Kinetic Theory wrap-up

Last time: \[ \varepsilon = \frac{3}{2} kT = \frac{1}{2} m u_{rms}^2 \]

\[ \Rightarrow \text{specific heat} \quad \Delta \varepsilon_m = N \Delta \varepsilon = N C_v \Delta T \]

\[ \Rightarrow \Delta \varepsilon = \frac{3}{2} k \Delta T = C_v \Delta T \]

\[ \Rightarrow C_v = \frac{3}{2} k \quad \text{monatomic gas} \]

\[ T_x, T_y, T_z \quad \text{3 degrees of freedom} \]

Equipartition Theorem: \[ \frac{1}{2} kT \text{ per degree of freedom} \]

Diatomic molecule: \[ O=O \]

\[ x, y, z, \omega_x, \omega_y, \omega_z \]

\[ \omega_x \text{ has } I_x = 0 \]

\[ \Rightarrow \varepsilon = \frac{5}{2} kT; \quad C_v = \frac{5}{2} k \]

\[ \Rightarrow \frac{1}{2} I_x \omega_x^2 = 0 \]

(Vibration not effective at \( T = 300 \text{ K} \))

At high \( T \), more degrees (vibrational) appear.

Eq. \( H_2 \)

\[ T \leq 100 \text{ K} \quad C_v = \frac{3}{2} k \quad \text{only translation} \]

\[ 100 \text{ K} < T < 1000 \text{ K} \quad \frac{5}{2} k \quad \text{trans + rotation} \]

\[ T > 1000 \text{ K} \quad \frac{7}{2} k \quad \text{trans + rot + vibration} \]

\[ 2 \text{ degs} \]

\[ \frac{1}{2} m u^2 + \frac{1}{2} kx^2 \]
Ch 19. Engines

Engines use cycle to convert heat to work

\[ Q_c : \text{Usually exhaust heat to cold reservoir (lake, ocean)} \]

\[ Q_h : \text{Usually heat input from burning something hot} \]

work done \( W = Q_h - Q_c \) (\( \Delta E = 0 \) over whole cycle)

\[ \text{efficiency} \quad \eta = \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h} \]

Expansion / Compression of a Working Gas

Carnot Cycle - ideal gas, ideal cycle

1. isothermal compression
\[ pV = NkT_c \]

2. adiabatic compression
\[ pV = \text{const} \quad T \to T_h \]

3. isothermal expansion \( \text{at} \ T_h \)
\[ pV = NkT_h \]

4. adiabatic expansion
\[ pV = \text{const} \quad T \to T_c \]

Average

Maximum efficiency!!
Other Engines

4-stroke Internal Combustion = Otto Cycle (19.71)

1. Intake Stroke
   - Draw fuel into cylinder
   - p $\neq$ const
   - No heat transfer during compression and power strokes (too fast)

2. Compression
   - Compress fuel
   - 2 + 3 are adiabatic

3. Power
   - Expands fuel, does work
   - $\eta = 1 - \frac{1}{r^{x-1}}$

4. Exhaust
   - Push exhaust out
   - Exhaust valve opens

Net work is adiabatic expansion of hot gas

Allotropic compression of cold fuel

$V = \text{bore} \times \text{stroke}$

Note: 19.71 is a simplified "Otto" cycle,
only compression and power strokes (2-stroke)
Diesel Cycle (1972)

Four strokes, but different ignition/power setup; no spark plug - spontaneous ignition due to compression of air before fuel injection.

Main difference: ignition takes place during initial power stroke @ constant p.

1. Compression of air
2. Ignition / expansion at p = const
3. Adiabatic expansion

\[ \eta = \text{m ess} \]

Brayton Cycle - approximates turbines

1. Adiabatic compression
2. Burnout (isotonic)
3. Adiabatic expansion
4. Cooling (isotonic)

\[ \text{Betz: } \eta = 1 - \left( \frac{\text{Power}}{\text{Input}} \right)^{8/9} \]