Puzzler

Two missiles speed directly toward each other, one at 9,000 miles per hour and the other at 21,000 miles per hour. They start 1,317 miles apart. Without using pencil and paper calculate how far apart they are one minute before they collide.

Solution: 500 miles

The two missiles approach each other at a combined speed of 30,000 miles per hour or 30,000/60 = 500 miles per minute.

So one minute before impact they are 500 miles apart.

Introduction to Audio and Music Engineering

Lecture 8

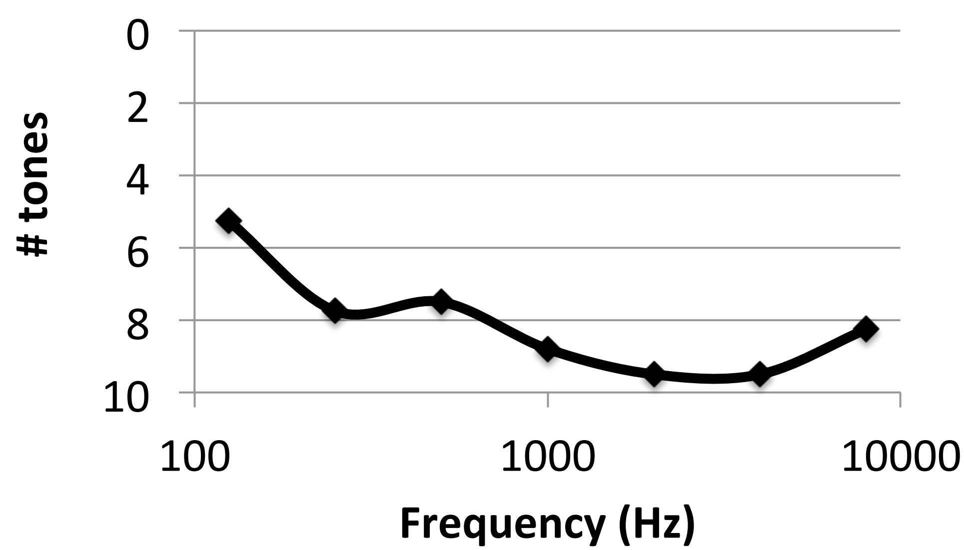
- Fletcher Munson curves
- Auditory masking
- Perceived loudness
- Acoustic waves in tubes
- Modes of tubes with various boundary conditions

Range of hearing

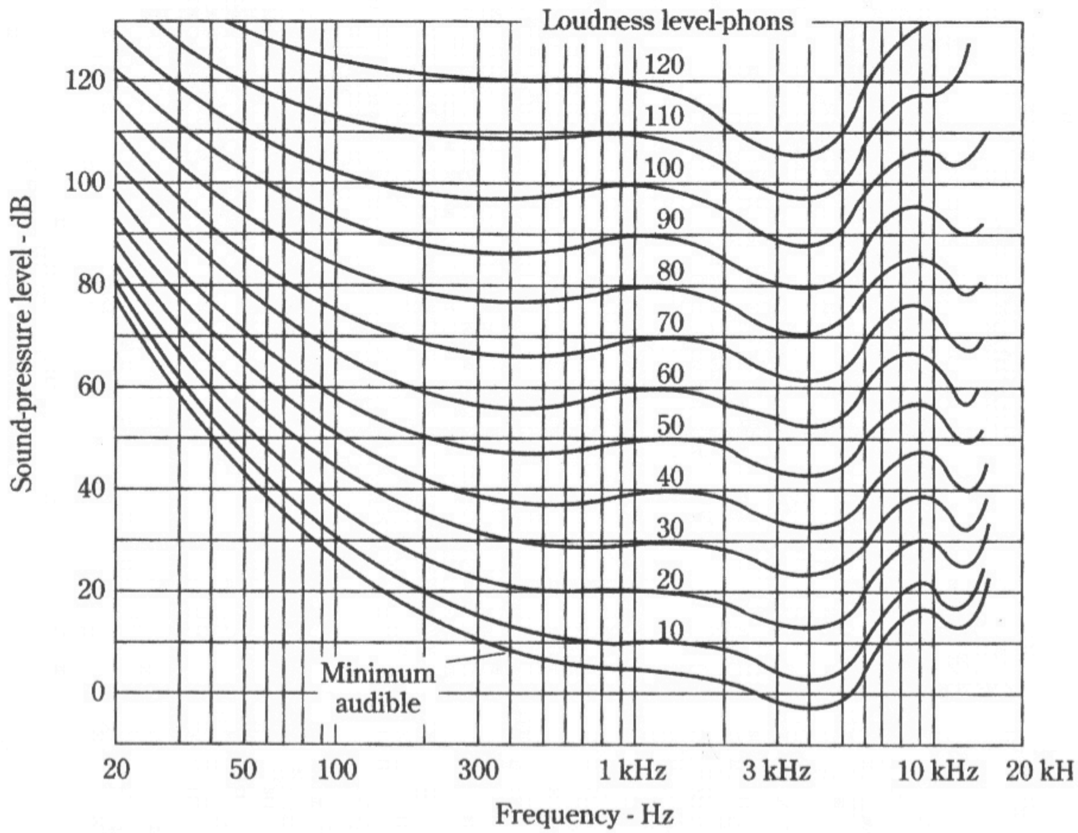
Listen to the sound file and determine how many "beeps" you can hear at each frequency.

Calibration Tone

Test



Fletcher Munson Curves



3-6 Equal-loudness contours of the human ear. These contours reveal the relative lack of sensitivity of the ear to bass tones, especially at lower sound levels. Inverting these curves give the frequency response of the ear in terms of loudness level. (After Robinson and Dadson.[8])

Auditory Masking

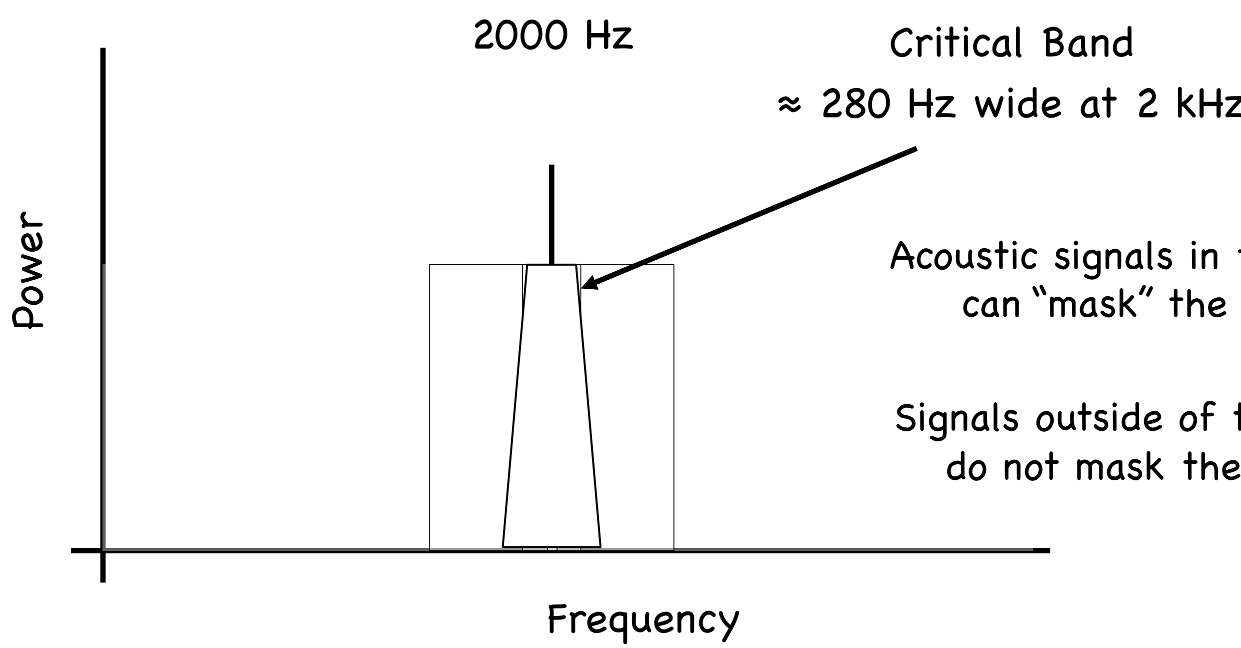

Unmasked Tone


Broadband Noise Masked


1000 Hz BW Noise


250 Hz BW Noise


10 Hz BW Noise



Acoustic signals in this band can "mask" the tone.

Signals outside of this band do not mask the tone.

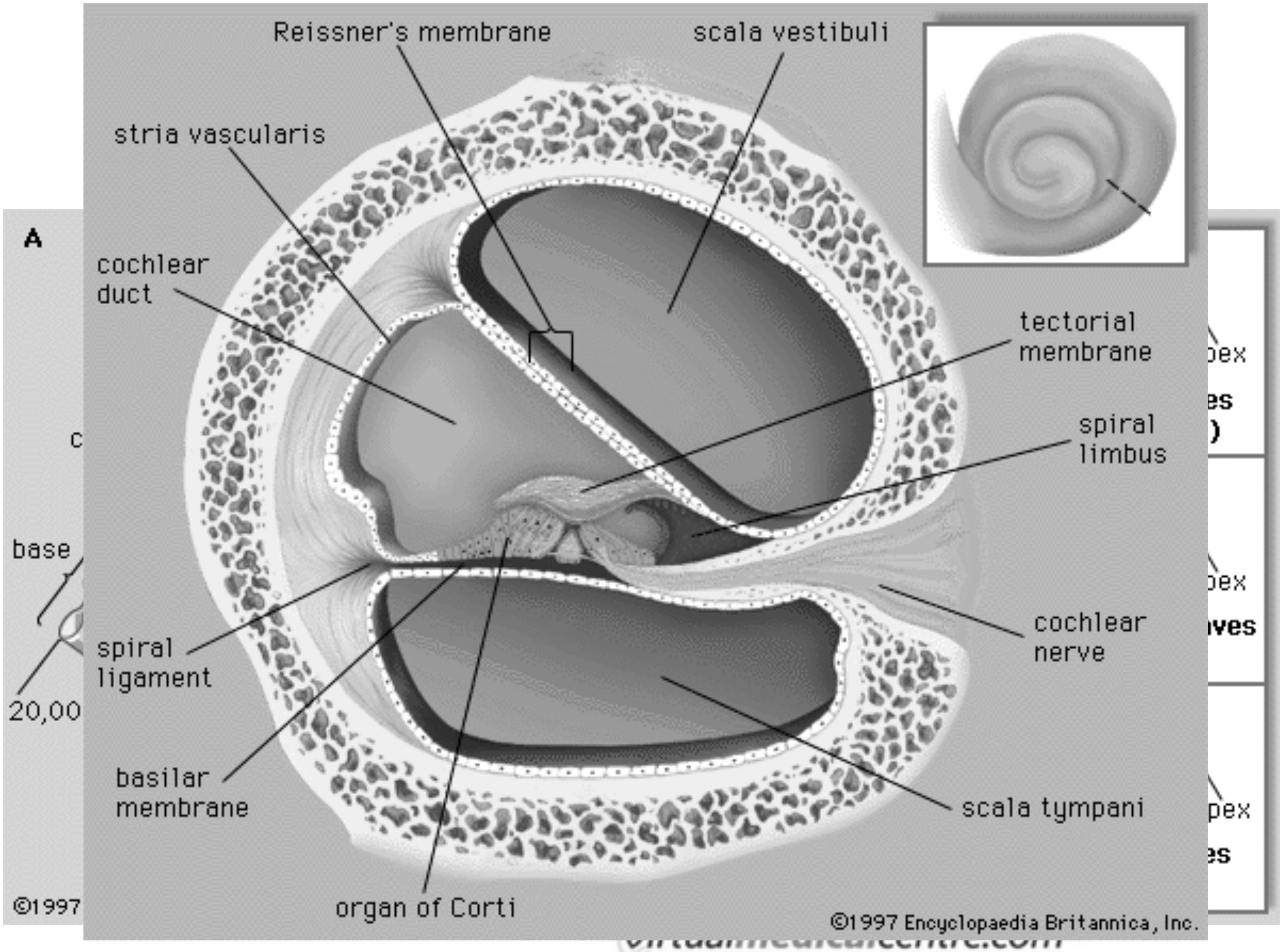
Bark Scale

Critical bands of Human Hearing

Table I.

Number	Center frequencies Hz	Cut-off frequencies Hz	Bandwidth Hz
		20	
1	50	100	80
2	150	200	100
3	250	300	100
4	350	400	100
5	450	510	110
6	570	630	120
7	700	770	140
8	840	920	150
9	1000	1080	160
10	1170	1270	190
11	1370	1480	210
12	1600	1720	240
13	1850	2000	280
14	2150	2320	320
15	2500	2700	380
16	2900	3150	450
17	3400	3700	550
18	4000	4400	700
19	4800	5300	900
20	5800	6400	1100
21	7000	7700	1300
22	8500	9500	1800
23	10 500	12 000	2500
24	13 500	15 500	3500

Critical Bands



Perceived Loudness

For each sample write down a number reflecting its loudness relative to the reference. Scale the reference as 100.

Explanation

Samples

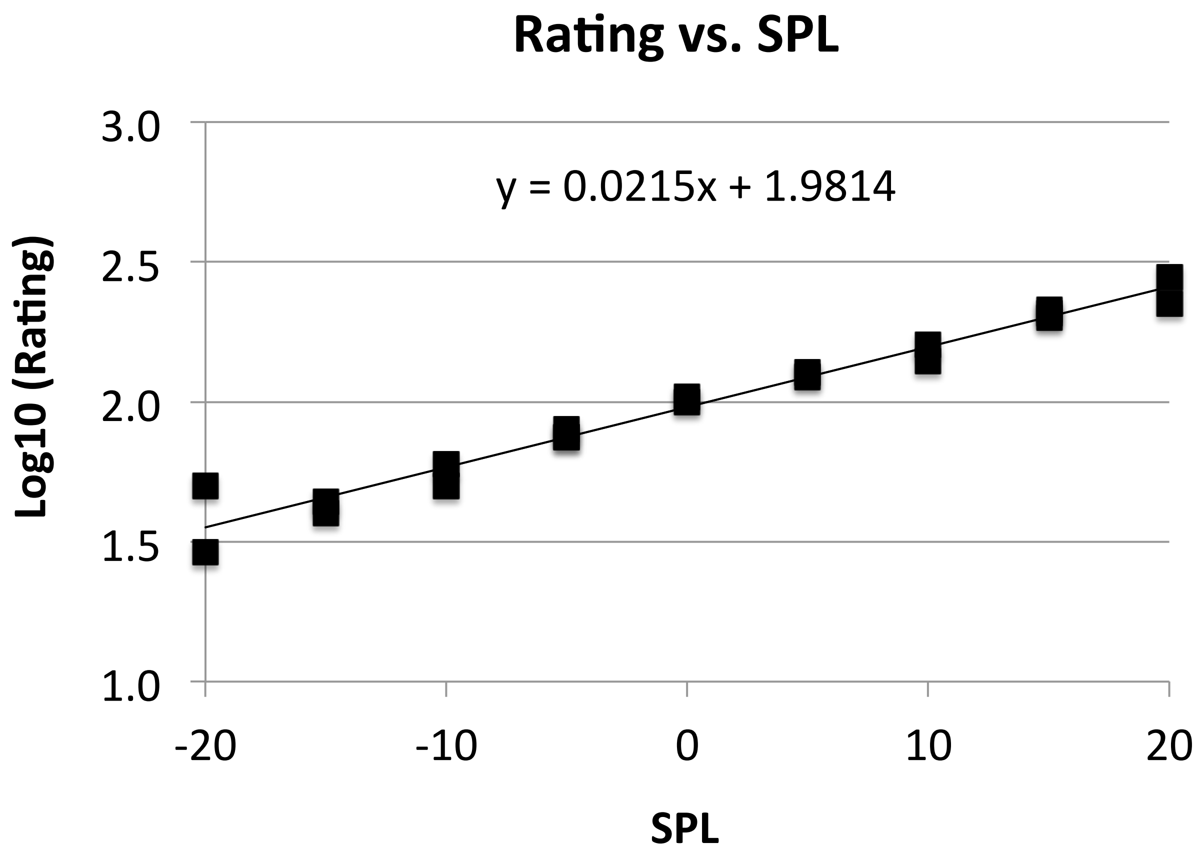
There are 20 samples of two noise bursts.

The reference is defined to be 0 dB.

The others are each one of these 9 values:

± 20 dB, ± 15 dB, ±10 dB, ±5 dB, 0 dB

Analysis



2x → $\log_{10}(2) = 0.30$

0.30/0.022 = 13.6 dB increase

to double the perceived loudness

Acoustic Modes

Acoustic waves obey the same wave equation as a string – just change the variables.

1-d

$$\frac{d^2 p(x,t)}{dt^2} = c^2 \frac{d^2 p(x,t)}{dx^2}$$

Boundary conditions:

open end → p = 0

closed end → p = maximum

Solutions of 1-d Acoustic wave equation

$$p(x,t) = \cos(n\omega_0 t)\left[\sin(n\pi\frac{x}{L}) \text{ or } \cos(n\pi\frac{x}{L})\right]$$

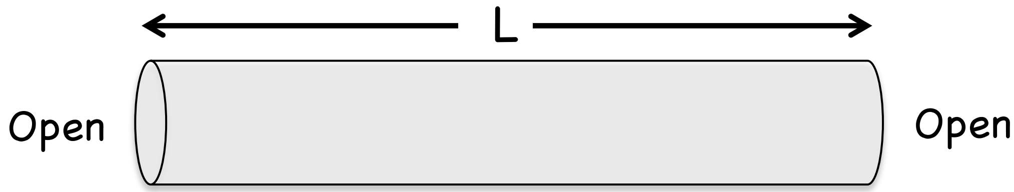
Oscillation in time

Both sine and cosine satisfy the wave equation.

How do we know which solution to choose?

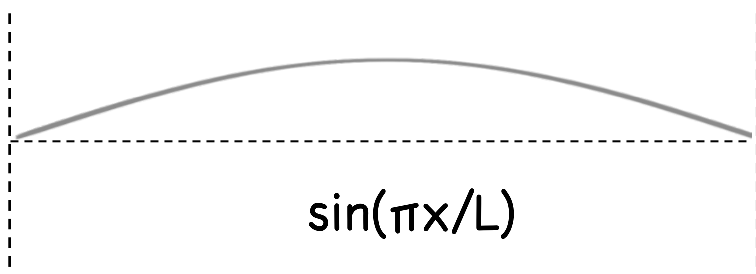
Choose the one that satisfies the boundary conditions.

flute



n = 1

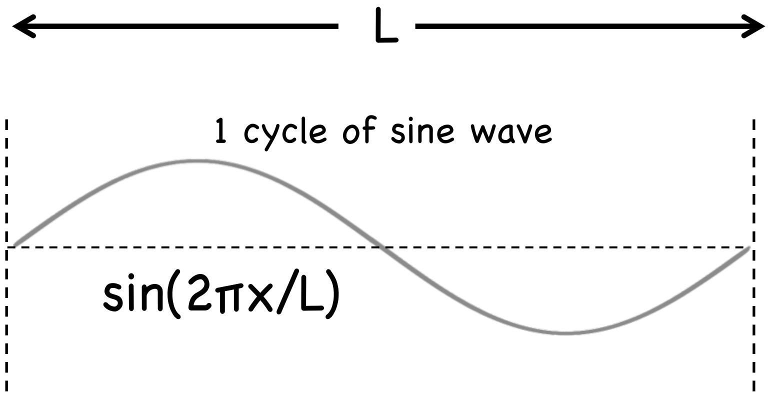
One-half of a sine wave



$$f_1 = \frac{c}{2L}$$

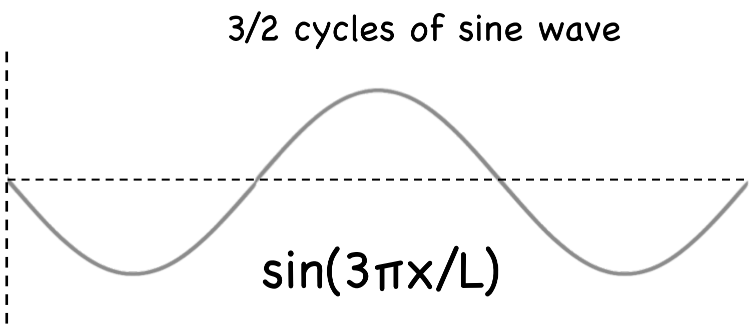
Same as fixed-fixed string!

Higher modes



n = 2

$$f_2 = 2\frac{c}{2L} = \frac{c}{L} = 2f_1$$



n = 3

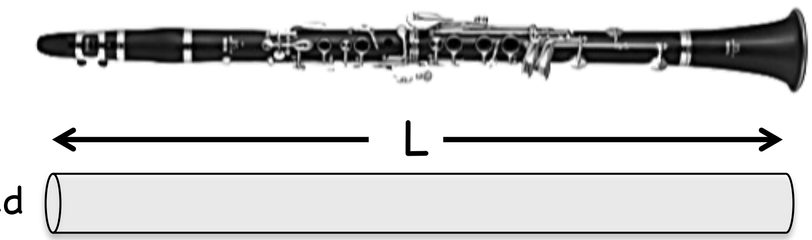
$$f_3 = 3\frac{c}{2L} = \frac{3}{2}\frac{c}{L} = 3f_1$$

Mode frequencies of open-open tube are the same as those for a fixed-fixed string.

Modes of open-open tube are multiples of one-half of a sine wave.

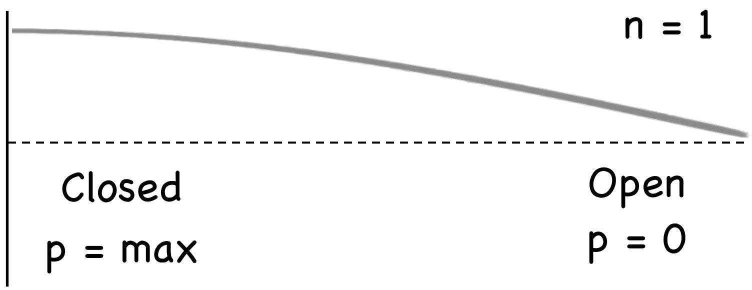
Closed-Open Boundary Condition

Clarinet



Closed

Open

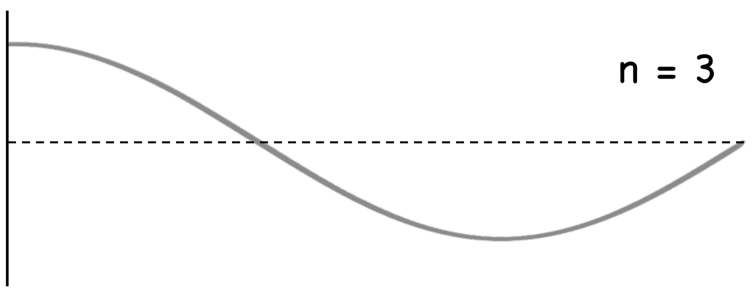


1/4 cycle of cosine

$$L = \frac{\lambda}{4}$$

$$\lambda_1 = 4L$$

$$f\lambda = c \quad \text{so} \quad f_1 = \frac{c}{\lambda_1} = \frac{c}{4L}$$

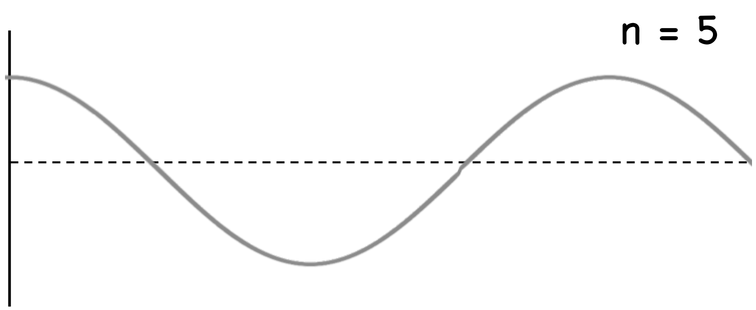


3/4 cycle of cosine

$$L = \frac{3}{4}\lambda$$

$$\lambda_3 = \frac{4L}{3}$$

$$f_3 = \frac{c}{\lambda_3} = 3\frac{c}{4L} = 3f_1$$



5/4 cycle of cosine

$$L = \frac{5}{4}\lambda$$

$$\lambda_5 = \frac{4L}{5}$$

$$f_5 = \frac{c}{\lambda_5} = 5\frac{c}{4L} = 5f_1$$

Summary

L

open-open

L ≈ 66 cm

$$f_1 = \frac{c}{2L}$$

C4

261.6 Hz

$$f_n = n\frac{c}{2L}$$

n = 1,2,3 ...

All harmonics

closed-open

L ≈ 60 cm

$$f_1 = \frac{c}{4L}$$

D3
"concert"

146.8 Hz

$$f_n = (2n-1)\frac{c}{4L}$$

n = 1,2,3 ...

Only odd harmonics

closed-closed

That's just dumb ...