PHY 113 A General Physics I
9-9:50 AM MWF Olin 101

Plan for Lecture 35:
Chapter 17 & 18 – Physics of wave motion

1. **Standing waves**
2. **Sound waves**
3. **Doppler effect**

23	11/05/2012	Fluid mechanics	14.1-14.4	14.8, 14.24	11/07/2012
24	11/07/2012	Fluid mechanics	14.5-14.7	14.39, 14.51	11/09/2012
25	11/09/2012	Temperature	19.1-19.5	19.1, 19.20	11/12/2012
26	11/12/2012	Heat	20.1-20.4	20.3, 20.14, 20.24	11/14/2012
27	11/14/2012	First law of thermodynamics	20.5-20.7	20.26, 20.35	11/16/2012
28	11/16/2012	Ideal gases	21.1-21.5	21.10, 21.19	11/19/2012
29	11/19/2012	Engines	22.1-22.8	22.3, 22.62	11/26/2012
	11/21/2012	*Thanksgiving Holiday*			
	11/23/2012	*Thanksgiving Holiday*			
	11/26/2012	Review	14,19-22		
	11/28/2012	Exam	14,19-22		
30	11/30/2012	Wave motion	16.1-16.6	16.5, 16.22	12/03/2012
31	12/03/2012	Sound & standing waves	17.1-18.8	17.35, 18.35	12/05/2012
	12/05/2012	Review	1-22		
	12/07/2012	Review	1-22		
	12/13/2012	Final Exam -- 9 AM			

Combinations of waves ("superposition")

Note that:

$$\sin A \pm \sin B = 2\sin[\tfrac{1}{2}(A \pm B)]\cos[\tfrac{1}{2}(A \mp B)]$$

$$y_{right}(x,t) = y_0 \sin\left(2\pi\left(\frac{x}{\lambda} - ft\right)\right) \qquad y_{left}(x,t) = y_0 \sin\left(2\pi\left(\frac{x}{\lambda} + ft\right)\right)$$

"Standing" wave:

$$y_{right}(x,t) + y_{left}(x,t) = 2y_0 \sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi ft)$$

$$\sin A \pm \sin B = 2\sin[\tfrac{1}{2}(A \pm B)]\cos[\tfrac{1}{2}(A \mp B)]$$

"Standing" wave:

$$y_{right}(x,t) + y_{left}(x,t) = 2y_0 \sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi f t)$$

iclicker exercise:

Why is this superposition result important?

A. Physics instructors like to torture their students.
B. While the trigonometric relation is always true, it is rarely useful for describing real situations.
C. It can describe the motion of a guitar string.

Standing wave solutions to the wave equation: $\frac{\partial^2 y}{\partial t^2} - c^2 \frac{\partial^2 y}{\partial x^2} = 0$

$$y_{\text{standing}}(x,t) = A\sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi f t)$$

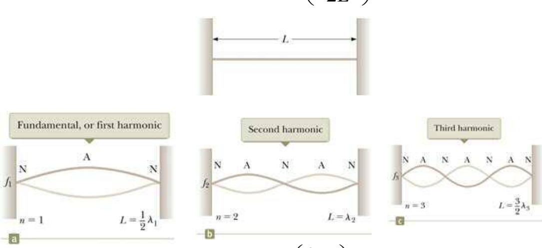
$$\text{Check: } \frac{\partial^2 y_{\text{standing}}}{\partial t^2} = -(2\pi f)^2 A\sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi f t)$$

$$\text{Check: } \frac{\partial^2 y_{\text{standing}}}{\partial x^2} = -\left(\frac{2\pi}{\lambda}\right)^2 A\sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi f t)$$

$$\frac{\partial^2 y}{\partial t^2} - c^2 \frac{\partial^2 y}{\partial x^2} = -A\sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi f t)\left((2\pi f)^2 - c^2\left(\frac{2\pi}{\lambda}\right)^2\right) = 0$$

Equality satisfied iff $f\lambda = c$

Possible spatial shapes: $A\sin\left(\frac{2\pi n x}{2L}\right)$ $\quad n = 1,2,3,4.....$



Standing wave form: $A\sin\left(\frac{2\pi x}{\lambda}\right)\cos(2\pi f t)$

$$\Rightarrow \lambda_n = \frac{2L}{n} \qquad f_n = \frac{nc}{2L} \qquad n = 1,2,3,4...........$$

iclicker question:
Which of the following statements are true about the string motions described above?

- **A. The human ear can directly hear the string vibrations.**
- **B. The human ear could only hear the string vibration if it occurs in vacuum.**
- **C. The human ear can only hear the string vibration if it produces a sound wave in air.**

Comments about waves in materials:

- **Solid materials can support both transverse and longitudinal wave motion**
- **Fluids, especially gases can support only longitudinal wave motion**

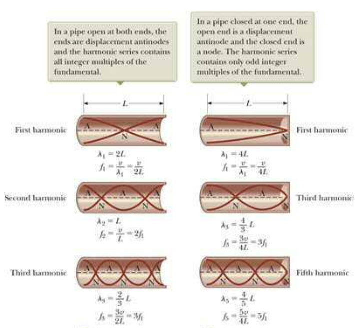
The linearized fluid equations in the ideal gas approximation, show that the density fluctuations $\delta\rho$ of air can be written:

$$\frac{\partial^2 \delta\rho}{\partial t^2} - c^2 \frac{\partial^2 \delta\rho}{\partial x^2} = 0 \qquad c^2 = \frac{\gamma p_0}{\rho_0} \approx 343 m/s$$

Alternatively, the sound wave can be expressed in terms of pressure fluctuations:

$$\frac{\partial^2 \delta P}{\partial t^2} - c^2 \frac{\partial^2 \delta P}{\partial x^2} = 0$$

Standing waves in air:



Coupling standing wave resonances in materials with sound:

iclicker question:
Suppose an “A” is played on a guitar string. The standing wave on the string has a frequency (f_g), wavelength (λ_g) and speed (c_g) . Which properties of the resultant sound wave are the same as wave on the guitar string?

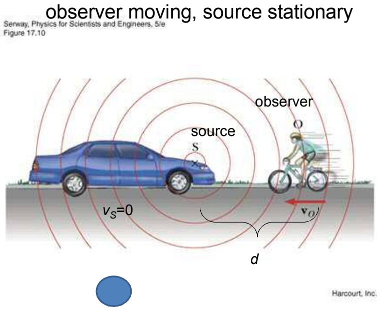
A. Frequency f_s
B. Wavelength λ_s
C. Speed c_s
D. A-C
E. None of these

coupling to sound

The “Doppler” effect

v=sound velocity

observer moving, source stationary



$$vt_1 = d - v_O t_1$$

$$v(t_2 - T) = d - v_O t_2$$

$$t_2 - t_1 = \frac{1}{f_O} = T\frac{v}{v + v_O}$$

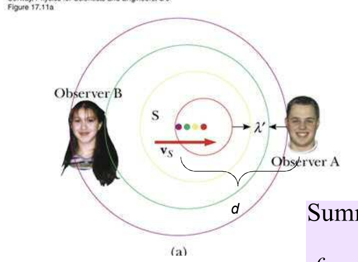
$$f_O = f_S \frac{v + v_O}{v}$$

The "Doppler" effect

v=sound velocity

observer stationary, source moving

Serway, Physics for Scientists and Engineers, 5/e Figure 17.11a



$$vt_1 = d$$
$$v(t_2 - T) + v_s T = d$$
$$t_2 - t_1 = \frac{1}{f_O} = T\frac{v - v_s}{v}$$
$$f_O = f_S \frac{v}{v - v_s}$$

Summary:
$$f_O = f_S \frac{v \pm v_O}{v \mp v_S}$$
toward
away

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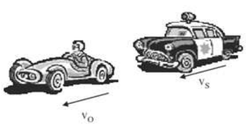

The figure on the left shows a car traveling at a velocity v_O being followed by a police car traveling at a velocity $v_S = 30$ m/s. The police car has a siren at frequency $f_S = 950$ cycles/s. The observer in the front car hears the siren at a frequency of $f_O = 920$ cycles/s.

(a) Is the front car moving faster or slower than the police car?

(b) What is the velocity of the front car v_O?

$$f_O = f_S \frac{v \pm v_O}{v \mp v_S}$$
toward
away

Velocity of sound:

v = 343 m/s

In this case :
$$f_O = f_S \frac{v - v_O}{v - v_S}$$
$$f_O < f_S \Rightarrow v_O > v_S$$
$$v_O = v - (v - v_s)\frac{f_O}{f_S} \approx 40\text{m/s}$$

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iclicker question

Is Doppler radar described by the equations given above for sound Doppler?

(A) yes (B) no

Is "ultra sound" subject to the sound form of the Doppler effect?

(A) yes (B) no

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Summary of sound Doppler effect:

$$f_O = f_S \frac{v \pm v_O}{v \mp v_S}$$

toward (upper signs) / away (lower signs)

Doppler effect for electromagnetic waves:

$$f_O = f_S \sqrt{\frac{v + v_R}{v - v_R}}$$

v_R: Relative velocity of source toward observer