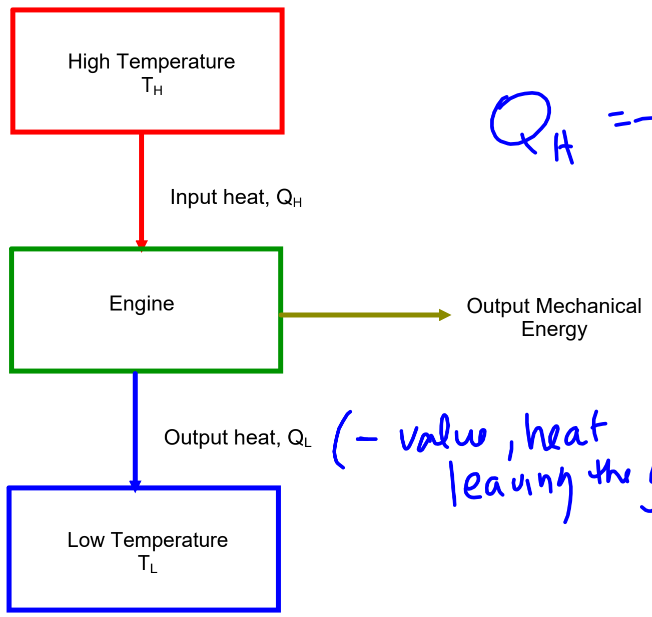
Day 7: Second Law of Thermodynamics

The law of conservation of energy says nothing about order. By conservation of energy, many processes could go both forward and backwards without violating the law. This led to a second law regarding heat transfer which states that *heat will naturally flow from a hot object to a cold object, but will not flow spontaneously flow a cold object to a hot object*.
[Claussius statement]

Of course this can be stated in other ways, more generally that *natural processes move toward a state of greater disorder*.
[general statement]

The second law is essentially a way of underscoring the lack of reversibility of some processes.

Heat Engines



$Q_H = -(W + Q_L)$

W (is negative value
- energy leaving the gas

(- value, heat leaving the gas)

Efficiency

$$e = \frac{E_{output}}{E_{input}}$$

since $|Q_H| = |W| + |Q_L|$

$$= \left|\frac{W}{Q_H}\right|$$

$$= \frac{|Q_H| - |Q_L|}{|Q_H|} = 1 - \left|\frac{Q_L}{Q_H}\right|$$

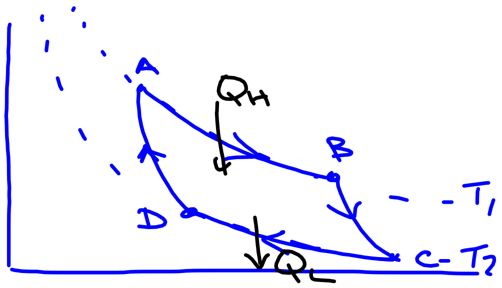
For an ideal engine so $\left|\frac{Q_L}{Q_H}\right| = \frac{T_L}{T_H}$ ← T in K

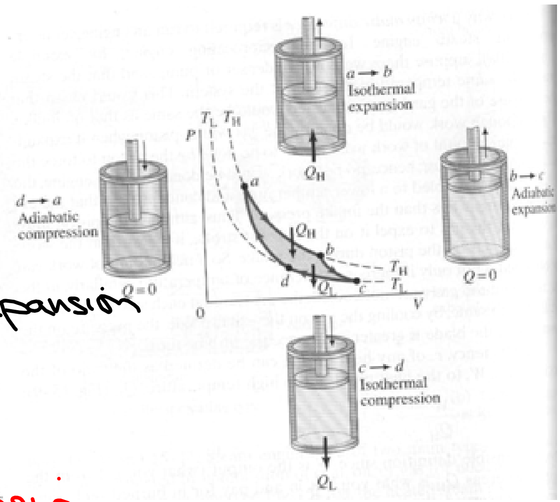
so $e = 1 - \frac{T_L}{T_H}$

$= 1 - \frac{300K}{900K}$ ← air temp (300K); ← near melting of engine block (900K)

$= 67\%$

The Carnot Engine





Step 1 A→B isothermal expansion

$\Delta U = \frac{3}{2} N k \Delta T = 0$

$Q_H = -W_{A\to B}$

Step 2 B→C adiabatic expansion

$Q = 0$

$\Delta U = W_{B\to C} = \frac{3}{2} N k \Delta T = \frac{3}{2} N k (T_2 - T_1)$ ← negative value

Step 3 C→D isothermal compression

$Q_L = -W_{C\to D}$ ($W_{C\to D}$ is +, so Q_L is negative since it is leaving the gas)

Step 4 D→A adiabatic comp.

$Q = 0$

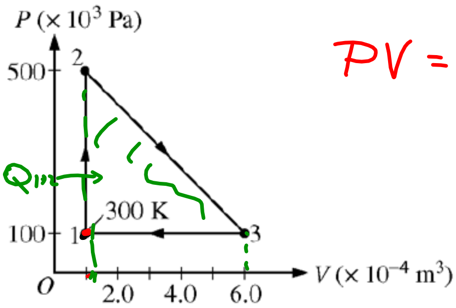
$\Delta U = \frac{3}{2} N k (T_1 - T_2) = W_{D\to A}$ (W is + since $T_1 > T_2$)

For the entire cycle, $\Delta U = 0$ — same T, P, V, N

$W = -Q_L - Q_H$

$Q_H = W + Q_L$

Example from 2008 AP Exam



$W = -A$

$W_{2\to3} = \ominus$

$W_{3\to1} = \oplus$

$PV = nRT$ ← $8.315\ J/mol \cdot K$

$\frac{P_1 V_1}{P_2 V_2} = \frac{nR T_1}{nR T_2}$

$\frac{P_1}{P_2} = \frac{T_1}{T_2}$

$\frac{1}{5} = \frac{300K}{T_2}$ $T_2 = 1500K$

6. (10 points)

A 0.0040 mol sample of a monatomic gas is taken through the cycle shown above. The temperature T_1 of state 1 is 300 K.

(a) Calculate T_2 and T_3.

$\frac{P_1 V_1}{P_3 V_3} = \frac{T_1}{T_3}$ $\frac{1}{6} = \frac{300}{T_3} = 1800\ K$

(b) Calculate the amount of work done on the gas in one cycle.

$\frac{bh}{2} = \frac{(5\times10^{-4}\ m^3)(400\times10^3\ N/m^2)}{2} = -100\ J$

(c) Is the net work done on the gas in one complete cycle positive, negative, or zero?

____ Positive ✓ Negative ____ Zero

(d) Calculate the heat added to the gas during process 1→2.

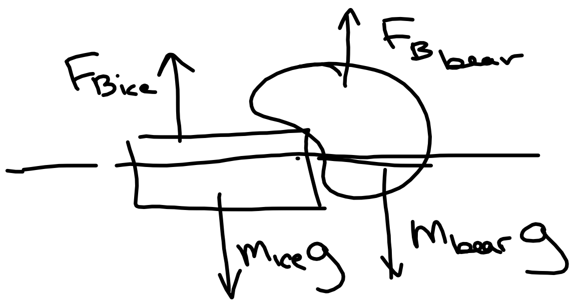
$W_{1\to2} = 0$ $\Delta U_{1\to2} = Q_{1\to2}$

$\Delta U_{1\to2} = \frac{3}{2} nR\Delta T$ (Nk)

$= \frac{3}{2}(0.0040)(8.315)(1500-300)$

$= \frac{3}{2}(0.0040)(8.315)(1200)$

$\approx 60\ J$



$$F_{B_{ice}} + F_{B_{bear}} = (m_{ice} + m_{bear}) g$$

$$\rho_{seawater}(V_{ice\ below} g + V_{bear\ below} g) = (m_{ice} + m_{bear}) g$$

$$1025(9.475 + 0.3 V_{bear}) = 10 \cdot 917 + m_{bear}$$

$$9717 + 0.3 \frac{m_{bear} \cdot 1025}{1000} = 9170 + m_{bear}$$

$$547 = m_{bear}(1 - 0.3075)$$

$$m_{bear} = \underline{790 kg}$$

$$f = 1 - \frac{\rho_{ice}}{\rho_{seawater}}$$

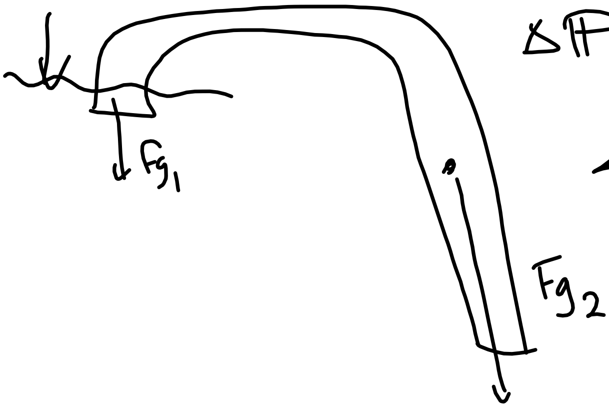
$$= 1 - \frac{0.917}{1.025} = 0.105$$

$V_{ice} = 10 m^3$ $\quad$ $1.05 m^3$ above water pre bear

post bear $V_{ice\ above} = \frac{1}{2}(1.05 m^3) = 0.525 m^3$

So $10 - 0.525 m^3$ below

$$9.\underline{475 m^3}$$



$\Delta P \propto V^2$