미시세계와 거시세계

6. G선 상의 아리아

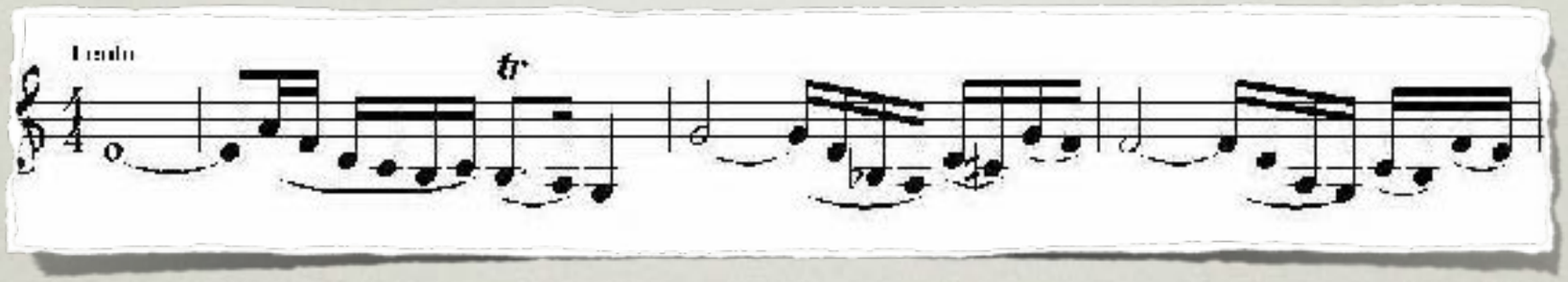
유재준

서울대 물리천문학부

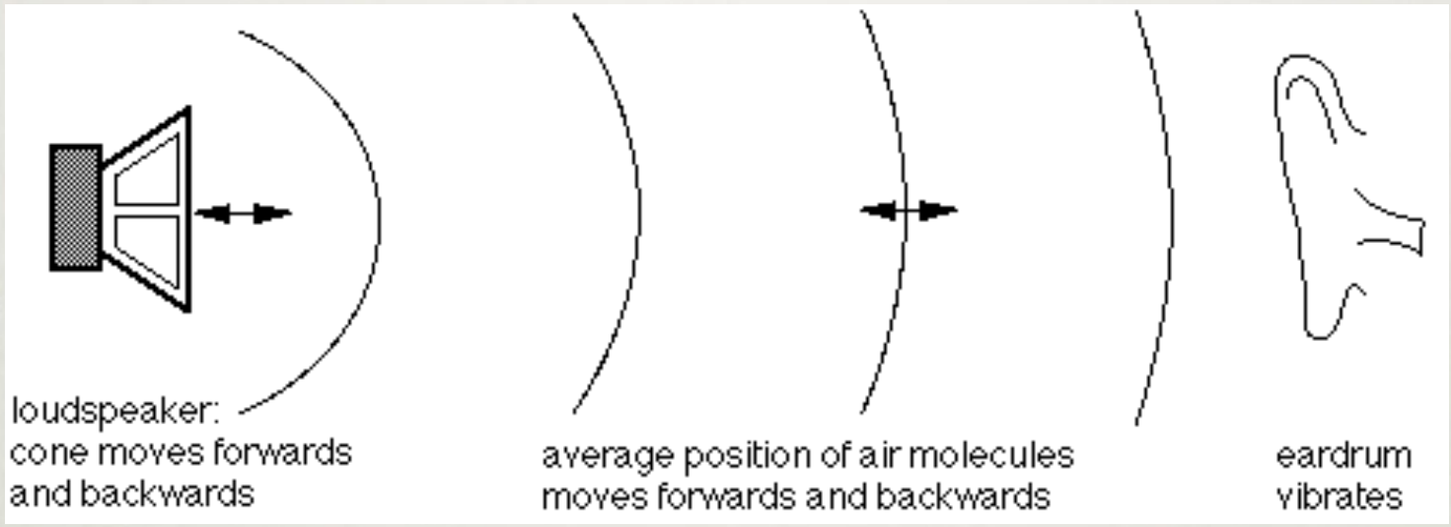
jyu@snu.ac.kr

2016/2학기

Orchestral Suite No.3 ('Air on G String')

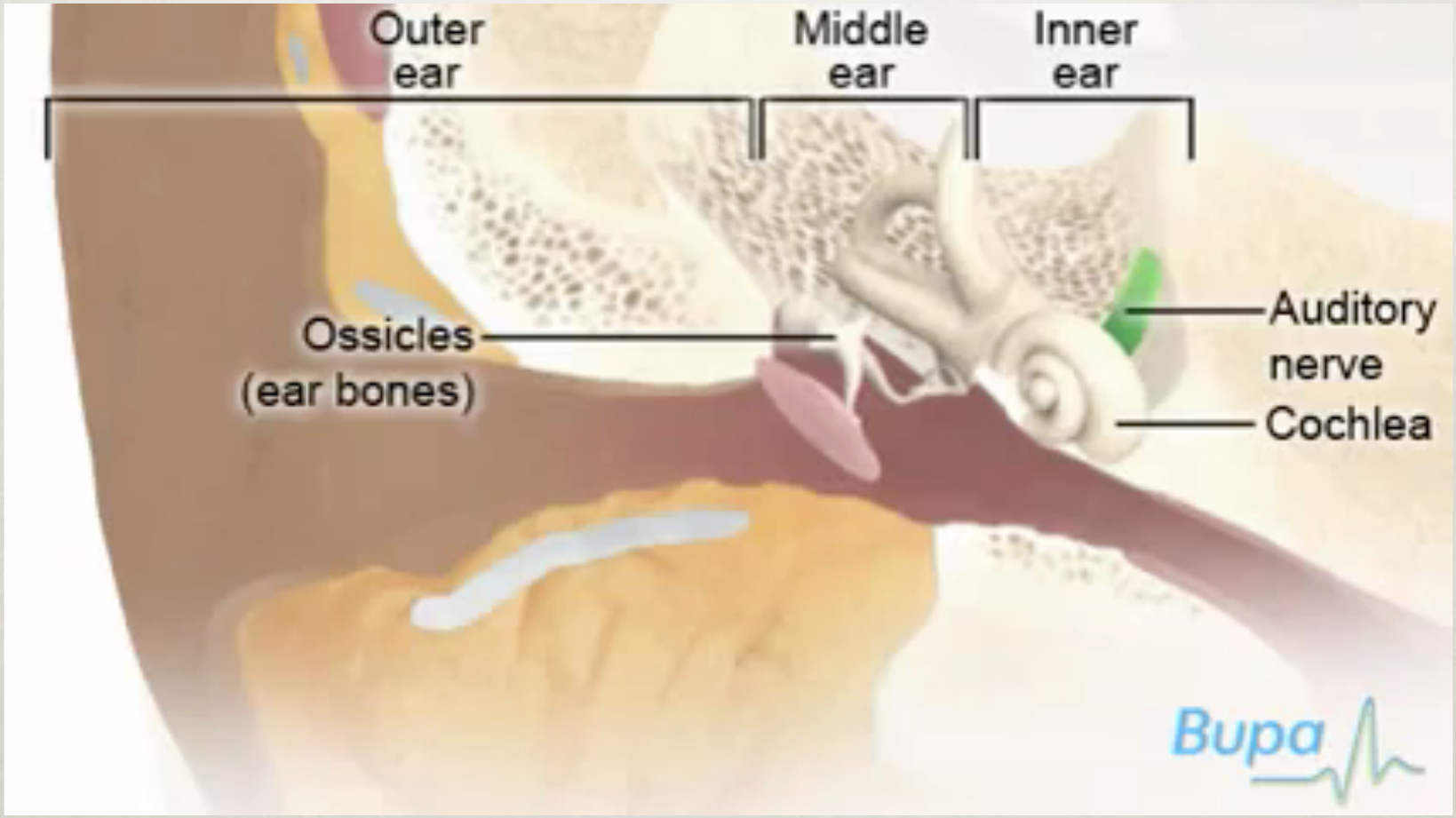


소리 듣기



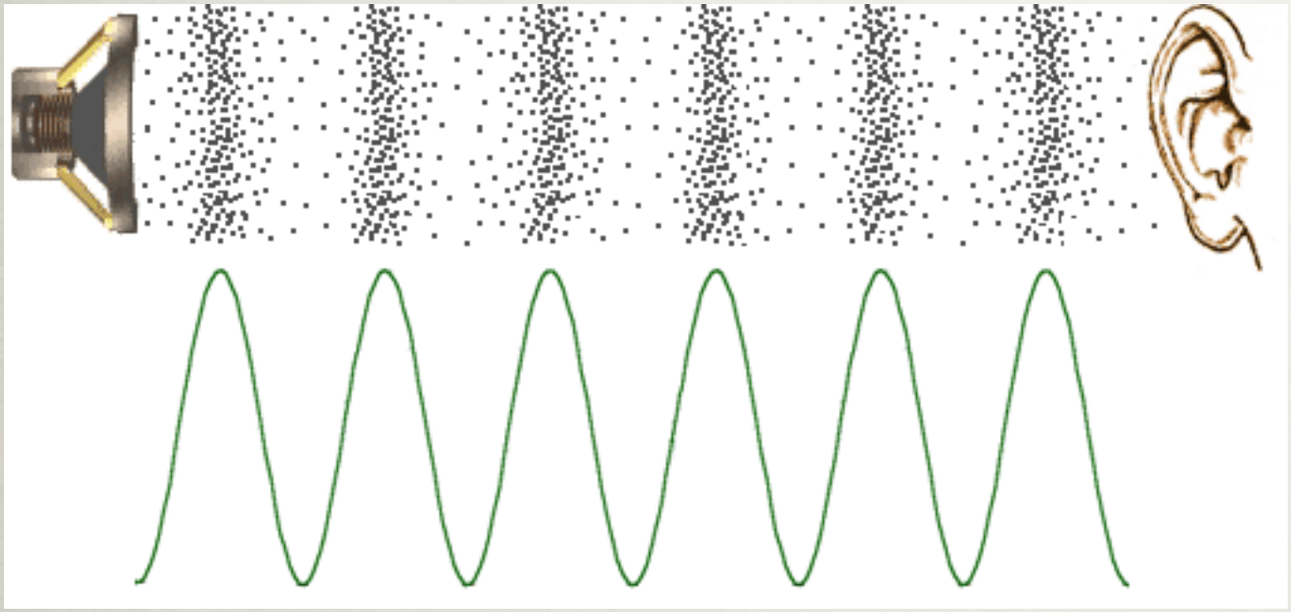
- 음속: **v = 331.5 m/s** (온도 상승에 따라, **0.6m/s** 씩 증가)
- 인간이 들을 수 있는 소리의 진동수: **20 Hz ~ 16,000 Hz**

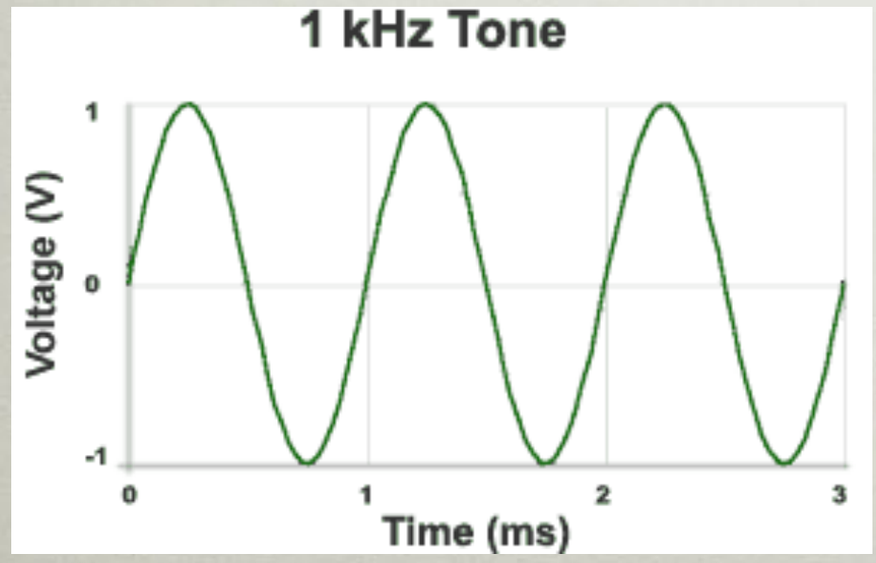
How the ear works

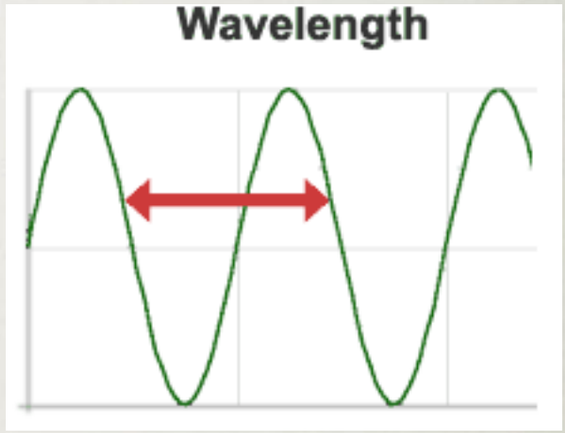


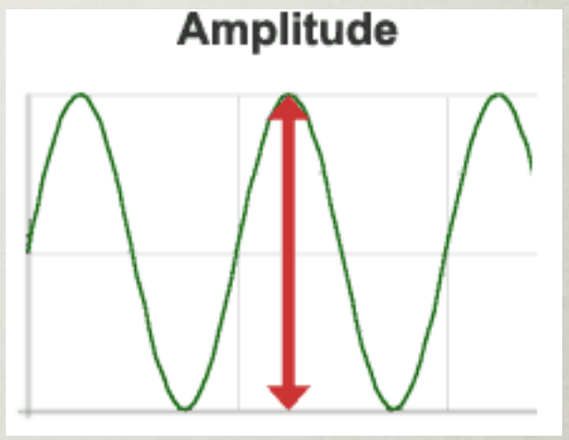
http://www.youtube.com/watch?v=ahCbGjasm_E

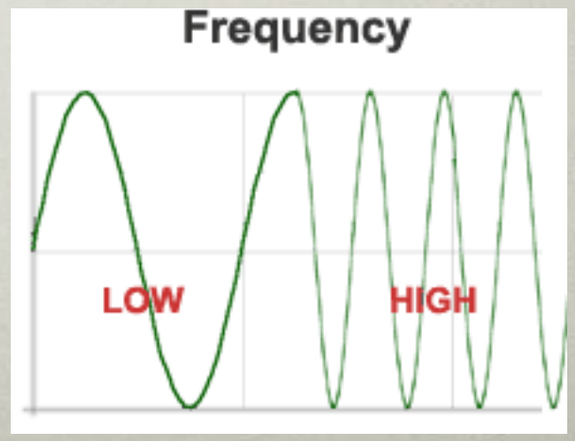
How sound wave propagates



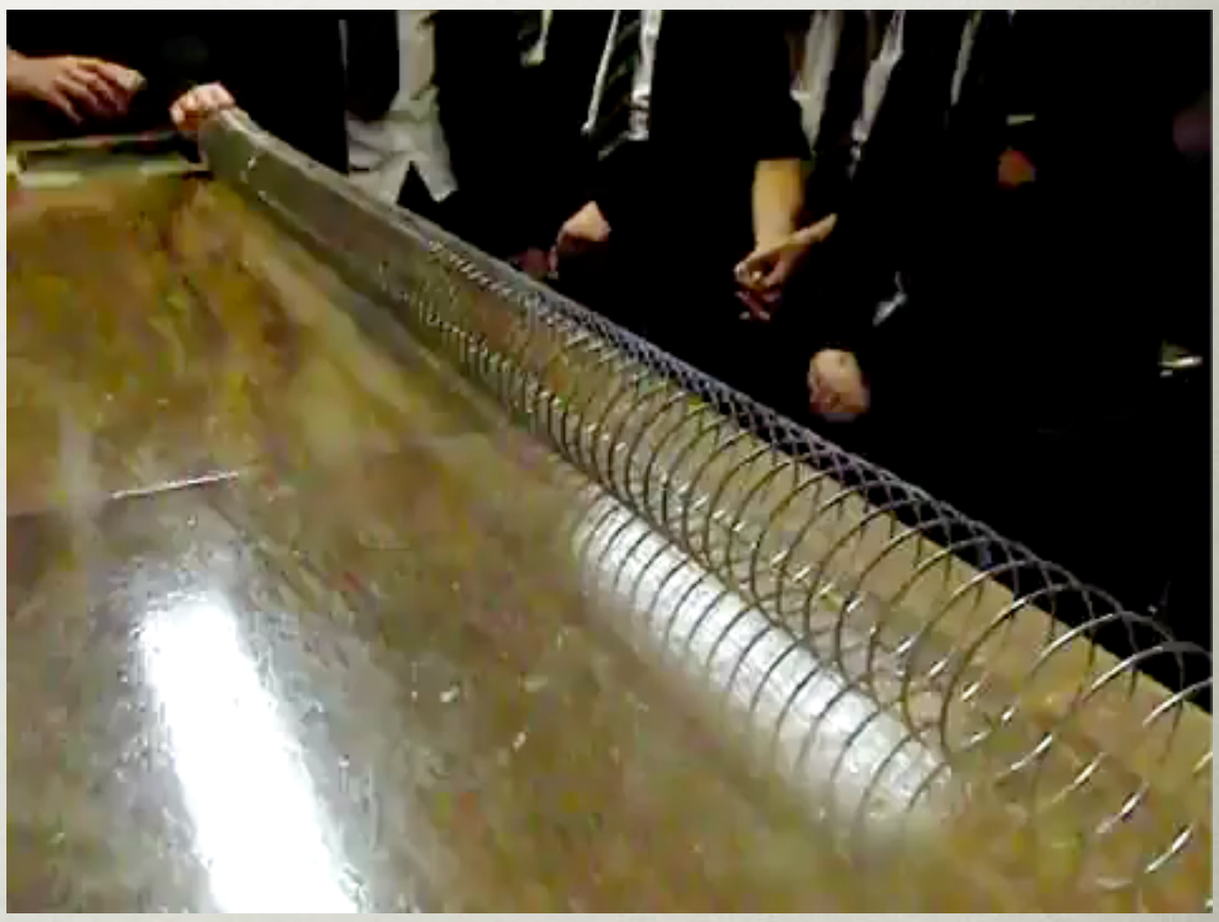






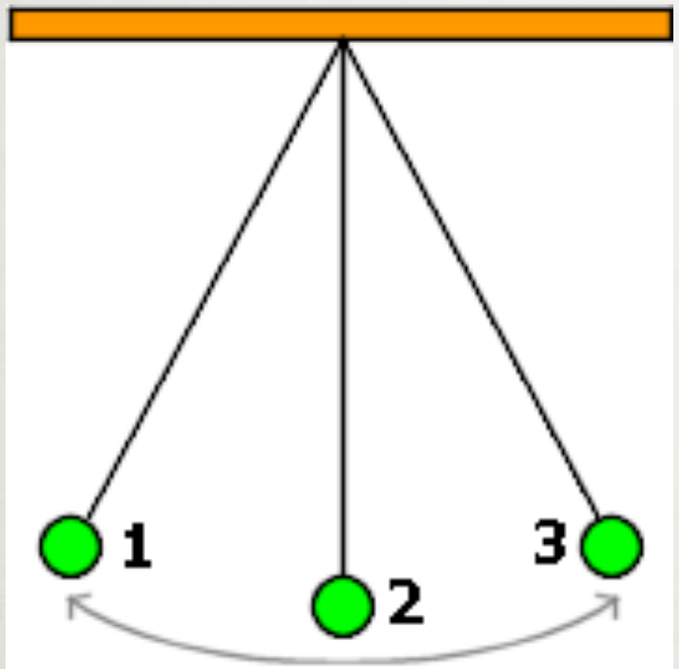


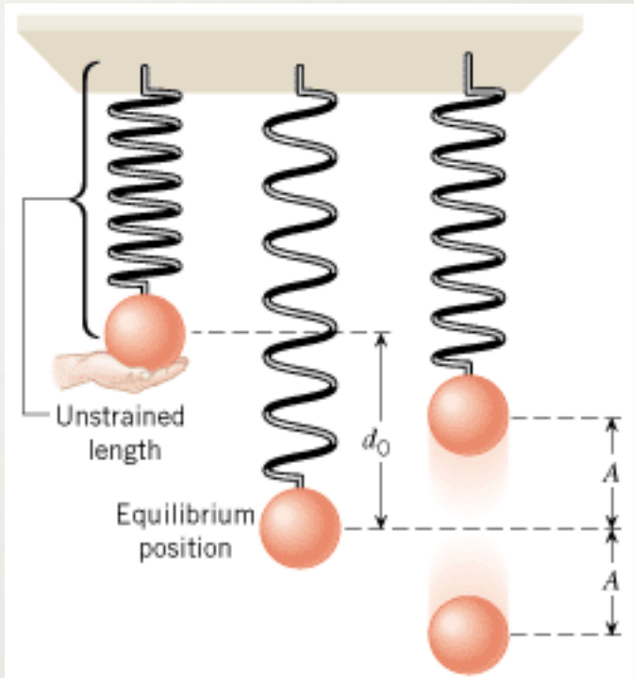
Wave: How does it progagate?

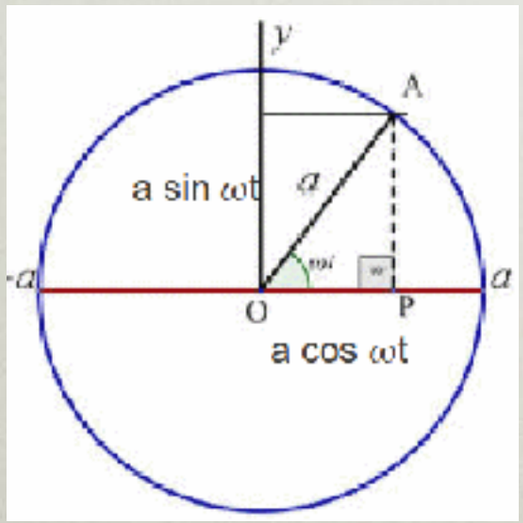


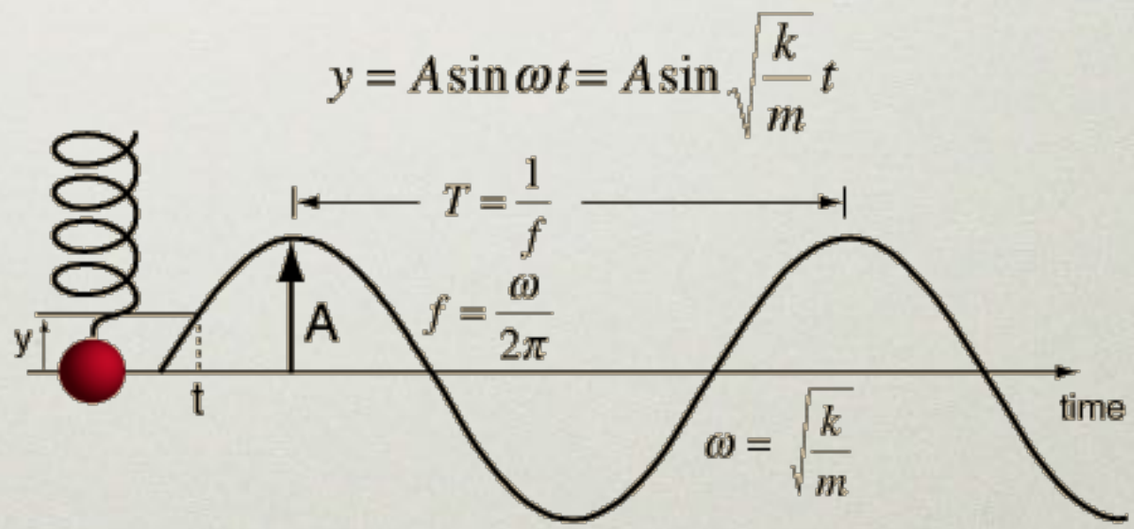
http://www.youtube.com/watch?v=TPlCsnCFfiM
http://www.youtube.com/watch?v=TPlCsnCFfiM

진동이란? What vibrates?

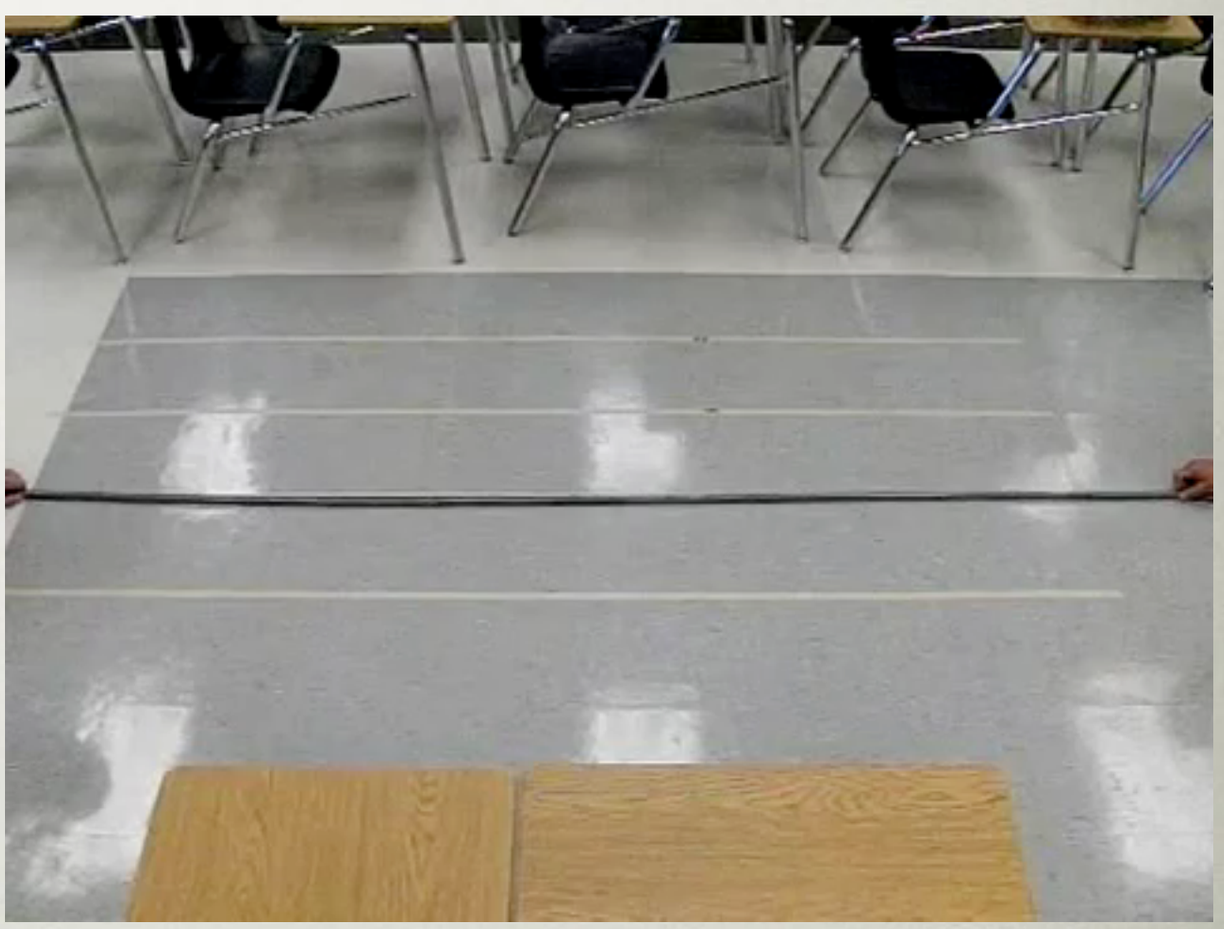








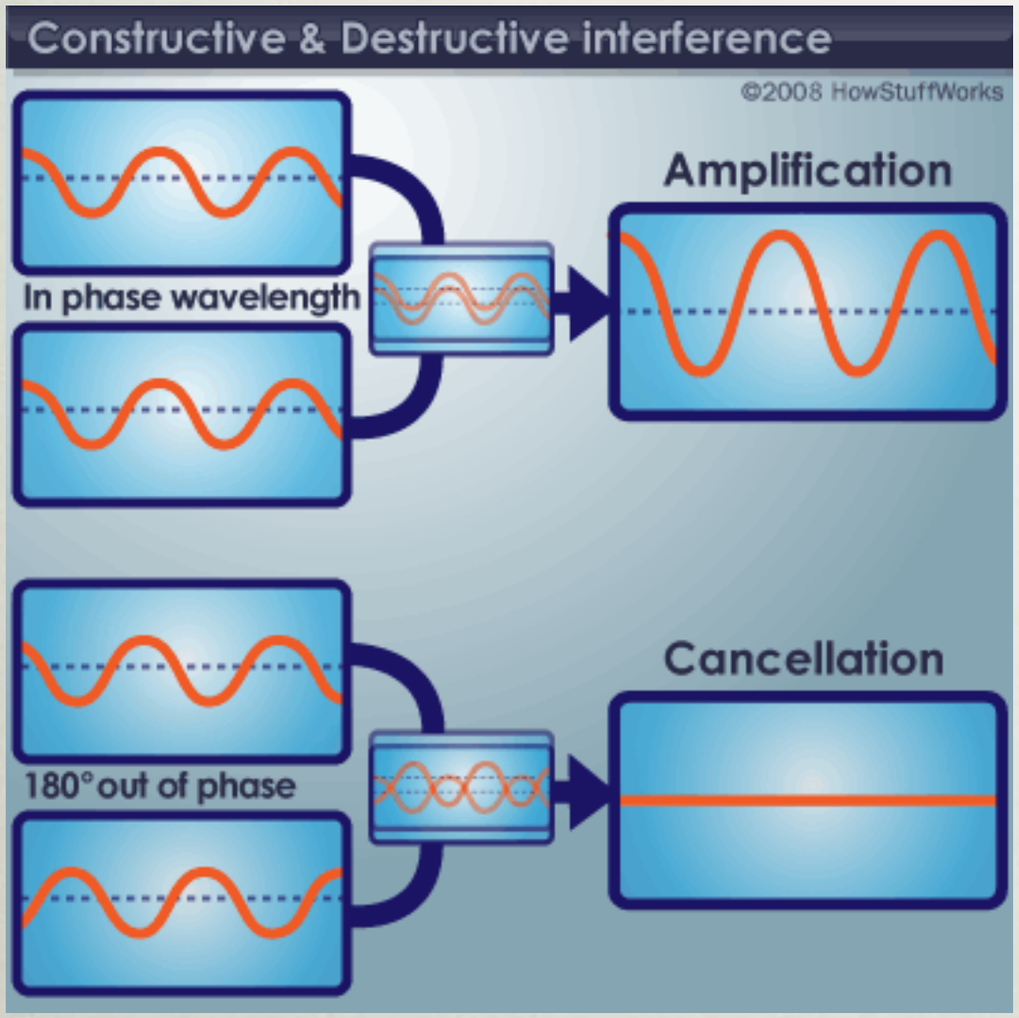
Interference (간섭)

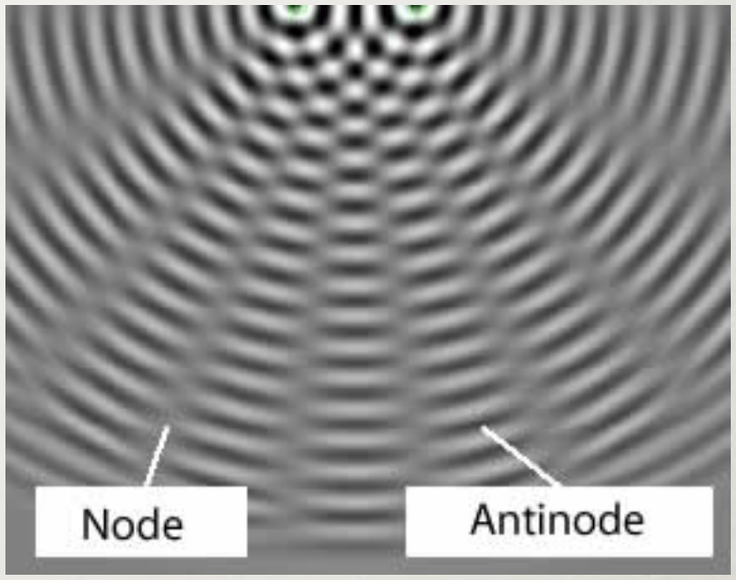


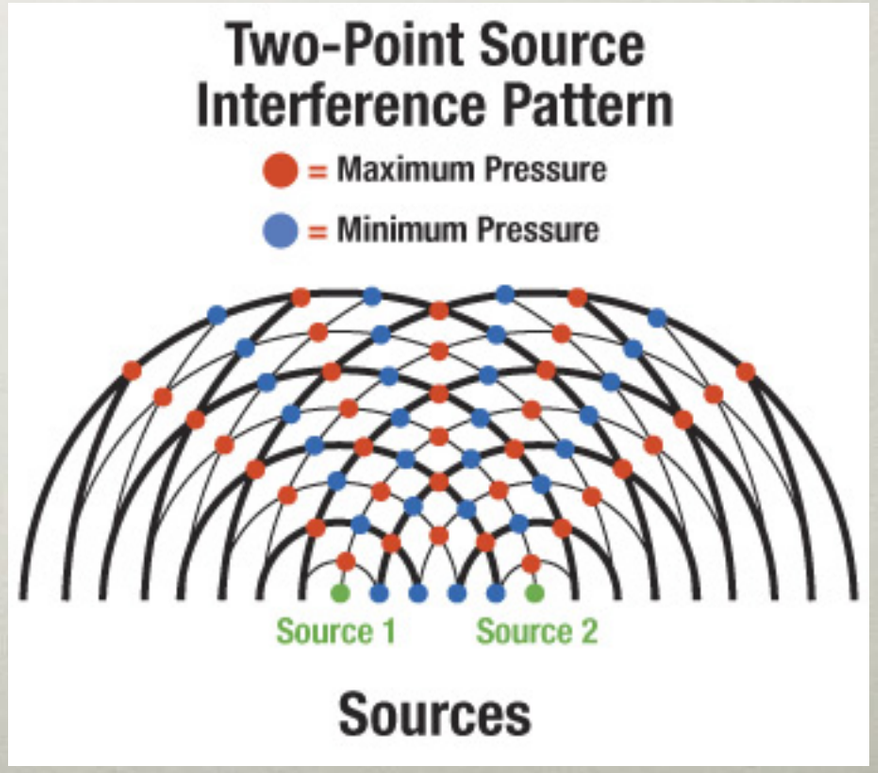
http://www.youtube.com/watch?v=1gcps37L0r4

http://www.youtube.com/watch?v=J4qFPComzoo

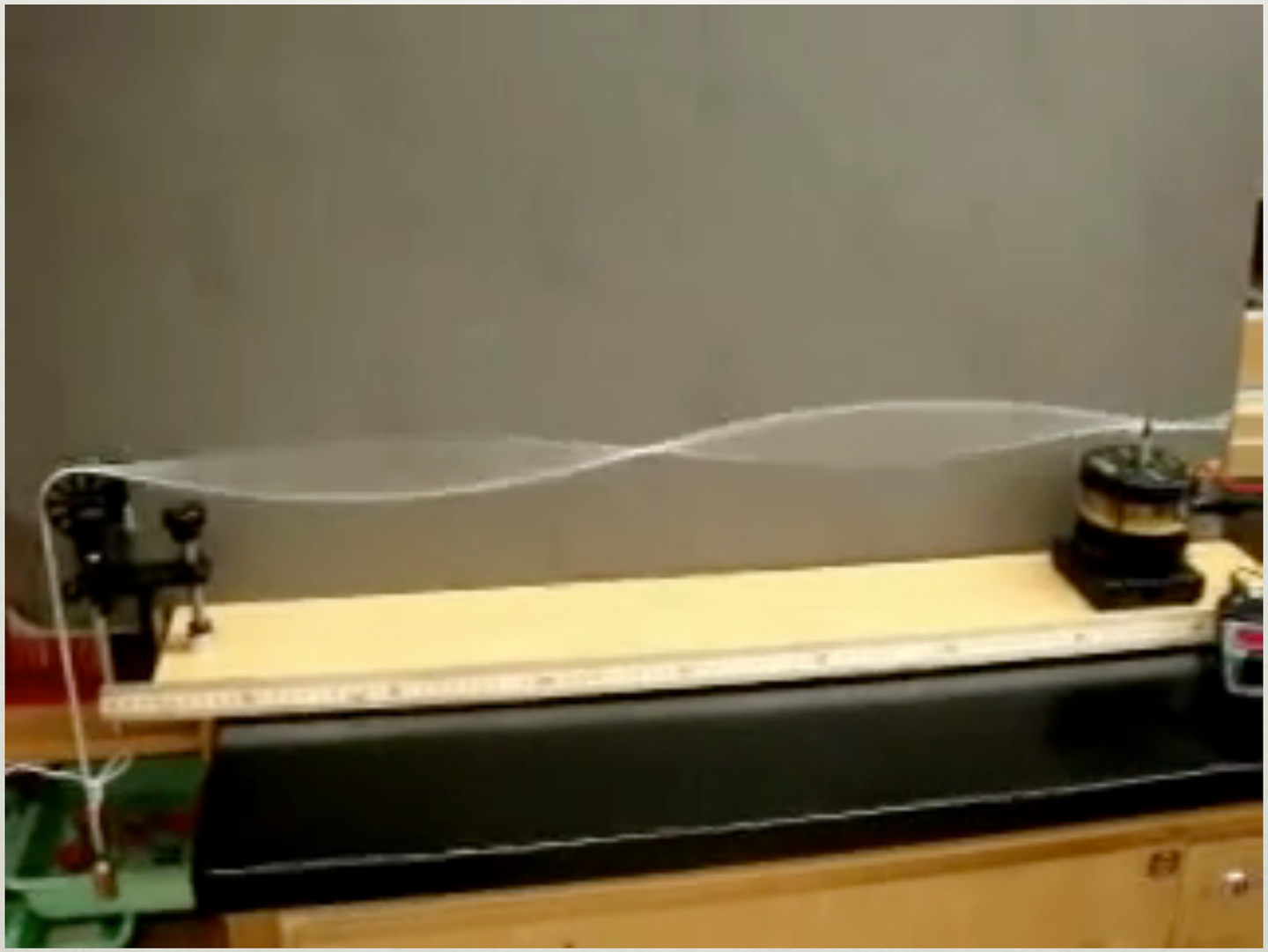
Interference (간섭)





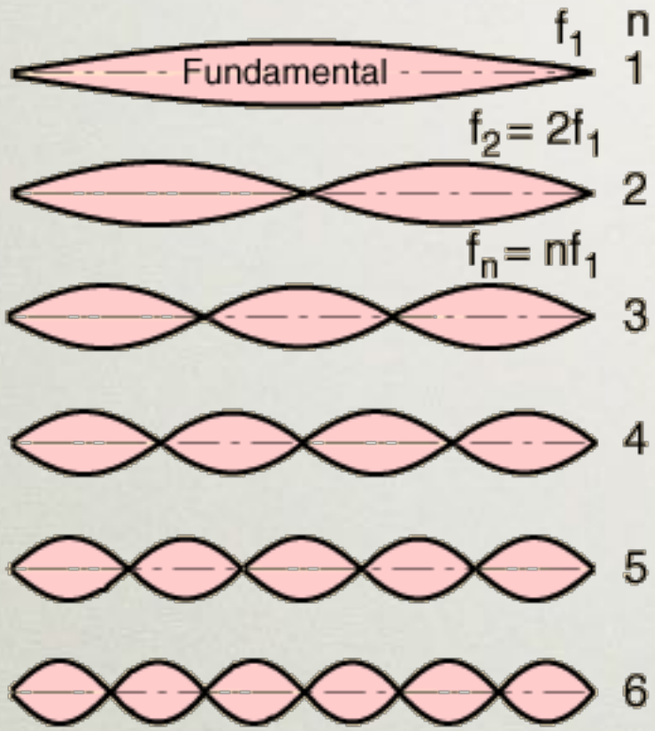


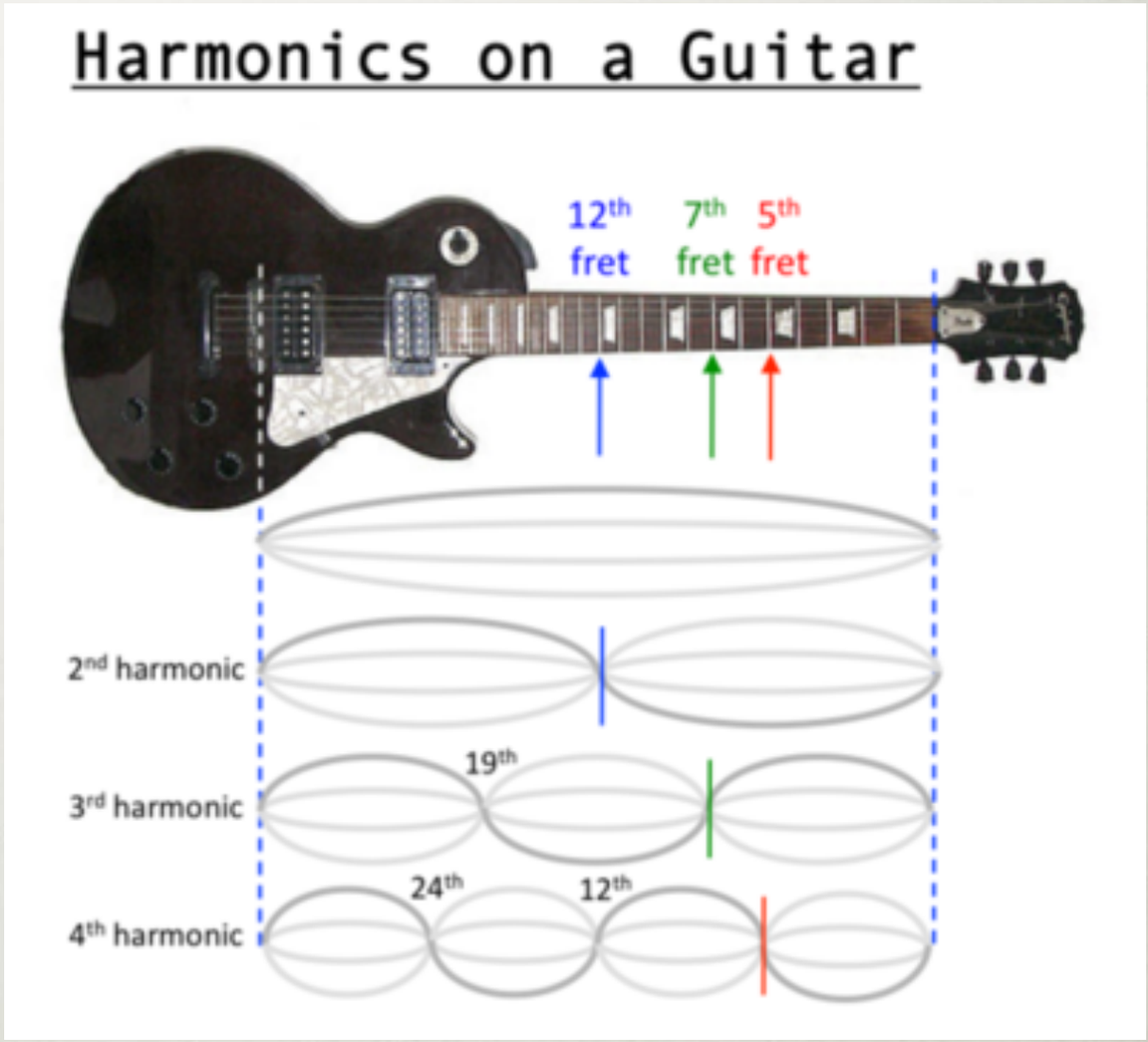
Standing wave (정상파)



http://www.youtube.com/watch?v=_S7-PDF6Vzc

정상파 - 악기

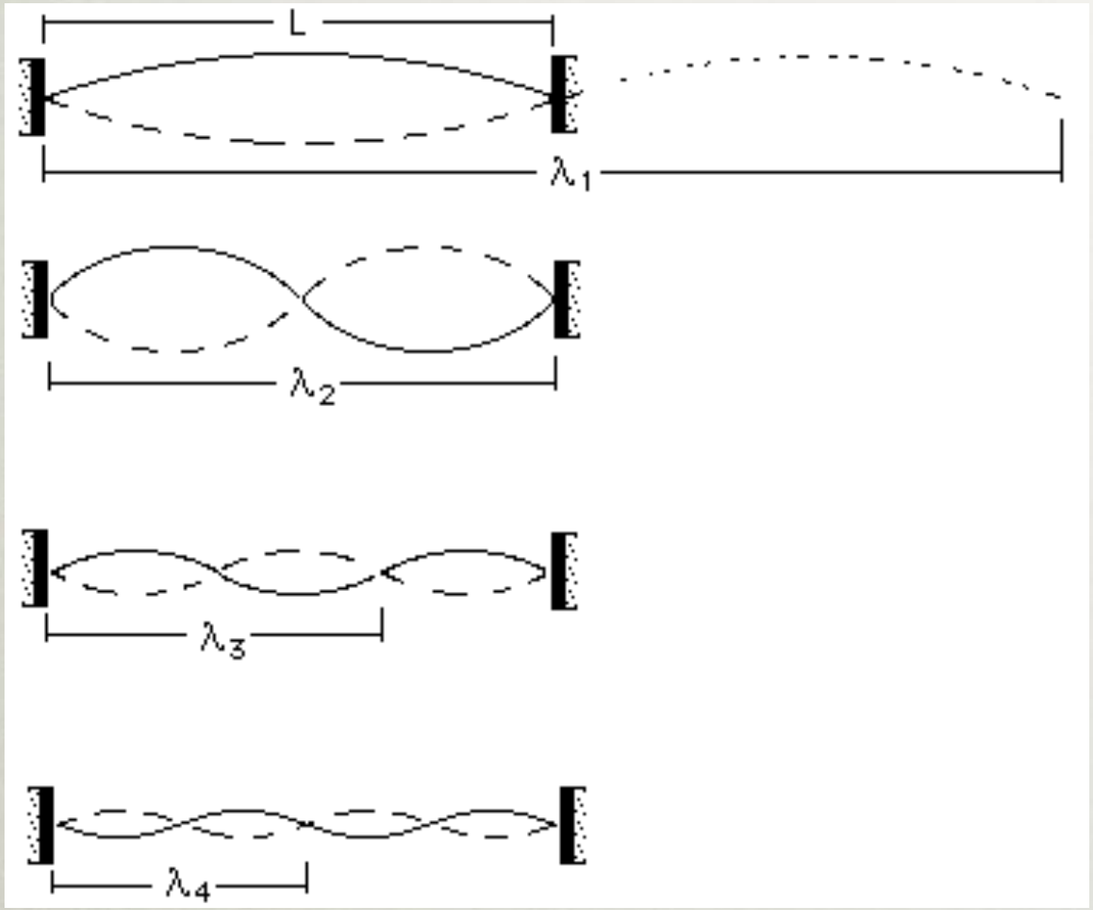

f_1
n
Fundamental
1
$f_2 = 2f_1$
2
$f_n = nf_1$
3
4
5
6

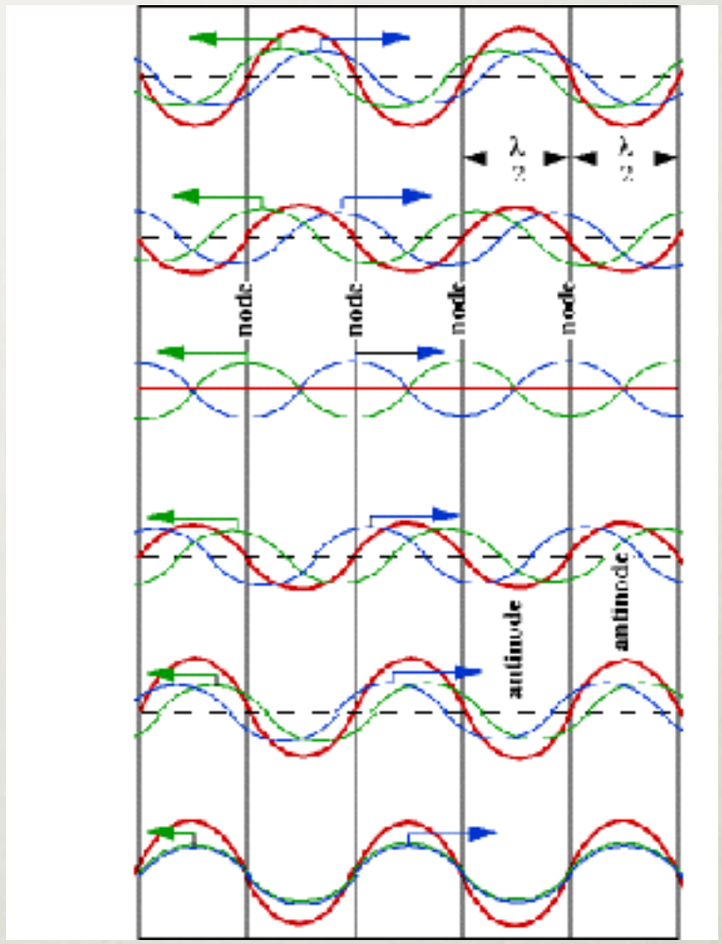

Harmonics on a Guitar
12th fret
7th fret
5th fret
2nd harmonic
19th
3rd harmonic
24th
12th
4th harmonic

Why G string?

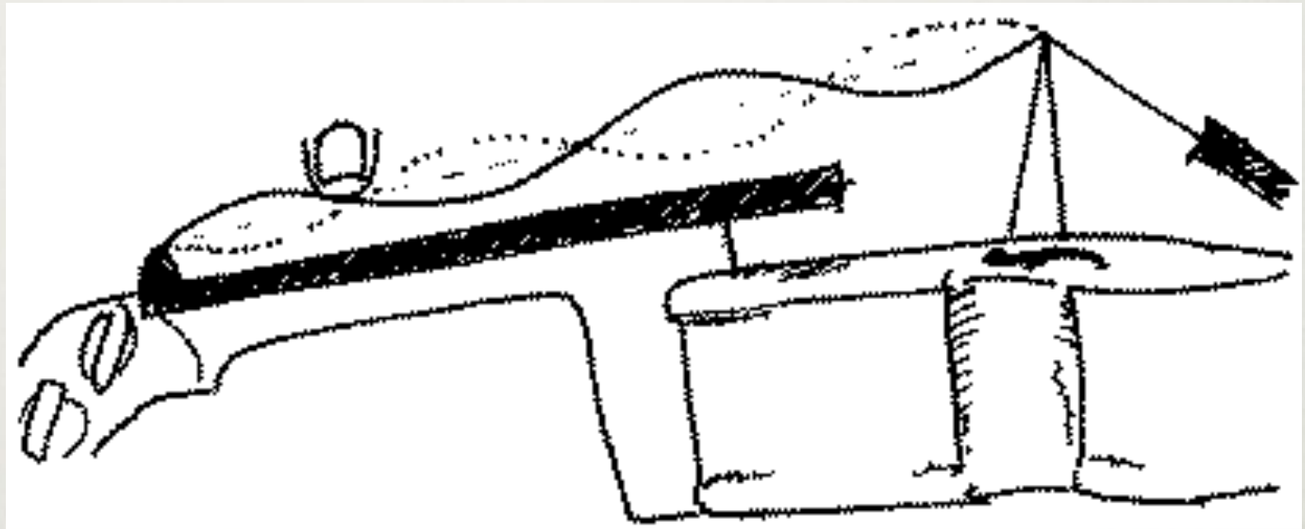
- **바이올린의 4 줄: E ->A -> D -> G**
  - 같은 길이, 그러나 다른 굵기의 줄을 이용하여 다른 음정을 만든다.
- **현의 진동수 f 를 결정하는 요소:**
  - 줄의 길이: $\frac{f}{f'} = \frac{l'}{l}$
  - 줄의 굵기: $\frac{f}{f'} = \frac{d'}{d}$
  - 줄에 걸린 장력: $\frac{f}{f'} = \frac{\sqrt{F}}{\sqrt{F'}}$
  - 줄의 밀도: $\frac{f}{f'} = \frac{\sqrt{D'}}{\sqrt{D}}$

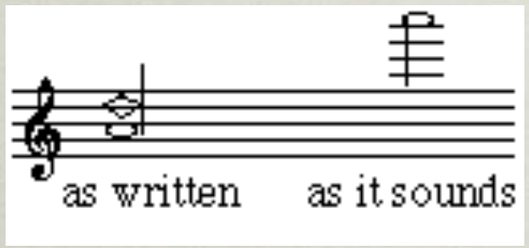
- **A-현를 기본 진동수 440 Hz에 맞춘다.**


L
λ1
λ2
λ3
λ4

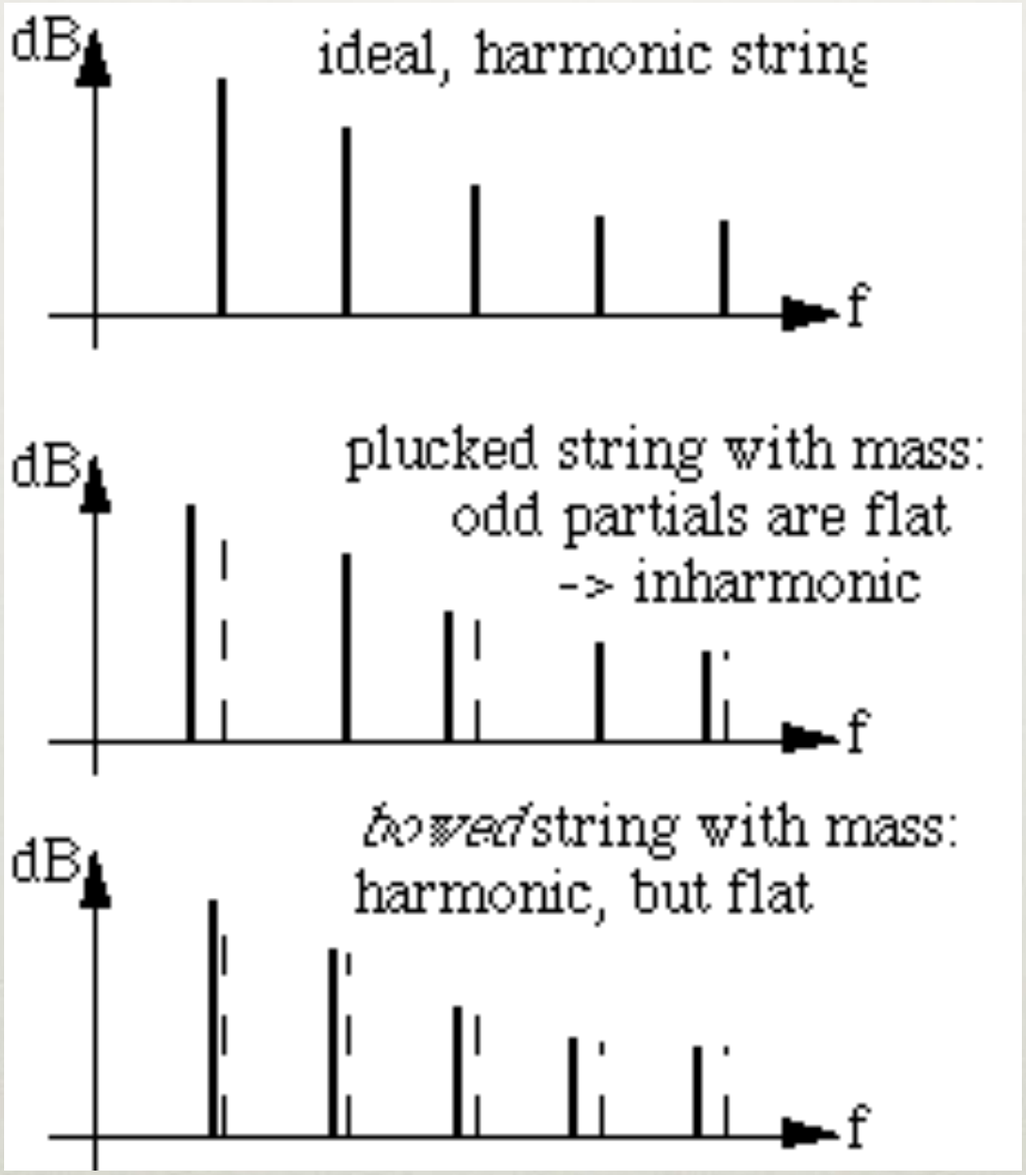

node
node
node
node
antinode
antinode

배음 (overtones)

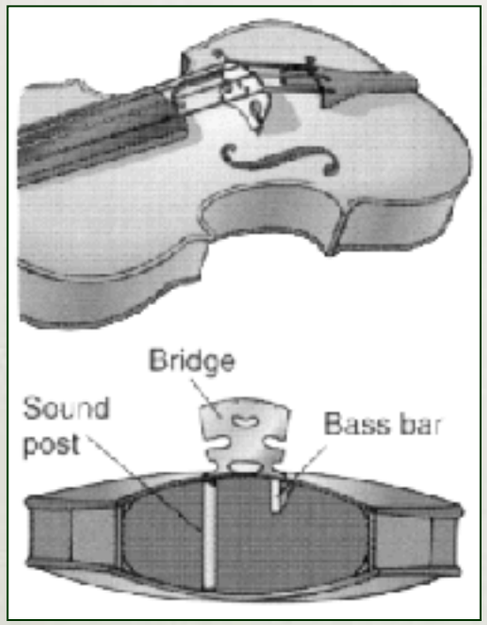


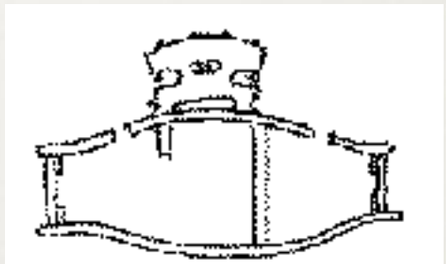


정확한 배음 만들기?
(How harmonic are harmonics?)

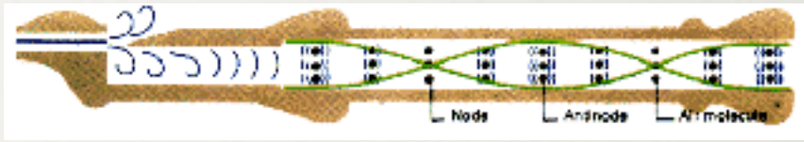


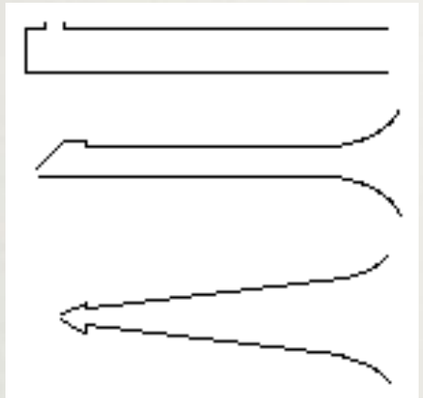
울림통

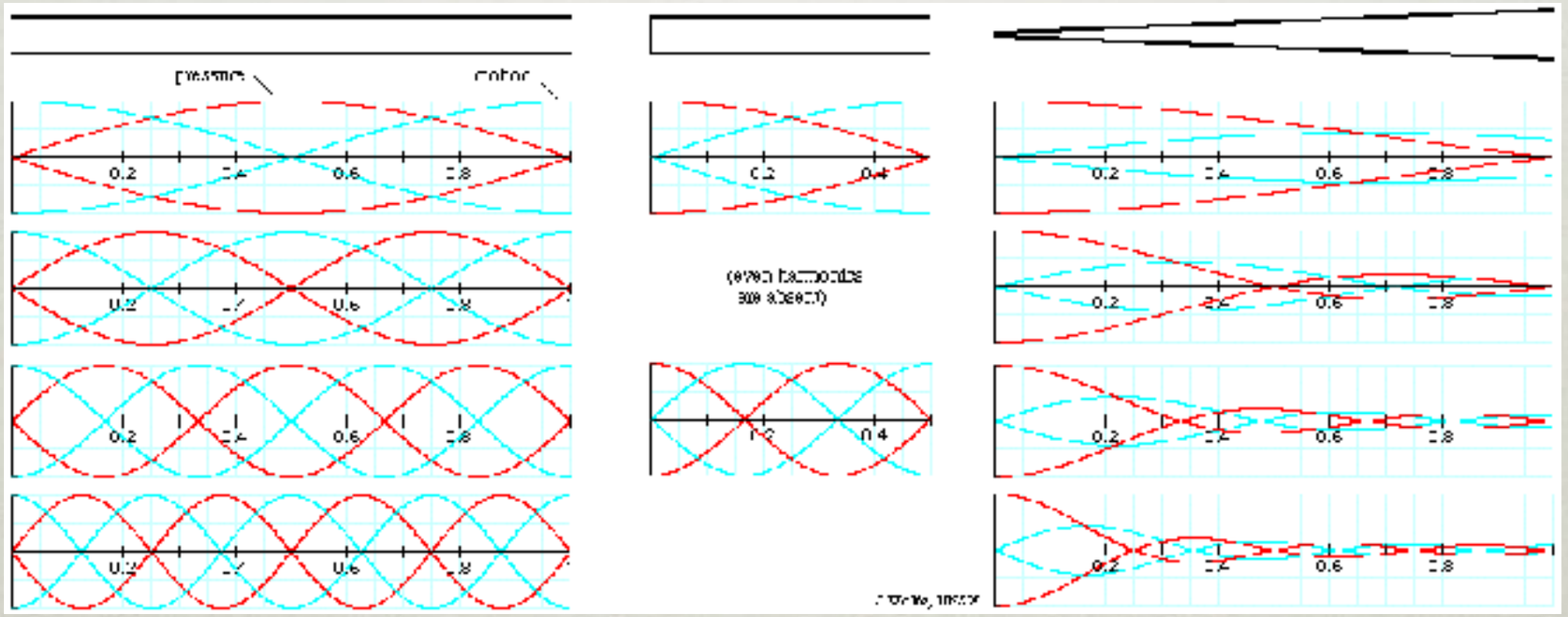




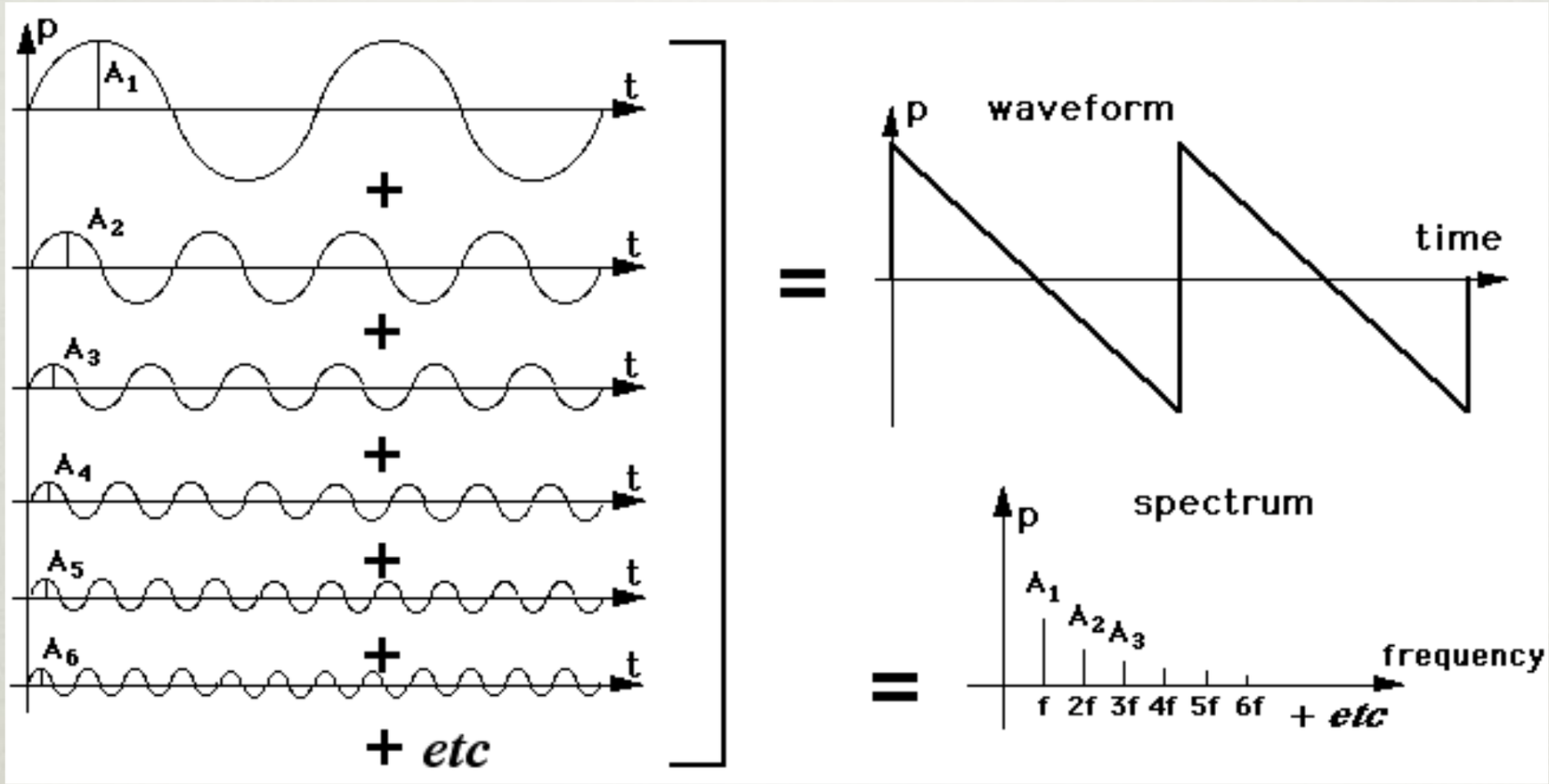
관악기


Node
Antinode
Air molecules

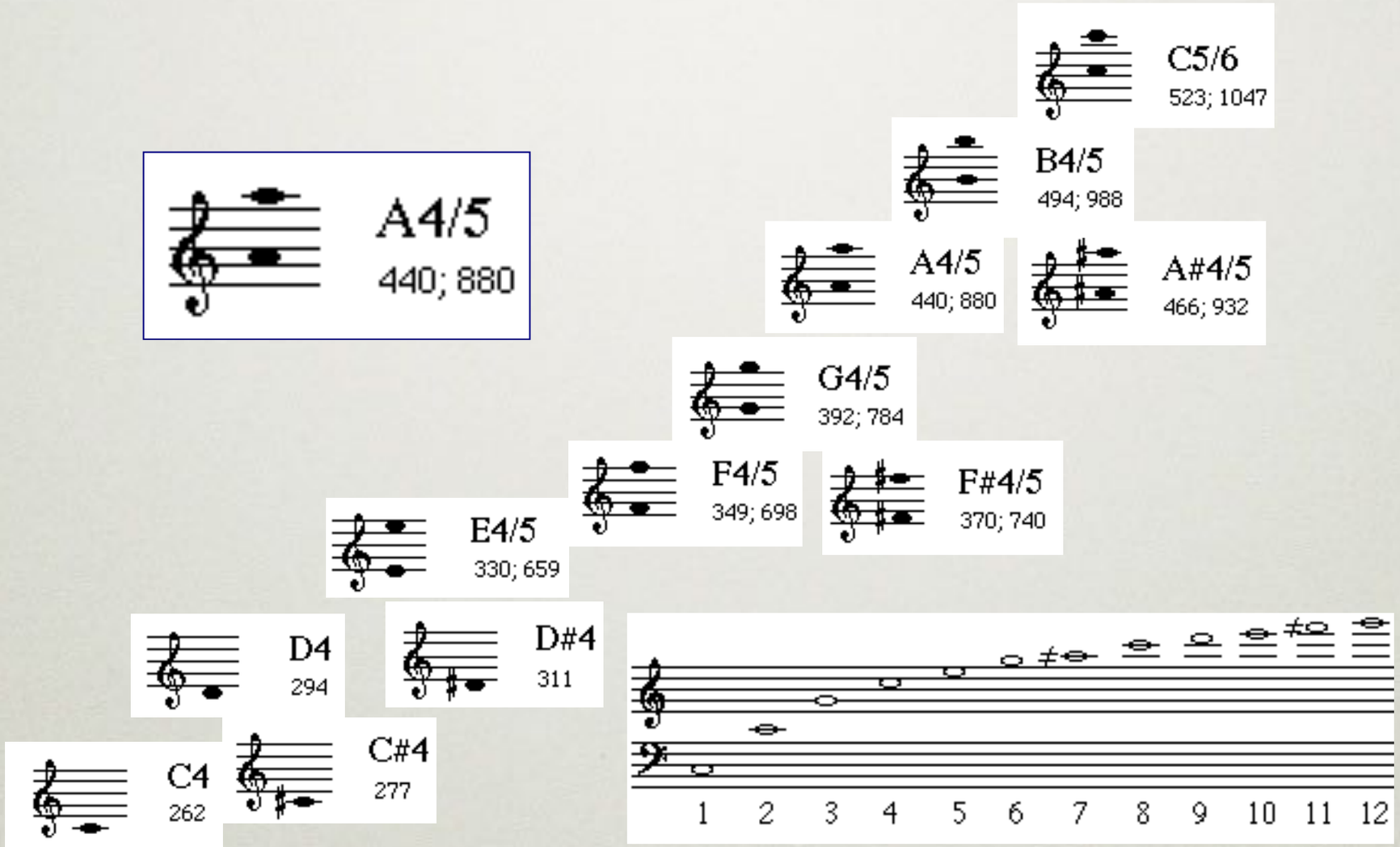



pressure
0.2
0.4
0.6
0.8
(even harmonics
are absent)

소리 스펙트럼


p
A1
t
+
A2
t
+
A3
t
+
A4
t
+
A5
t
+
A6
t
+ etc
=
p waveform
time
=
p
spectrum
A1
A2
A3
frequency
f 2f 3f 4f 5f 6f + etc

음 높이 (pitch)


A4/5
440; 880
C5/6
523; 1047
B4/5
494; 988
A4/5
440; 880
A#4/5
466; 932
G4/5
392; 784
F4/5
349; 698
F#4/5
370; 740
E4/5
330; 659
D4
294
D#4
311
C4
262
C#4
277
1 2 3 4 5 6 7 8 9 10 11 12

음 높이의 수학

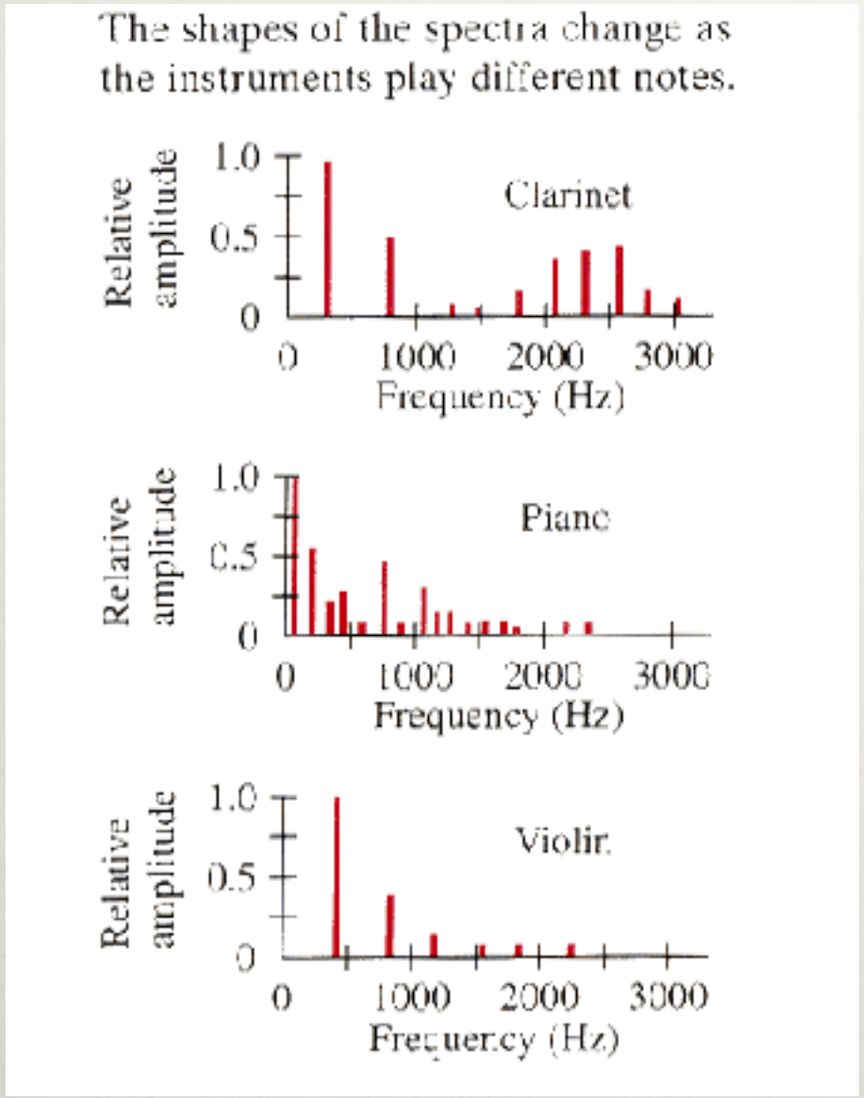
- **피타고라스의 조화수**
  (후에 갈릴레이가 고침)
  - 듣기 좋은 음의 체계를 찾아봄. (경험적)
  - 옥타브 -> 1:2
  - 5번째 음 -> 2:3

도	레	미	파	솔	라	시	도
1	9/8	5/4	4/3	3/2	5/3	15/8	2
24	27	30	32	36	40	45	48

순정음 vs. 평균율

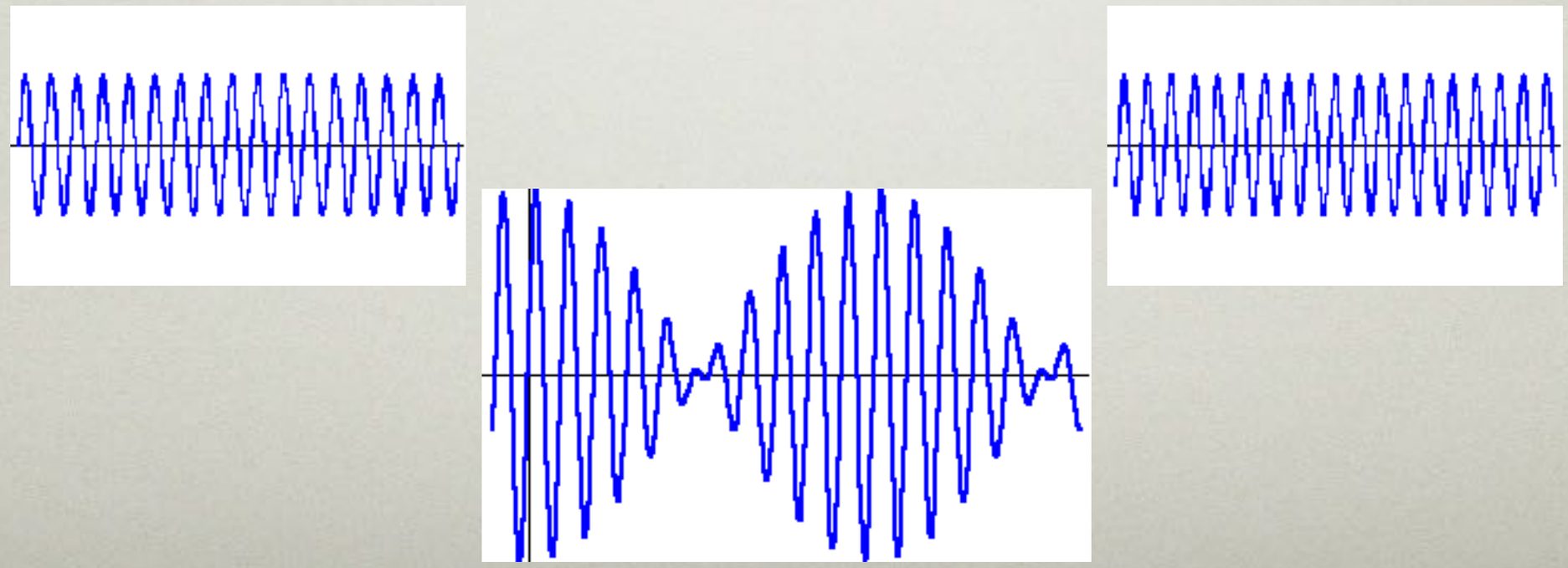
Interval	Ratio to Fundamental Just Scale	Ratio to Fundamental Equal Temperament
Unison	1.0000	1.0000
Minor Second	25/24 = 1.0417	1.05946
Major Second	9/8 = 1.1250	1.12246
Minor Third	6/5 = 1.2000	1.18921
Major Third	5/4 = 1.2500	1.25992
Fourth	4/3 = 1.3333	1.33483
Diminished Fifth	45/32 = 1.4063	1.41421
Fifth	3/2 = 1.5000	1.49831
Minor Sixth	8/5 = 1.6000	1.58740
Major Sixth	5/3 = 1.6667	1.68179
Minor Seventh	9/5 = 1.8000	1.78180
Major Seventh	15/8 = 1.8750	1.88775
Octave	2.0000	2.0000

음색 (tone; timbre)

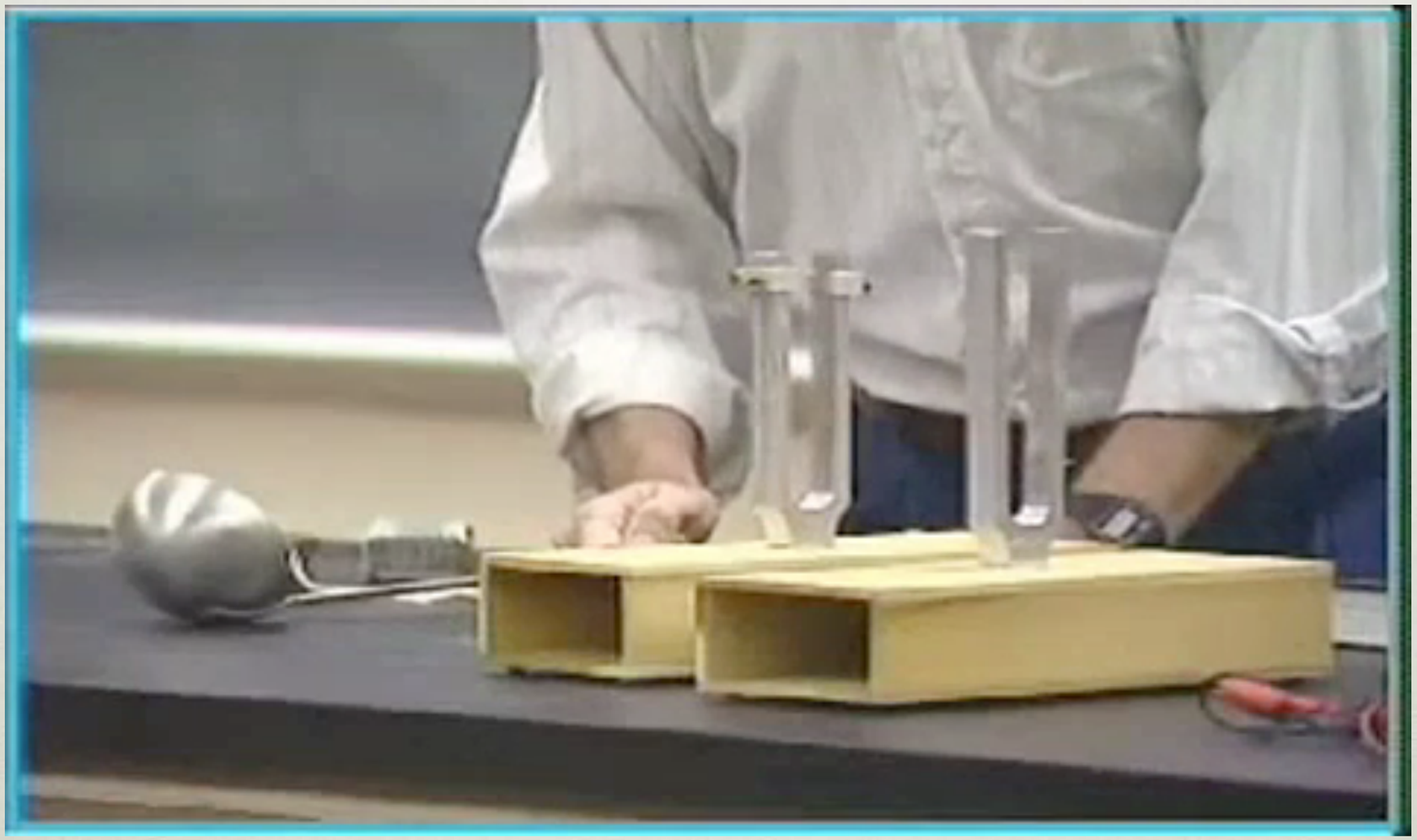


조율 (Tuning)

- **각 음간의 간격은 일정한 비율로 정해짐:**
  - Two notes separated by a perfect fifth have a frequency ratio of 3:2.
  - Notice that 2nd and 3rd harmonic on string are perfect 5th
- **맥놀이 (beating)**



Beating



http://www.youtube.com/watch?v=dD9gtq08tss