Heat Engine

- Device that is used to extract energy from the environment to do useful work.

* The working substance in an engine must operate in a <u>cycle</u>.

→ Closed series of thermodynamic processes

In an ideal engine:

- All processes are reversable
- no wasteful energy transfers.

Thermodynamic Processes

1) isothermal Expansion $\Delta E_{int} = 0$ $\downarrow P \uparrow V - T$ $Q = W$

2) adiabatic Expansion $Q = 0$ $\downarrow P \downarrow T \uparrow V$ $\Delta E_{int} = -W$ $(\downarrow E_{int} \uparrow W)$

3) isothermal Compression $\Delta E_{int} = 0$ $\uparrow P \downarrow V - T$ $Q = W$

4 adiabatic Compression $Q = 0$ $\uparrow P \uparrow T \downarrow V$ $\Delta E_{int} = -W$ $(\uparrow E_{int} \downarrow W)$

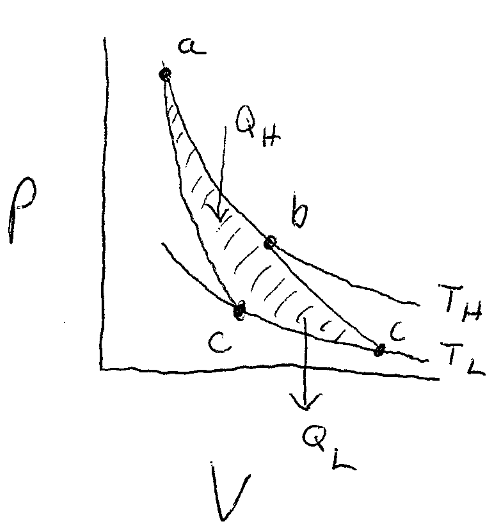
Carnot Engine

- Example of an ideal heat engine

- Cycle consists of

1) isothermal expansion
2) adiabatic expansion
3) isothermal compression
4) adiabatic compression

P vs V Carnot Engine



Work done by Carnot engine

$W_{ab} = Q_H$

$W_{cd} = -Q_L$

$W_{bc} = n c_V \Delta T = n c_V (T_L - T_H)$

$W_{da} = n c_V \Delta T = n c_V (T_H - T_L)$

$W_{Net} = W_{ab} + W_{bc} + W_{cd} + W_{da}$

$= Q_H + (n c_V T_L + -n c_V T_H) + -Q_L + (n c_V T_H + -n c_V T_L)$

$W = Q_H - Q_L$

$$\Delta S_{gas} = \Delta S_H + \Delta S_L = \Delta S_{cycle} = 0$$

$$\frac{Q_H}{T_H} \qquad \frac{Q_L}{T_L}$$

* Temperature of reservoirs remain constant

Relative to the gas Q_H is positive and Q_L is negative

$$\frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

Efficiency (ε)

$$\varepsilon = \frac{\text{output}}{\text{input}} = \frac{W}{Q_H}$$

work is the desired output.

Energy input is from high temp. reservoir

Carnot Efficiency

$$\varepsilon_c = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

$$\frac{Q_L}{T_L} = \frac{Q_H}{T_H} \Rightarrow \frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

* This (ε_c) represents the maximum efficiency of a heat engine.

⇒ Implies that all heat engines will operate with an efficiency less than one.

Refrigerator

- Device used to transfer heat from a low temp. reservoir to a high temp. reservoir.

Coefficient of Performance (K)

$$K = \frac{\text{output}}{\text{input}} = \frac{Q_L}{W}$$

Q_L ← desired output is removal of heat

W ↖ work is now an input (something must run refrigerator engine)

Carnot Refrigerator

$$W = Q_H - Q_L \qquad \frac{Q_H}{T_H} = \frac{Q_L}{T_L} \Rightarrow \frac{T_L}{T_H} = \frac{Q_L}{Q_H}$$

$$K_c = \frac{Q_L}{Q_H - Q_L} = \frac{Q_L}{Q_H} - 1 = \frac{T_L}{T_H} - 1$$

$$\Delta S = \frac{Q}{T_H} + \frac{-Q}{T_L}$$

Q is amount of heat removed from low temp reservoir

ΔS is always negative because $T_H > T_L$