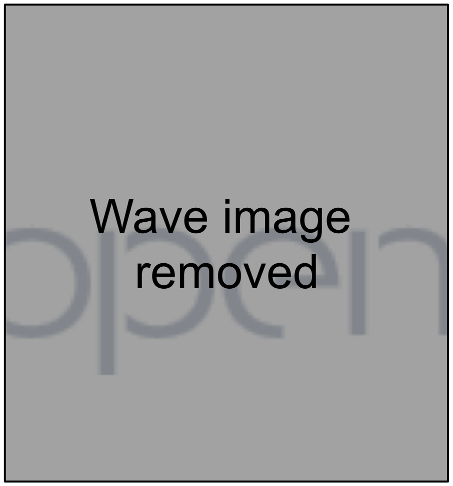
Physics 140 – Fall 2007
lecture #26: 6 Dec

<u>Ch 16 topics:</u>

- sound waves
- speed of sound
- sound intensity, decibel scale
- standing waves, harmonics
- interference, beats
- Doppler effect



http://www.privateline.com/TelephoneHistory/speech.jpg

Final exam is **next Friday, 14 Dec, 7:30–9:30pm**

Alternate: 4:00–6:00pm

- bring: up to **four** 3x5 notecards or one 8.5x11 sheet, calculator, #2 pencils, student ID

Sound Waves

Sound waves are ***longitudinal pressure variations*** that move through a medium. Any sound can be represented as a sum of scaled and phased *pure tones*, each characterized by an amplitude of pressure variations Δp, angular frequency ω and phase constant ϕ

$$\Delta p(x,t) = \Delta p_m \sin(kx \pm \omega t + \phi)$$

where $+x$ is the direction of propagation of the sound.

The angular wavenumber k can be determined through the relation to the speed of sound v in the medium $k=v/\omega$.

Associated with the pressure fluctuation are displacements $y(x,t)$ of elements of the medium aligned with the direction of propagation

$$y(x,t) = A\cos(kx \pm \omega t + \phi)$$

For a medium with density ρ, the amplitudes are related by

$$\begin{aligned} \Delta p_m &= (\rho v^2)kA \\ &= BkA \qquad \text{(for fluid w/ bulk mod } B\text{)} \end{aligned}$$

Speed of sound

Sound propagates at speed v by the continual transfer of energy between oscillating elements of a medium. The generic form for the sound speed

$$v = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

reflects the fact that the speed of sound is linked to the *efficiency of mechanical energy transport*.

Mediums with higher elasticity or lower inertia will transport energy more efficiently, resulting in higher sound speeds.

Air at room temperature (20˚C) and at atmospheric pressure (10^5 Pa) has a sound speed

$$v = 343 \text{ m/s}$$

Sound intensity

Sound waves transport energy in the form of pressure variations.

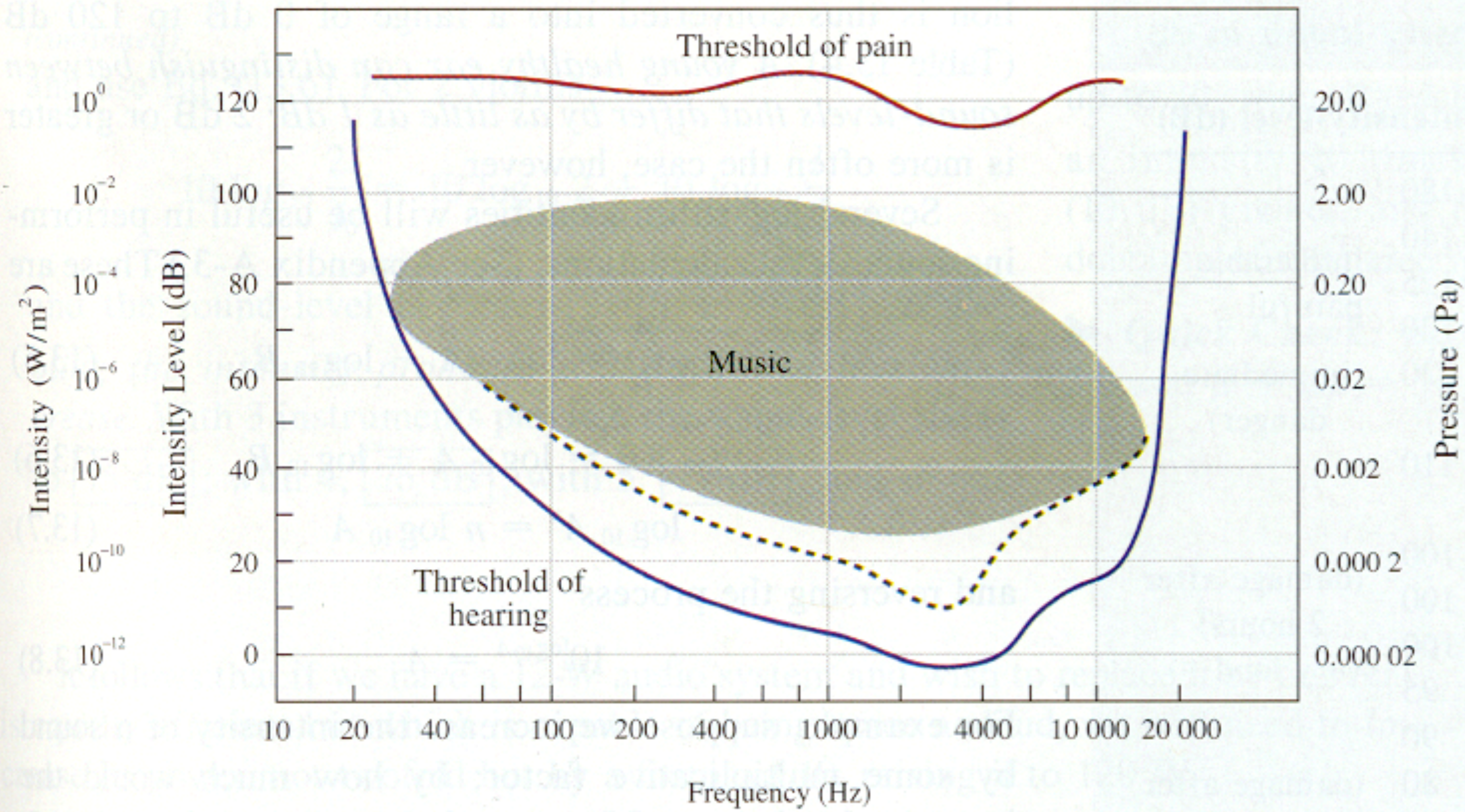
$$I = \langle p(t) v_y(t) \rangle_{\text{cycle}} = \frac{1}{2} B \omega k A^2 = \frac{1}{2} \rho v \omega^2 A^2$$

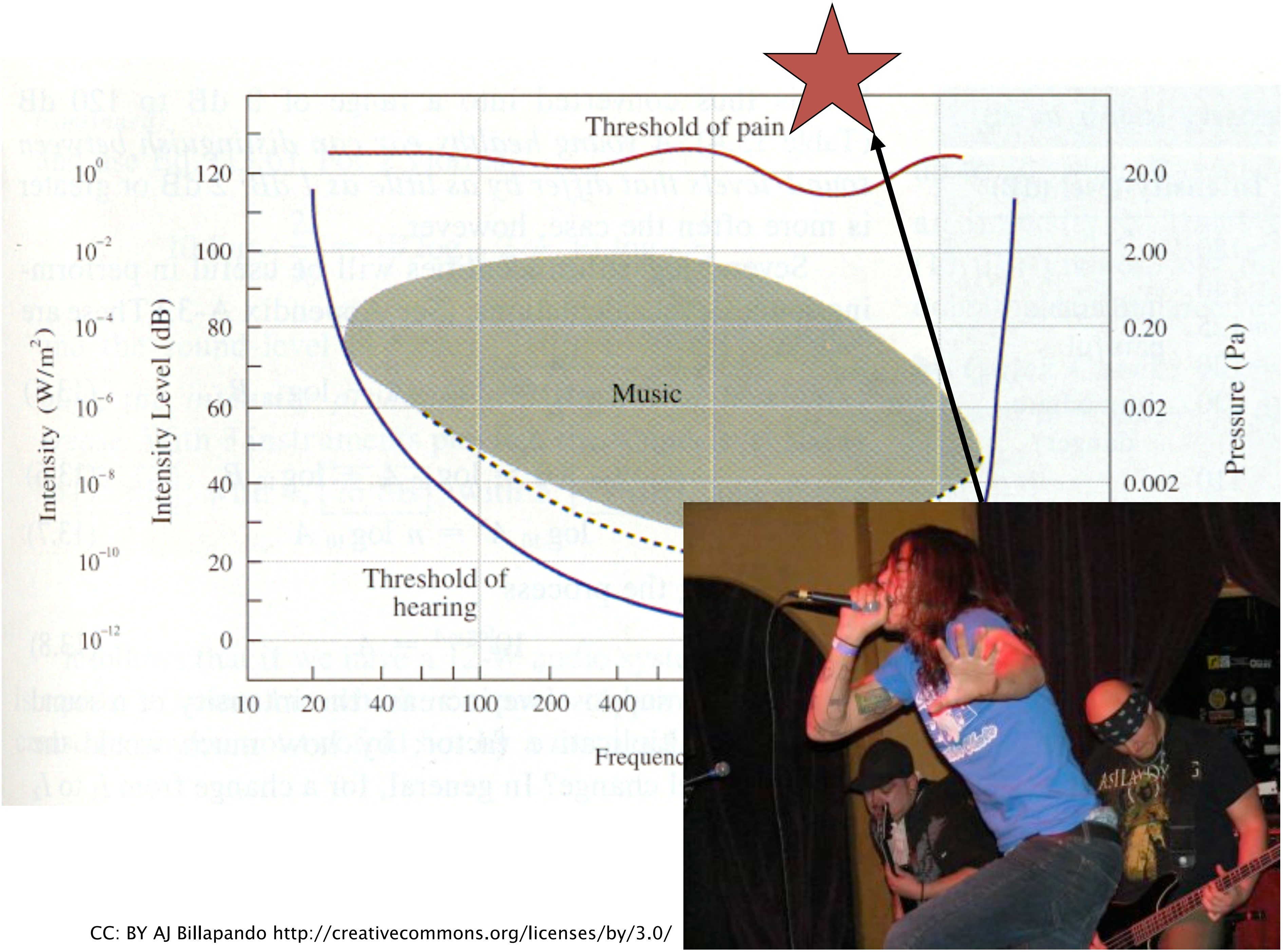
Human ears can typically detect sounds with intensity above a minimum value $I_0 = 10^{-12}\ \mathrm{W/m^2}$. The ***decibel scale*** is a common measure of ***sound intensity***. It uses the logarithm (decimal, not natural) of the intensity

$$\beta = (10\ \mathrm{dB})\ \log_{10}(I / I_0)\ .$$

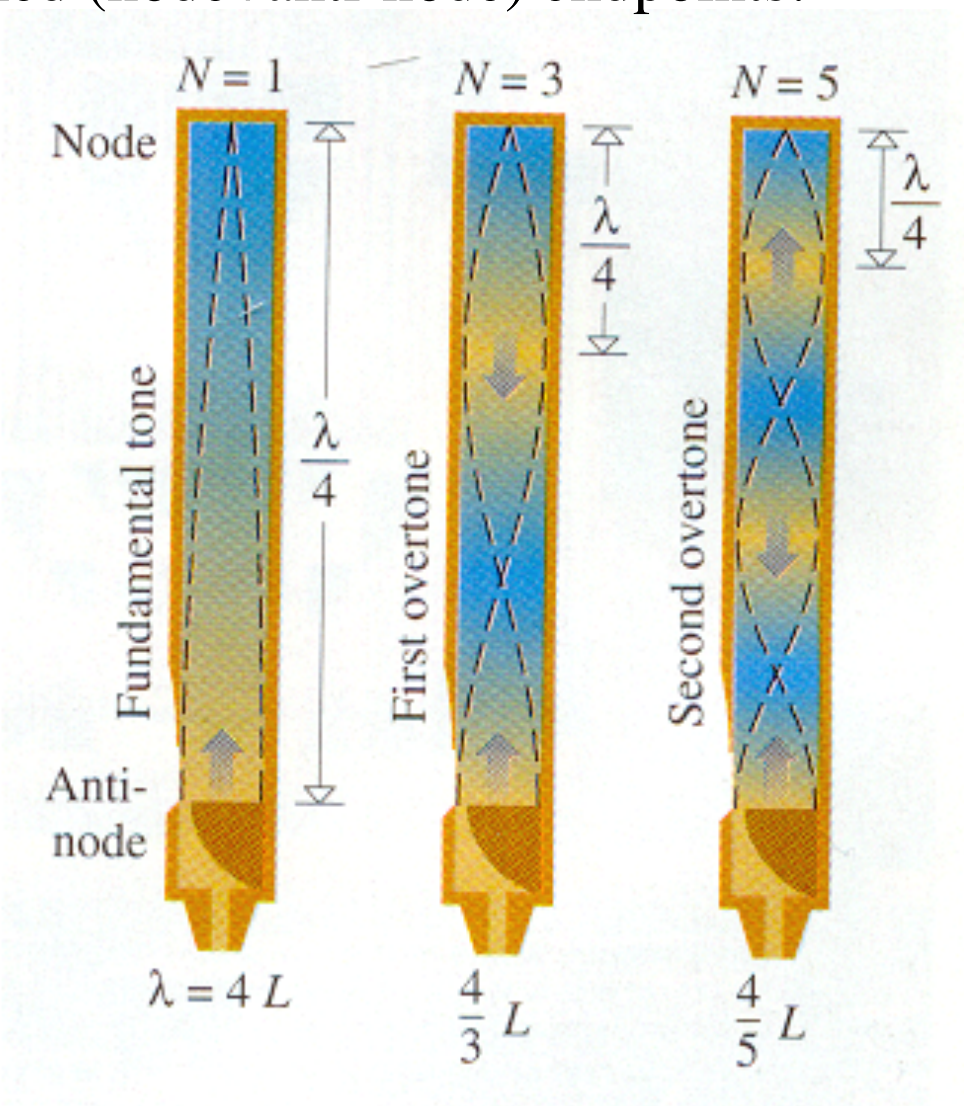
Whereas a change of 10 dB corresponds to a factor 10 increase in intensity, a change of 20 dB corresponds to a factor 100 increase (not a factor 20).

The threshold of pain for the human ear occurs at 120 dB, an **amazing factor of 10^{12}** (one trillion) times more intense than the threshold for hearing.


Threshold of pain
Music
Threshold of hearing
Intensity (W/m²)
10⁰
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻¹²
Intensity Level (dB)
120
100
80
60
40
20
0
Pressure (Pa)
20.0
2.00
0.20
0.02
0.002
0.000 2
0.000 02
10
20
40
100
200
400
1000
4000
10 000
20 000
Frequency (Hz)


Threshold of pain
Music
Threshold of
hearing
Intensity (W/m^2)
Intensity Level (dB)
Pressure (Pa)
Frequenc
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
120
100
80
60
40
20
0
20.0
2.00
0.20
0.02
0.002
10
20
40
100
200
400

Fundamental and first two harmonics of standing waves with mixed (node+anti-node) endpoints.



Standing waves and musical instruments

Different harmonic frequencies arise from string or wind instruments of a given length L, depending on whether the endpoints are nodes (zero summed amplitude) or anti-nodes (max summed amplitude).

- node : node (e.g., guitar, violin)

$$f_n = n\,(v/\,2L)\ ;\ n = 1, 2, 3, \ldots$$

- anti-node : anti-node (e.g., flute, organ pipe)

$$f_n = n\,(v/\,2L)\ ;\ n = 1, 2, 3, \ldots$$

- node : anti-node (e.g., clarinet, saxophone)

$$f_n = n\,(v/\,4L)\ ;\ n = 1, 3, 5, \ldots\quad (\underline{\text{odd}}\text{ harmonics})$$

What would be the wavelength of the third harmonic of an organ pipe of length L, open to air at both ends?

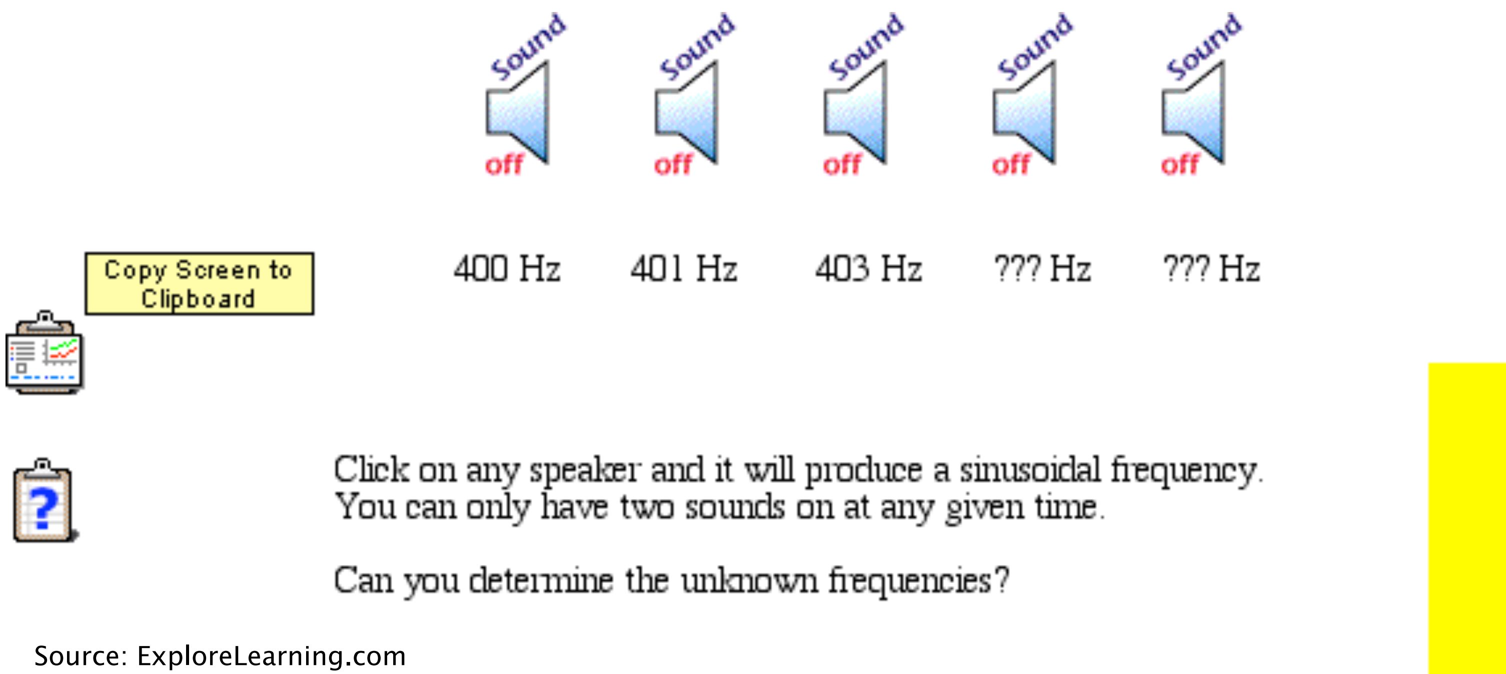
1) $2L$
2) $3L/2$
3) L
4) $2L/3$
5) $L/2$

Beats

Two pure, equal amplitude tones, with frequencies w_1 and w_2, superpose to create a *modulated sound pattern* that varies in time as

$$y(t) = 2A\sin[\tfrac{1}{2}(\omega_1 - \omega_2)\mathrm{t}]\cos[\tfrac{1}{2}(\omega_1 + \omega_2)\mathrm{t}]$$

and is especially noticeable when $w_2 - w_1 << w_2 + w_1$.



Source: ExploreLearning.com

http://www.explorelearning.com/index.cfm?method=cResource.dspView&ResourceID=48

Doppler effect for sound

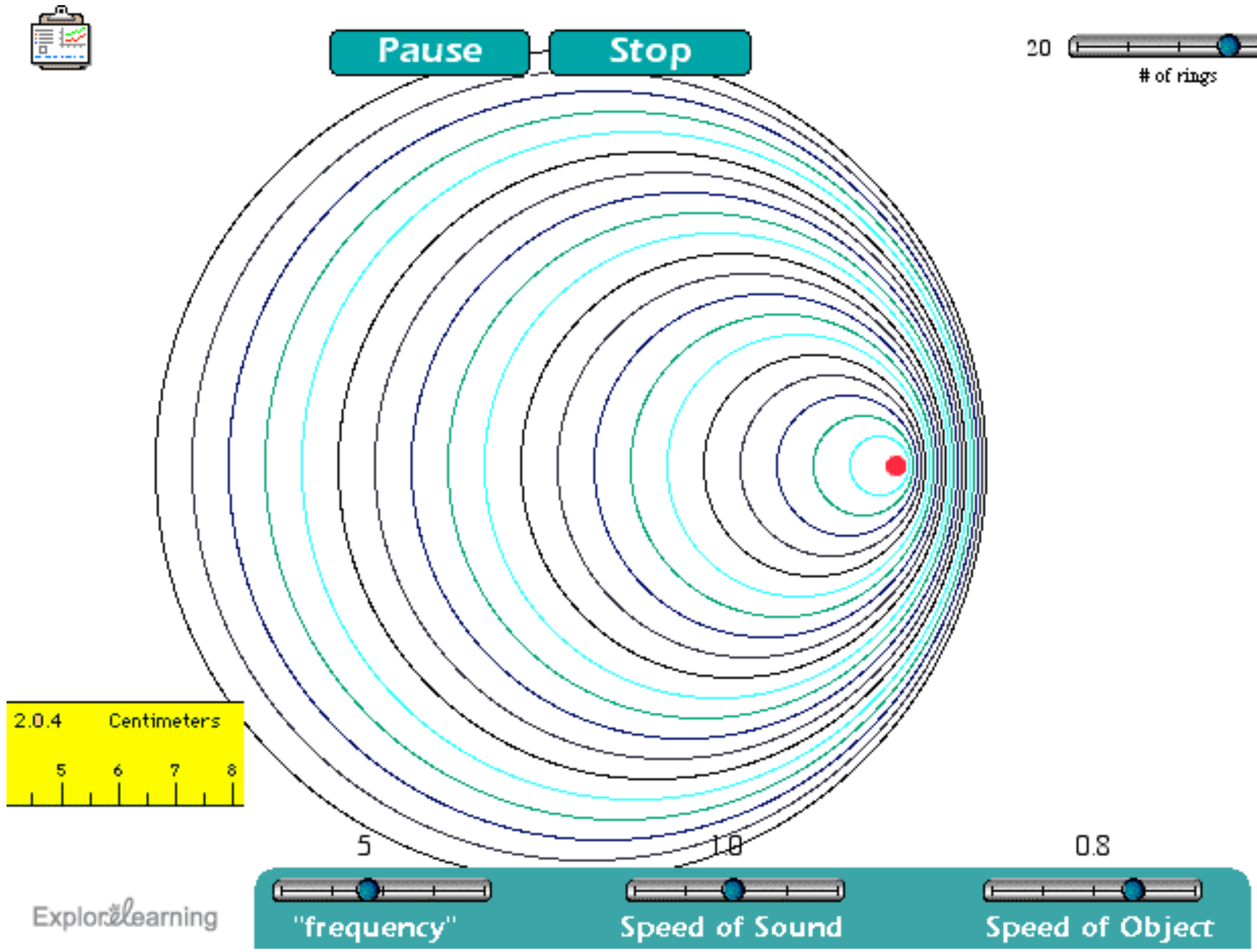
When there is ***relative motion*** between a wave source and detector, the frequency (and wavelength) of the source will differ from the received values. This phenomenon is known as the *Doppler effect*.

For a source and detector with speeds v_S and v_D along the source-detector direction, the detected frequency is related to that of the source by

$$f_D = f_S \frac{v \pm v_D}{v \pm v_S}$$

The velocities are measured with respect to the medium and the sign convention is as follows:

source approaching detector	$-v_S$	f increases
source receding from detector	$+v_S$	f decreases
detector approaching source	$+v_D$	f increases
detector receding from source	$-v_D$	f decreases



Source: ExploreLearning.com

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You are on the freeway traveling side by side at 75 mph alongside a police car with siren blaring. Compared to the tone of the siren at rest, the tone you hear is

1) pitched higher (higher f)
2) pitched lower (lower f)
3) pitched the same (same f)
4) depends on the pitch (on f)

The police car then veers off and heads away from you. Compared to the tone of the siren at rest, the tone you hear now is

1) pitched higher (higher f)
2) pitched lower (lower f)
3) pitched the same (same f)
4) depends on the pitch (on f)