- Final Exam (cumulative): Tuesday December 14th, 12:30pm to 2:30pm.
- You must go to the following locations based on the 1st letter of your last name:

A to K	NPB1001 (Physics)
L to Z	NRN 137 (Norman Hall)

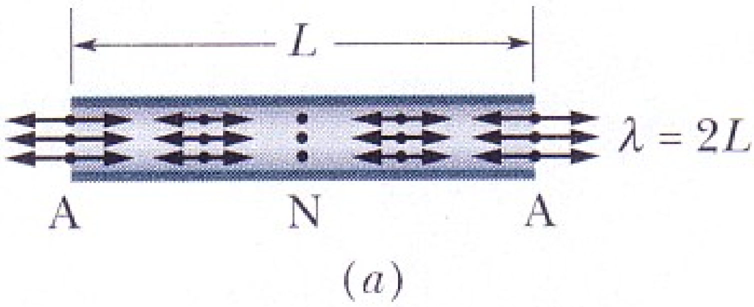
- One more review session: Thurs. Dec. 9 (Woodard), 6:15 to 8:10pm in NPB1001 (HERE!)
- HiTT data have been emailed to you.
- Exams returned today. Exam scores posted on WebAssign yesterday.
- Come and see either Dr. Woodard or myself if you suspect any irregularities (exams, quizzes, etc..)

Class 43 - Waves II
Chapters 17 - Wednesday December 8th

- Sources of musical sound
- The doppler effect
- Sonic boom
- Sample problem
- HiTT problem

Reading: pages 445 to 467 (chapter 17) in HRW
Read and understand the sample problems
Assigned problems from chapter 17 (**due TONIGHT!!!**):
82, 14, 17, 30, 36, 42, 46, 47, 52, 64, 78

Standing waves in air columns

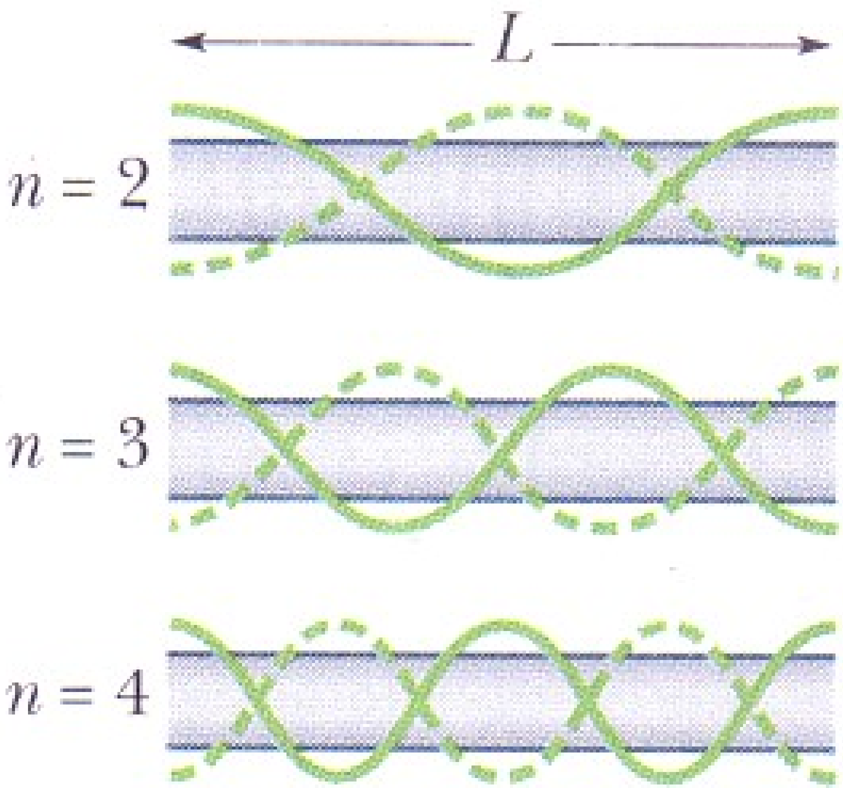


$$\lambda_1 = 2L = 2L/1$$

- Simplest case:
  - 2 open ends
  - Antinode at each end
  - 1 node in the middle
- Although the wave is longitudinal, we can represent it schematically by the solid and dashed green curves.

Standing waves in air columns

A harmonic series



$$\lambda_1 = 2L = 2L/1 \qquad \left(L = \frac{1}{2}\lambda_1\right)$$

$$\lambda_2 = 2L/2 = L \qquad \left(L = \frac{2}{2}\lambda_2\right)$$

$$\lambda_3 = 2L/3 \qquad \left(L = \frac{3}{2}\lambda_3\right)$$

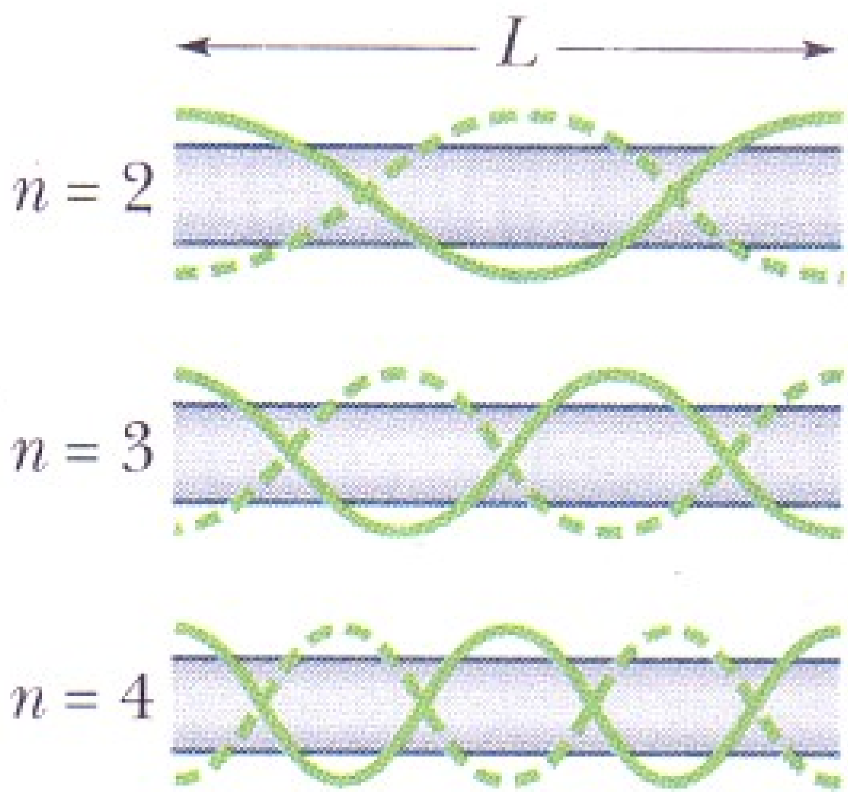
$$\lambda_4 = 2L/4 = L/2 \qquad \left(L = \frac{4}{2}\lambda_4\right)$$

$$\lambda = \frac{2L}{n}, \quad \text{for } n = 1, 2, 3, \ldots.$$

$$f = \frac{v}{\lambda} = \frac{nv}{2L}, \qquad \text{for } n = 1, 2, 3, \ldots$$

Standing waves in air columns

A harmonic series



$\lambda_1 = 2L = 2L/1$ $\quad \left(L = \frac{1}{2}\lambda_1 \right)$

$\lambda_2 = 2L/2 = L$ $\quad \left(L = \frac{2}{2}\lambda_2 \right)$

$\lambda_3 = 2L/3$ $\quad \left(L = \frac{3}{2}\lambda_3 \right)$

$\lambda_4 = 2L/4 = L/2$ $\quad \left(L = \frac{4}{2}\lambda_4 \right)$

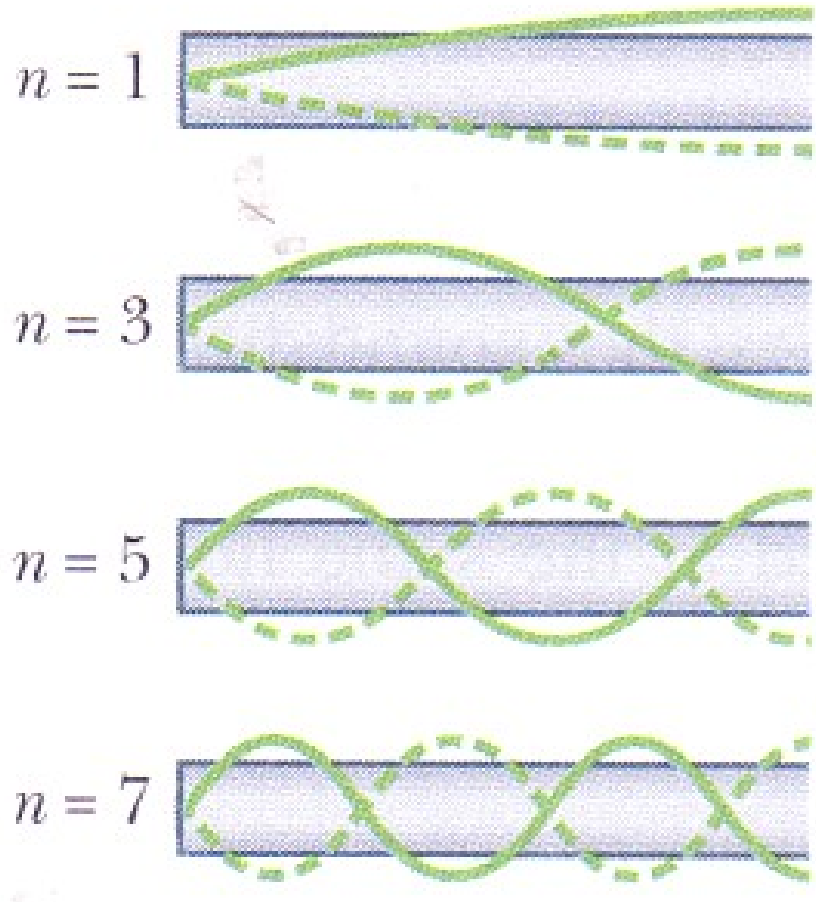
Another way to remember these harmonic series

$$\lambda = \frac{4L}{n'}, \quad \text{for } n' = 2,4,6,....$$

$$f = \frac{v}{\lambda} = \frac{n'v}{4L}, \qquad \text{for } n' = 2,4,6,...$$

Standing waves in air columns

A different harmonic series



$\lambda_1 = 4L$ $\left(L = \frac{1}{4}\lambda_1 \right)$

$\lambda_3 = 4L/3$ $\left(L = \frac{3}{4}\lambda_3 \right)$

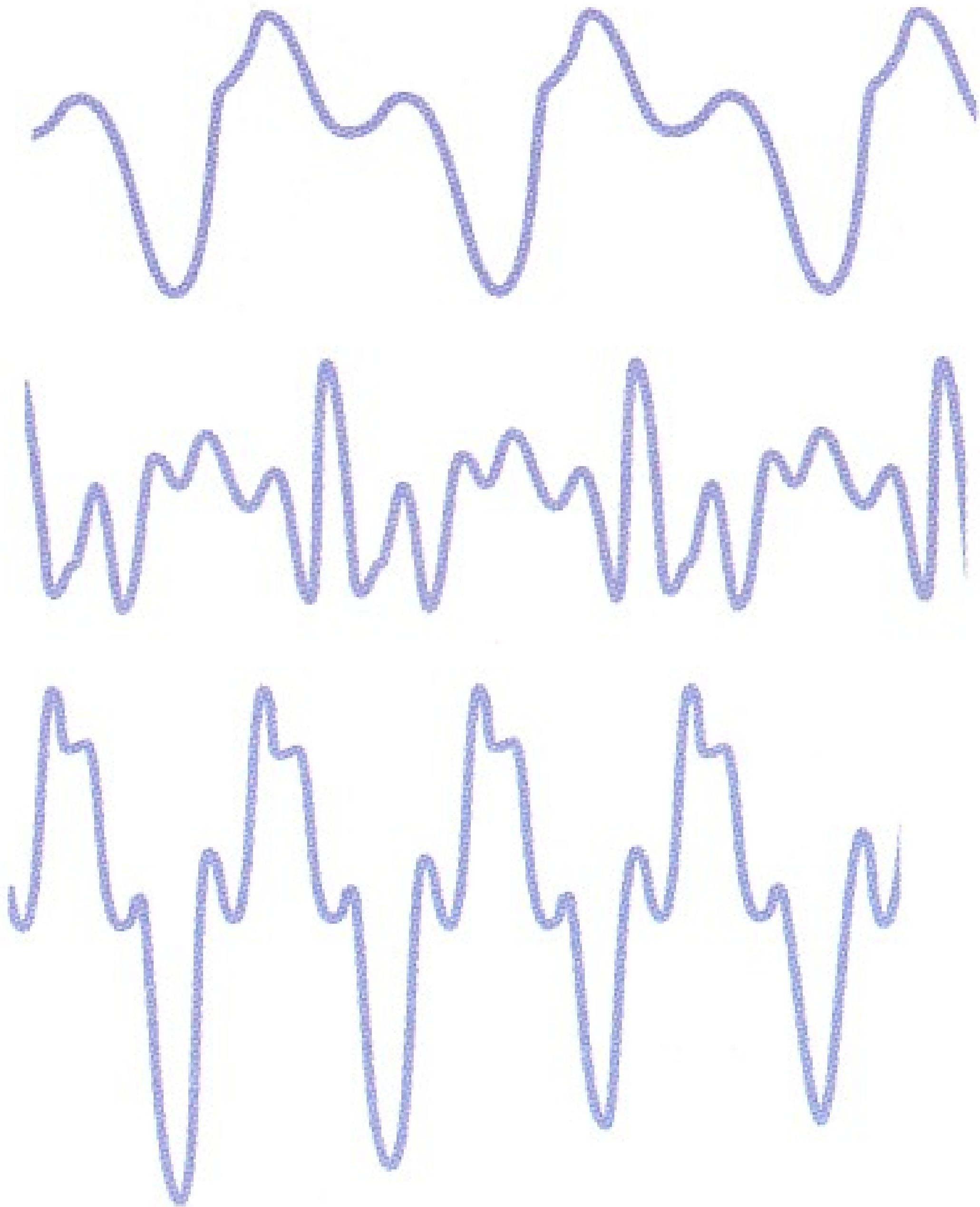
$\lambda_5 = 4L/5$ $\left(L = \frac{5}{4}\lambda_5 \right)$

$\lambda_7 = 4L/7$ $\left(L = \frac{7}{4}\lambda_7 \right)$

$$\lambda = \frac{4L}{n}, \quad \text{for } n = 1,3,5,\ldots.$$

$$f = \frac{v}{\lambda} = \frac{nv}{4L}, \qquad \text{for } n = 1,3,5,\ldots$$

Musical instruments



Flute

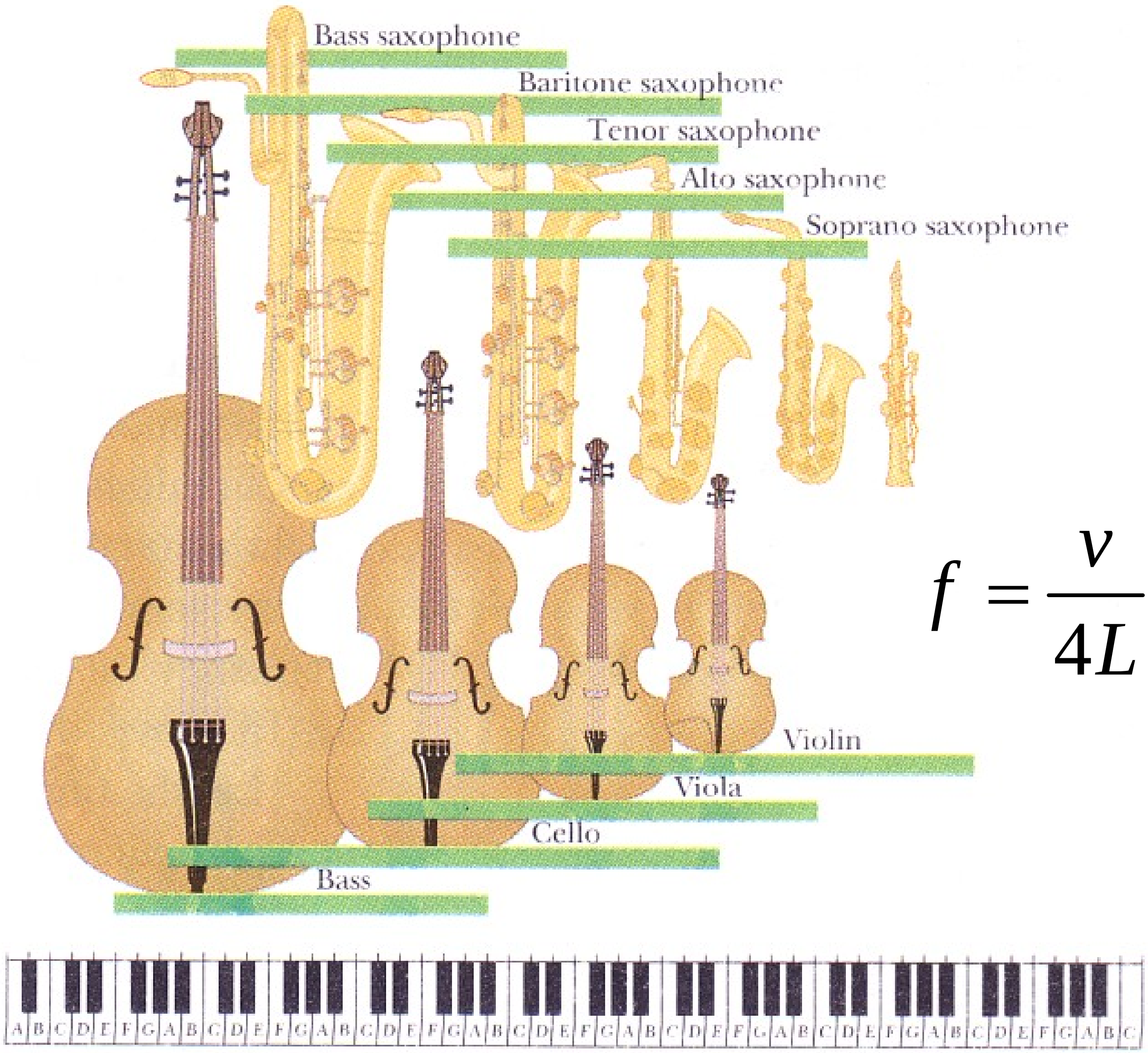
Oboe

Saxophone

Link1 Link2

Link3

Musical instruments



$$f = \frac{v}{4L} \times \text{number}$$

Doppler effect

- You may have noticed that when a police car sounds its siren at 1000 Hz, the pitch sounds higher when it comes towards you, and then reduces as it passes by you.
- The reason for this change is due to the relative motion between you and the police car.
- The same would be true if you drove past a stationary siren.
- These motion related frequency shifts are an example of the **Doppler effect**.
- The "classical" Doppler effect holds for all waves (sound, electro-magnetic, etc..), provided the velocities involved are not relativistic.

Link1 **Link2**

Doppler effect

- We use *S* to denote the source, and *D* to denote the detector.
- We then assume that *S* and *D* move either directly towards each other or directly away from each other along a straight line, at speeds less than the sound velocity, then

$$f' = f\frac{v \pm v_D}{v \pm v_S} \qquad \text{general Doppler formula}$$

- v is the sound velocity, v_S is the source velocity, and v_D is the detector velocity; all velocities are measured relative to stationary observers.

When the motion of the detector or source is towards the other, the sign on its speed must give an upward shift in frequency. When the motion of the detector or source is away from the other, the sign on its speed must give an downward shift in frequency.

Mach cone angle: $\sin\theta = \frac{v}{v_S}$