Lecture 30

Goals:

• Wrap up chapter 20.
• Review for the final.

• Final exam on Friday, Dec 23, at 10:05 am in BASCOM 272.
  Final will cover Chapters 1-20 (excluding Chapter 13).
  Semi-cumulative.
• HW 12 due tomorrow night.

The Doppler effect

The frequency of the wave that is observed depends on the relative speed between the observer and the source.

$V_s$  

observer
The Doppler effect

Approaching source:
\[ f = f_0 \left/ \left(1 - \frac{v_s}{v}\right) \right. \]

Receding source:
\[ f = f_0 \left/ \left(1 + \frac{v_s}{v}\right) \right. \]

Waves

The figure shows a snapshot graph \( D(x, t = 2 \text{ s}) \) taken at \( t = 2 \text{ s} \) of a pulse traveling to the left along a string at a speed of 2.0 m/s. Draw the history graph \( D(x = -2 \text{ m}, t) \) of the wave at the position \( x = -2 \text{ m} \).
A concert loudspeaker emits 35 W of sound power. A small microphone with an area of 1 cm$^2$ is 50 m away from the speaker.

What is the sound intensity at the position of the microphone?

How much sound energy impinges on the microphone each second?
The power hitting the microphone is:

\[ P_{\text{microphone}} = I A_{\text{microphone}} \]

### Intensity of sounds

If we were asked to calculate the intensity level in decibels:

\[ \beta = 10 \log_{10} \left( \frac{I}{I_0} \right) \]

\( I_0 \): threshold of human hearing

\( I_0 = 10^{-12} \text{ W/m}^2 \)
Suppose that we measure intensity of a sound wave at two places and found them to be different by 3 dB. By which factor, do the intensities differ?

\[
\begin{align*}
\beta_1 &= 10 \log_{10} \left( \frac{I_1}{I_0} \right) \\
\beta_2 &= 10 \log_{10} \left( \frac{I_2}{I_0} \right) \\
\beta_1 - \beta_2 &= 10 \log_{10} \left( \frac{I_1}{I_2} \right) = 3 \\
\frac{I_1}{I_2} &= 10^{0.3} = 2
\end{align*}
\]

Engines

For the engine shown below, find, \( W_{\text{out}} \), \( Q_H \) and the thermal efficiency. Assume ideal monatomic gas.

![Engine diagram](image)
First, use the ideal gas law to find temperatures

\[ Q = 90 \text{ J} \]

\[ nC_v \Delta T = 90 \text{ J} \]

\[ n(3R/2)6T_i = 90 \text{ J} \]

\[ nRT_i = 10 \text{ J} \]

From the right branch, we have:

\[ W_{out} = \text{area} = 3P_i V_i = 3nRT_i = 30 \text{ J} \]
From energy conservation:

\[ W_{\text{out}} = Q_H - Q_C \]
\[ W_{\text{out}} = 30 \text{J} \]
\[ Q_C = 115 \text{J} \]

The thermal efficiency is:

\[ \eta = \frac{W_{\text{out}}}{Q_H} = \frac{\text{what you get}}{\text{what you had to pay}} \]

\[ \eta = 0.2 \]

The Carnot Engine

- Carnot showed that the thermal efficiency of a Carnot engine is:

\[ \eta_{\text{Carnot cycle}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}} \]

- All real engines are less efficient than the Carnot engine because they operate irreversibly due to the path and friction as they complete a cycle in a brief time period.
For which reservoir temperatures would you expect to construct a more efficient engine?

A) $T_{\text{cold}}=10^\circ\text{C}, \ T_{\text{hot}}=20^\circ\text{C}$

B) $T_{\text{cold}}=10^\circ\text{C}, \ T_{\text{hot}}=800^\circ\text{C}$

C) $T_{\text{cold}}=750^\circ\text{C}, \ T_{\text{hot}}=800^\circ\text{C}$

**Kinetic theory**

A monatomic gas is compressed isothermally to 1/8 of its original volume.

Do each of the following quantities change? If so, does the quantity increase or decrease, and by what factor? If not, why not?

a. The temperature
b. The $\text{rms}$ speed $v_{\text{rms}}$
c. The mean free path
d. The molar heat capacity $C_V$
\[ \lambda = \frac{1}{4\sqrt{2}\pi(N/V)r^2} \]

\( N/V \): particles per unit volume

\( \epsilon_{\text{avg}} = (1/2) m v_{\text{rms}}^2 = (3/2) k_B T \)

\( C_V = 3R/2 \) (monatomic gas)

**Simple Harmonic Motion**

A Hooke’s Law spring is on a horizontal frictionless surface is stretched 2.0 m from its equilibrium position. An object with mass \( m \) is initially attached to the spring however, at equilibrium position a lump of clay with mass 2\( m \) is dropped onto the object. The clay sticks.

What is the new amplitude?
The speed when the mass reaches the equilibrium position:

\[ \frac{1}{2} k A^2 = \frac{1}{2} m v_{\text{max}}^2 \]

\[ v_{\text{max}} = \omega A \]

The speed after clay sticks can be found using momentum conservation:

\[ m v_{\text{max}} = (m + 2m) v_{\text{new}} \]

\[ v_{\text{new}} = \frac{v_{\text{max}}}{3} \]

The new amplitude can be found using energy conservation:

\[ \frac{1}{2} (m + 2m) v_{\text{new}}^2 = \frac{1}{2} k A_{\text{new}}^2 \]

\[ A_{\text{new}} = A / \sqrt{3} \]

**Fluids**

What happens with two fluids?

Consider a U tube containing liquids of density \( \rho_1 \) and \( \rho_2 \) as shown:

Compare the densities of the liquids:

(A) \( \rho_1 < \rho_2 \)  
(B) \( \rho_1 = \rho_2 \)  
(C) \( \rho_1 > \rho_2 \)
Fluids

- What happens with two fluids??
- Consider a U tube containing liquids of density $\rho_1$ and $\rho_2$ as shown:
- At the red arrow the pressure must be the same on either side. $\rho_1 \times = \rho_2 \times$
  - Compare the densities of the liquids:

  (A) $\rho_1 < \rho_2$  
  (B) $\rho_1 = \rho_2$  
  (C) $\rho_1 > \rho_2$