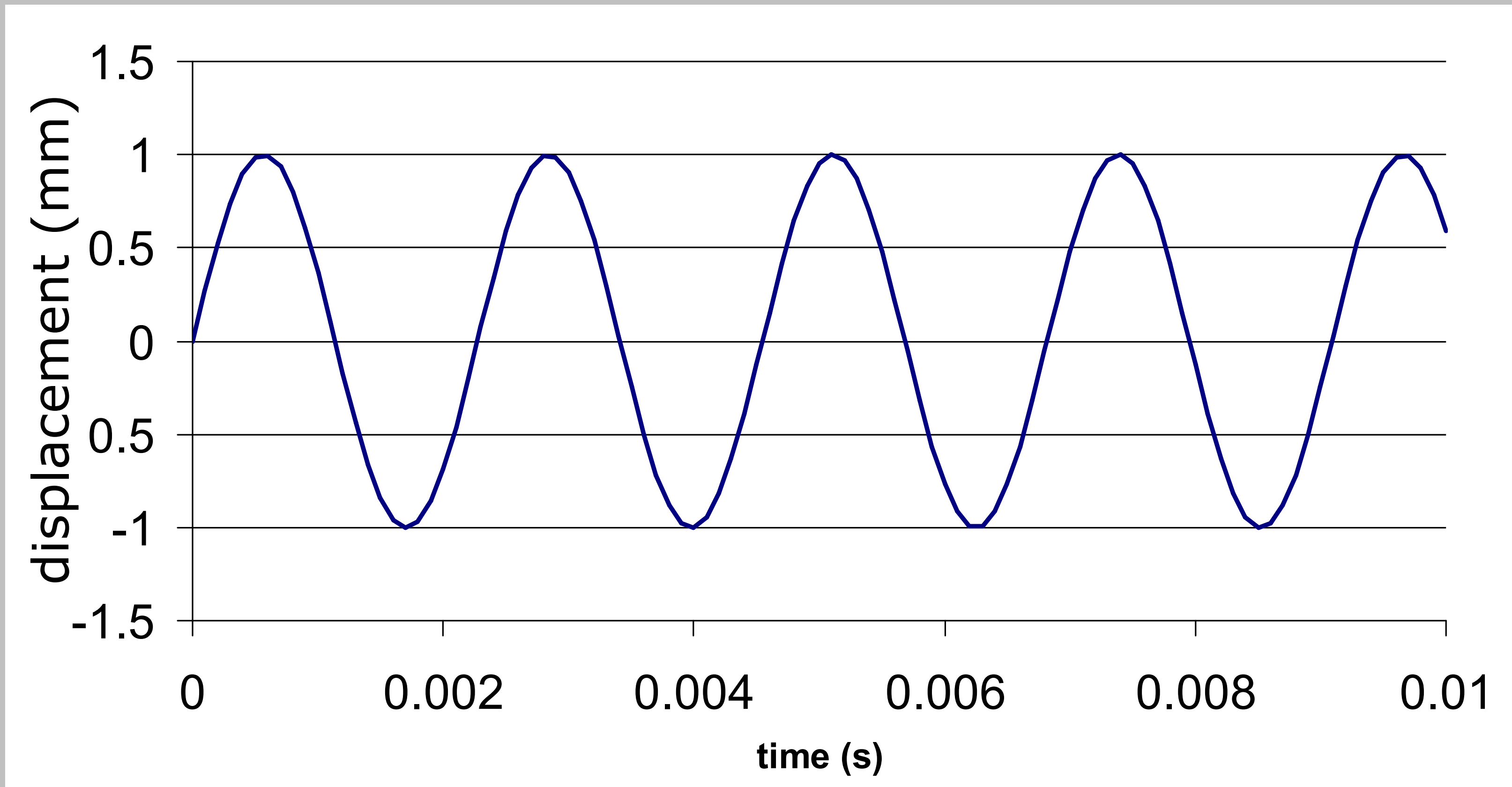
- We cannot hear an electrical wave directly, so need to convert it …
- by feeding to the headphones
- which *transduce* the variations in the electrical wave to a mechanical wave
  - the changes in voltage cause the headphone diaphragm to vibrate, which makes the sound

Just like a miniature loudspeaker

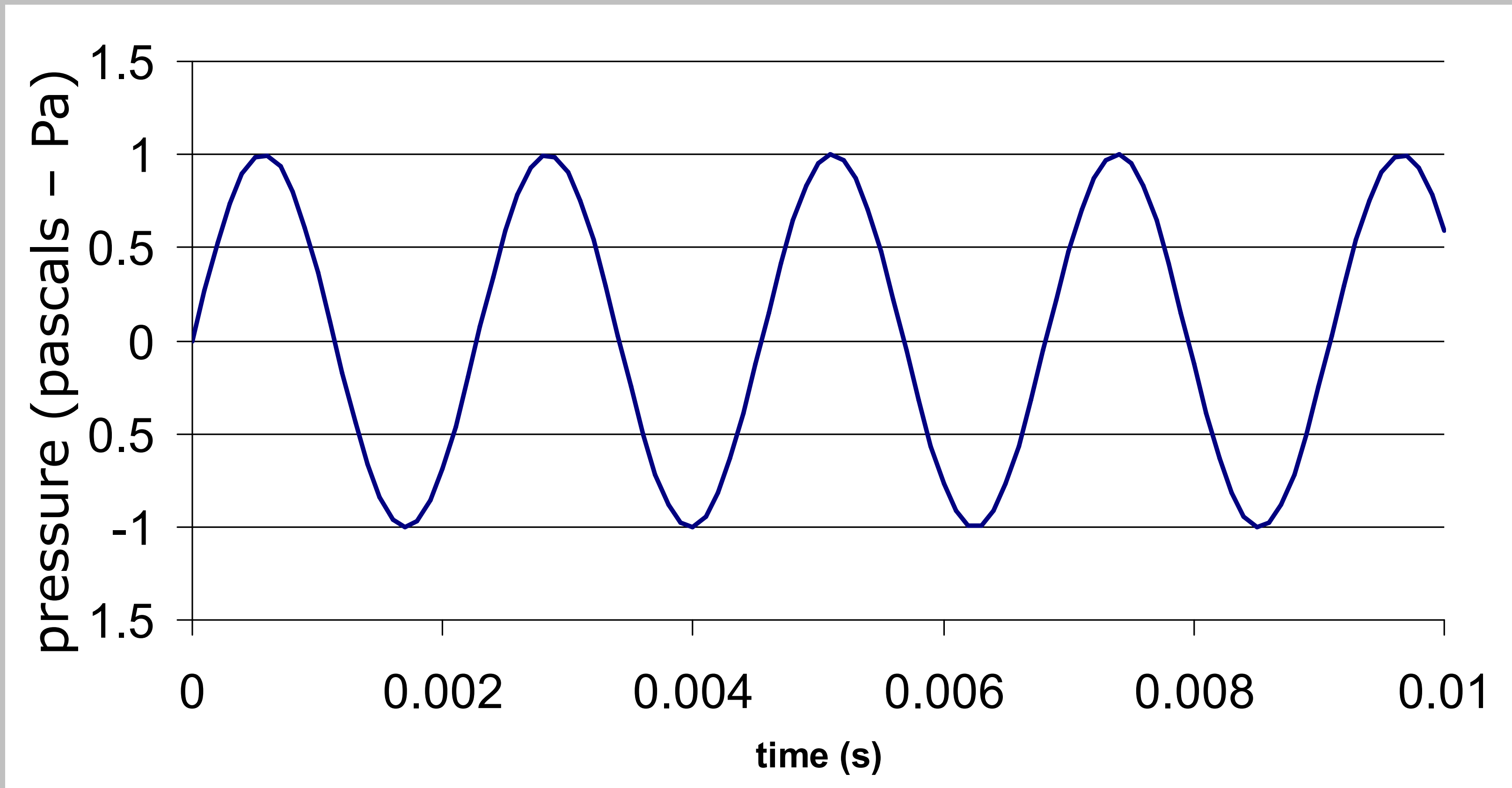


http://electronics.howstuffworks.com/speaker5.htm

Movement of the headphone diaphragm



Sound pressure fluctuations in the air



Look at the units on the y-axis

Today's laboratory: Measure thresholds with a simple audiometer'

Measuring thresholds I

- Set oscillator to desired frequency and attenuator to 0 (maximum level)
- Present a tone for about 1 s by pressing the button
- The ‘patient’ indicates having heard the tone by raising a finger

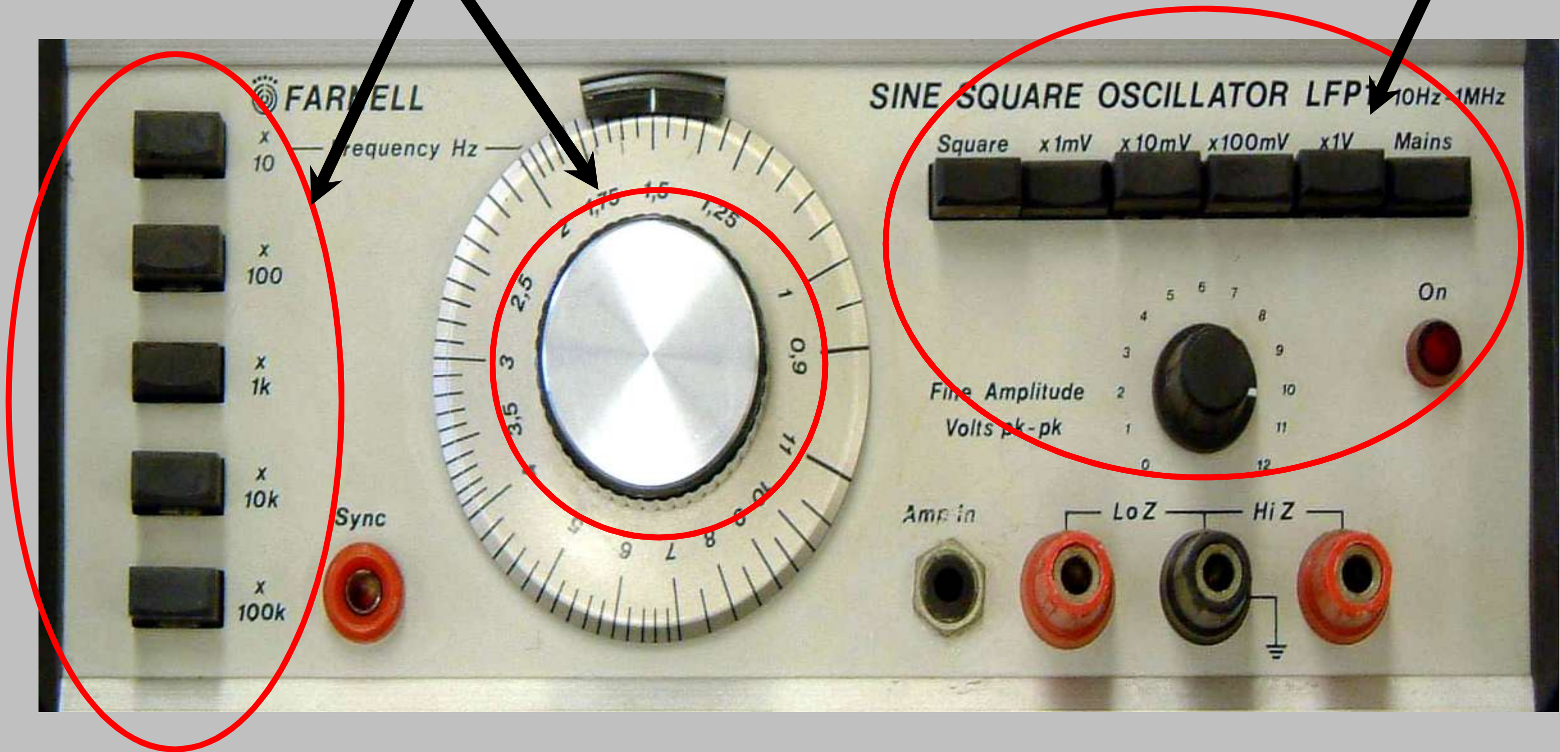
Measuring thresholds II

- If heard, decrease level by 10 dB (2 clicks clockwise)
- If not heard, increase level by 5 dB (1 click counter-clockwise)
- Present tone
- Repeat steps above to find lowest level at which the ‘patient’ hears the tone on 2 of 2, 3 or 4 tries on the ascent (at least 50%)
- Do all the frequencies specified

Observe!

Adjust frequency with these buttons and dial

Do not touch these buttons



Observe!

Adjust level with this dial

What do you need to know in order to know what threshold a person has (in dB SPL)?

Things you need to know

- Keep the data from any lab you do. You will need some of it to do your exercise sets.
- Today: 4 set-ups available in sound-proof rooms (work in pairs)
- Once you have your thresholds as attenuation values, come back to the lab (do not do your calculations in the cubicles). Ensure you write down the calibrated values from the particular set of equipment you used.
- Do the lab ‘Explore signals’ while you are not doing audiometry. We will do the calculations later.

Laboratory session: Measuring thresholds

Part 2

dB SPL examples: a reminder

- Threshold of Hearing (20 μPa)

  $20 \times \log_{10}(20\ \mu Pa/20\ \mu Pa)$

  $= 20 \times \log_{10}(1) = 20 \times 0$

  $= 0$ dB SPL

- Threshold of Pain (200 Pa)

  $20 \times \log_{10}(200\ Pa/20\ \mu Pa)$

  $= 20 \times \log_{10}(10000000) = 20 \times 7$

  $= 140$ dB SPL

- An inaudible sound (2 μPa)

  $20 \times \log_{10}(2\ \mu Pa\ /20\ \mu Pa)$

  $= 20 \times \log_{10}(0.1) = 20 \times -1$

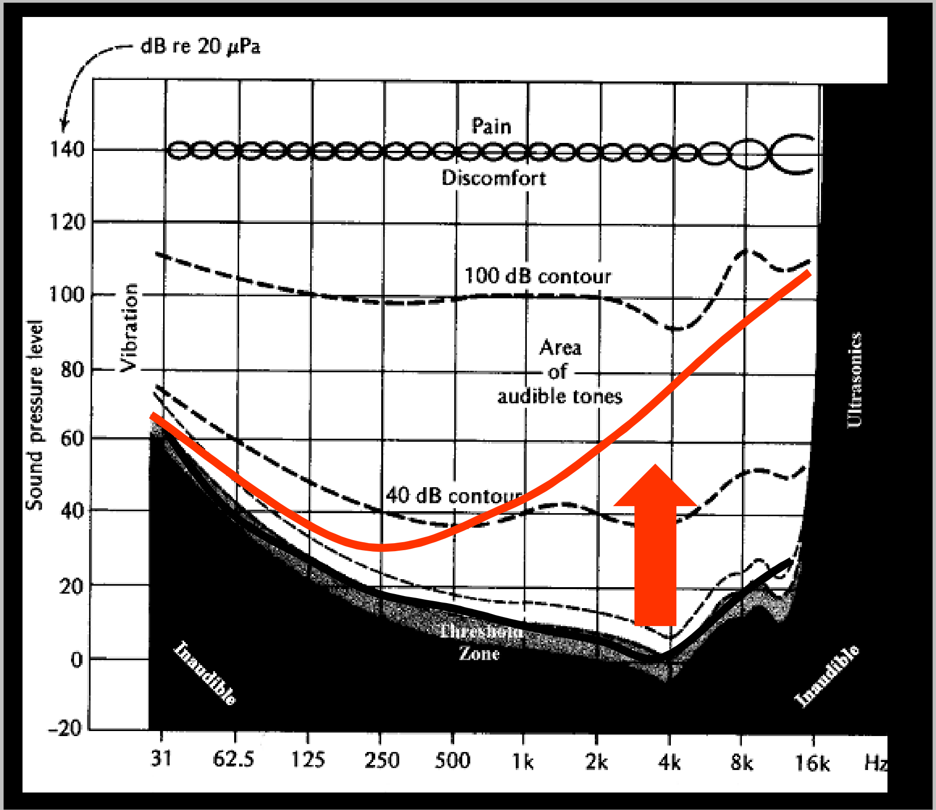
  $= -20$ dB SPL

dB SPL: working backwards
db SPL $\rightarrow$ Pa

- If threshold of hearing for a 125 Hz sinusoid is 30 dB SPL, how many Pa is this?
  - 30 dB SPL = $20 \times \log_{10}(\theta\ \mu Pa/20\ \mu Pa)$
  - $30/20 = \log_{10}(\theta\ \mu Pa\ /20\ \mu Pa)$
  - Note: $10^{\log 10\ (\theta)} = \theta$
    - *e.g.,* $10^{\log 10\ (100)} = 10^{\log 10\ (10^2)} = 10^2 = 100$
  - $10^{30/20} = (\theta\ \mu Pa\ /20\ \mu Pa)$
  - $20 \times 10^{30/20} = \theta$
  - $20 \times 10^{30/20} = 20 \times 10^{1.5} = 20 \times 31.62 = 632.5\ \mu Pa$

- More generally
  - λ dB SPL = $20 \times \log_{10}(\theta\ \mu Pa\ /20\ \mu Pa)$
  - $\lambda\ /20 = \log_{10}(\theta\ \mu Pa\ /20\ \mu Pa)$
  - $10^{\ \lambda/20} = (\theta\ \mu Pa\ /20\ \mu Pa)$
  - $20 \times 10^{\ \lambda/20} = \theta\ \mu Pa$

Measuring hearing loss



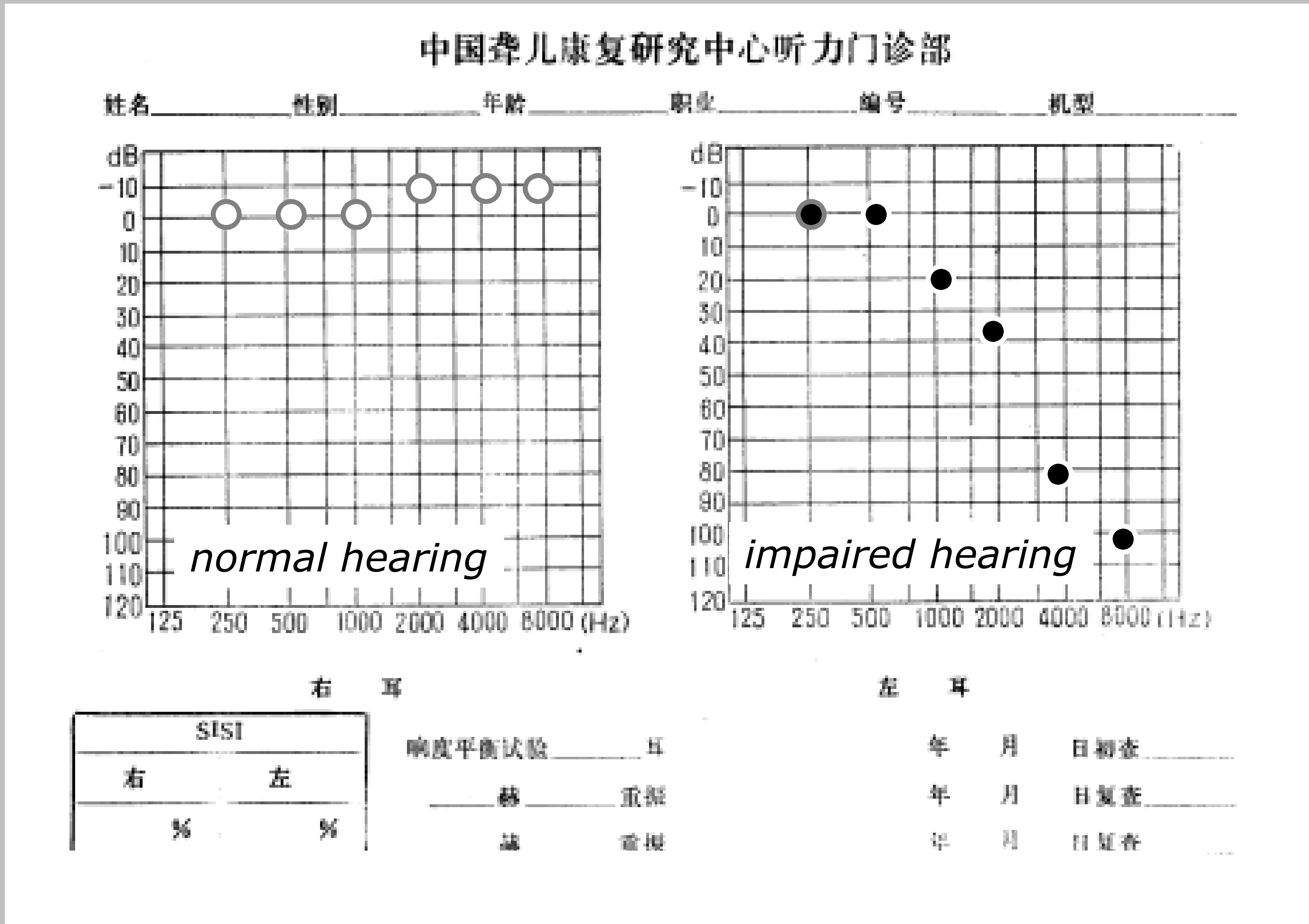
Poorer hearing leads to higher thresholds

- Someone with a hearing loss would have higher thresholds
- Here, for example, the loss is small at low frequencies and great at high (a typical pattern)
- We're interested in **differences** to normal thresholds

Displaying a threshold curve in a clinically relevant way — the *audiogram*

- For clinical purposes, it's easier to judge *deviations* from normality.
- Use dB Hearing Level (HL) instead of dB SPL
- To calculate a person's Hearing Level ...
  - Find the absolute threshold in dB SPL ….
  - Subtract the normal value of the absolute threshold (again in dB SPL) ...
  - And plot increasing positive values downward (higher thresholds = more hearing loss = points further down the page).

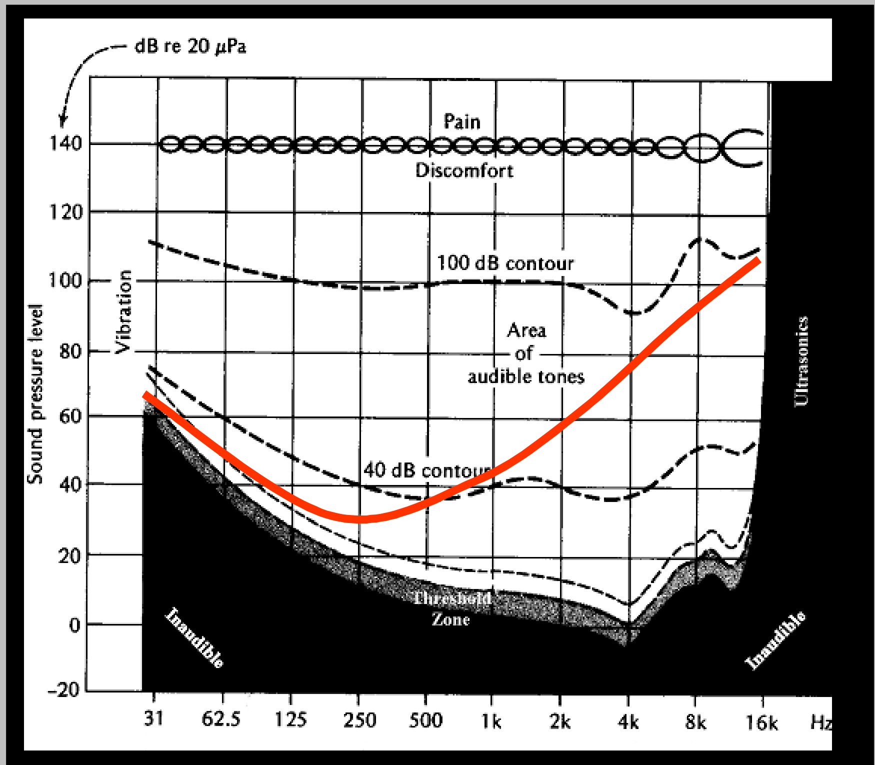
Example audiograms

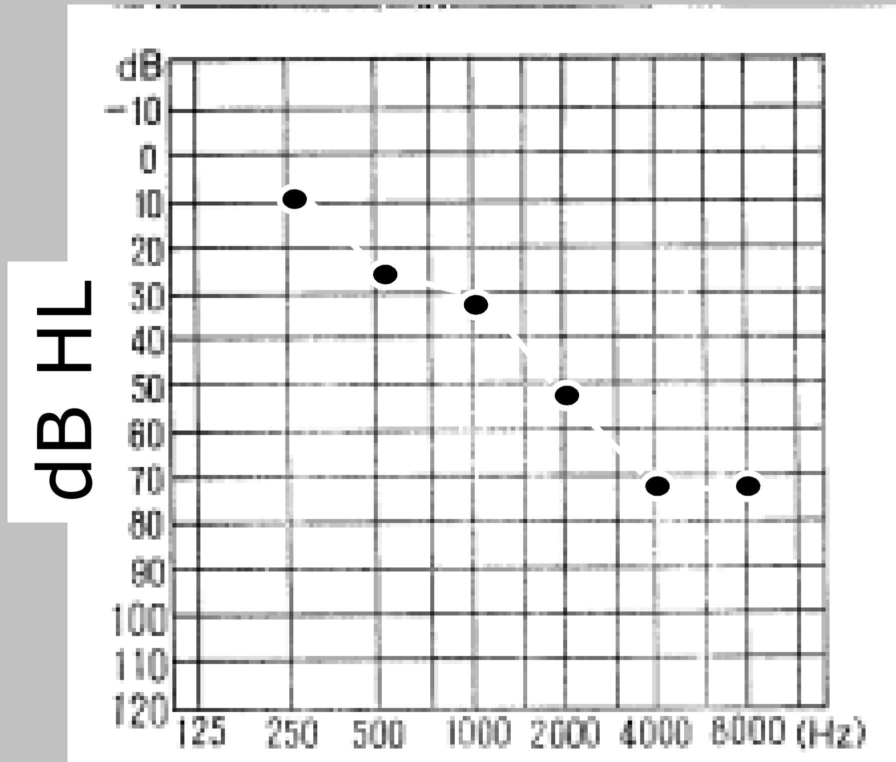


From the China Rehabilitation Research Center for Deaf Children, Beijing.

Constructing an audiogram (converting dB SPL to dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
patient SPL	30	38	42	60	73	92
‘normal’ SPL	20	10	8	4	0	20
patient HL	10	28	34	56	73	72





dB SPL vs. dB HL for sinusoids

- dB SPL = 20 x $\log_{10}(p/20\ \mu Pa)$
  - the same reference level for every frequency
- dB HL = 20 x $\log_{10}(p/\theta\ \mu Pa)$
  - where θ μPa is the normal absolute threshold *for that particular frequency*
  - so reference level typically is different for every frequency

An example of dB HL

- Normal threshold of hearing at 125 Hz = 632.5 μPa)
- Suppose someone's threshold is 356 μPa, then
  - $20 \times \log_{10}(356\ \mu Pa / 632.5\ \mu Pa) = -5$ dB HL
  - So dB HL just has a different reference level than dB SPL
- But also note
  - $20 \times \log_{10}(356\ \mu Pa / 20\ \mu Pa) = 25$ dB SPL
  - $20 \times \log_{10}(632.5\ \mu Pa / 20\ \mu Pa) = 30$ dB SPL
- So, you can also obtain dB HL by subtracting the normal threshold from the obtained one:
  - 25 dB SPL - 30 dB SPL = -5 dB HL

Back to the lecture …