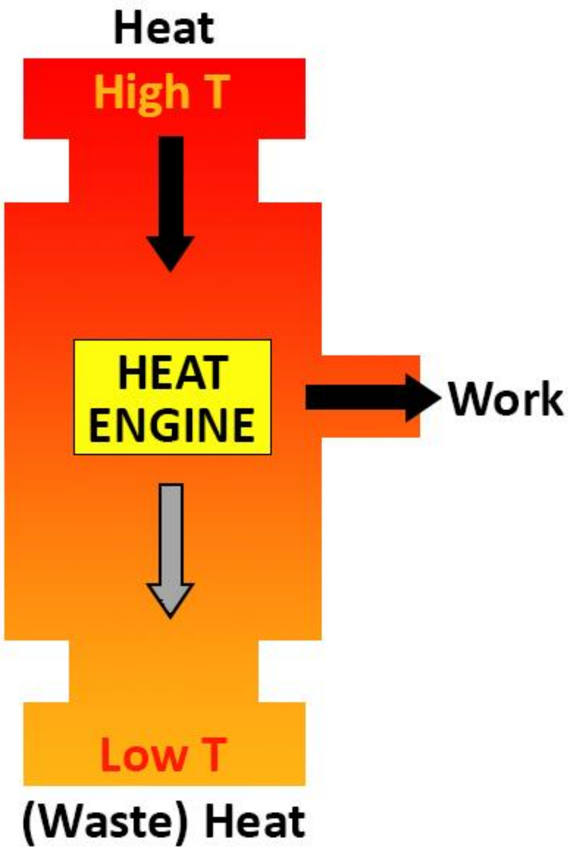
Picture taken from https://www.e-education.psu.edu/egee102/node/1941

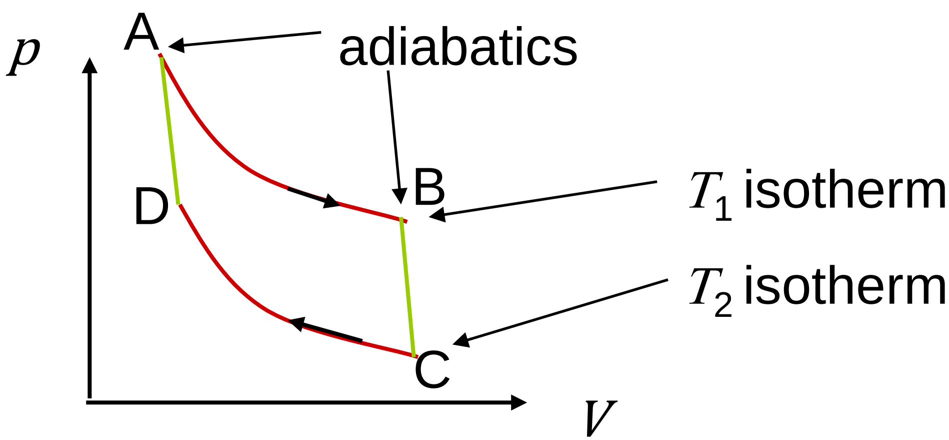


Heat engines

Refrigerators

*from https://opentextbc.ca/chemistry/chapter/16-2-entropy/

Heat engine
(a vital thought experiment)



Nicholas Léonard Sadi Carnot*

operates in a cycle

A to B takes in heat Q_1 at temperature T_1 (along isotherm)

B to C does work W (no $đQ$, so adiabatic)

C to D gives out heat Q_2 at temperature T_2 (another isotherm)

D to A surroundings do work on system (no $đQ$ again)

A heat engine that has a cycle made of isotherms and adiabatics is a *Carnot engine*. (PH10002).

Heat engine
(a vital thought experiment)

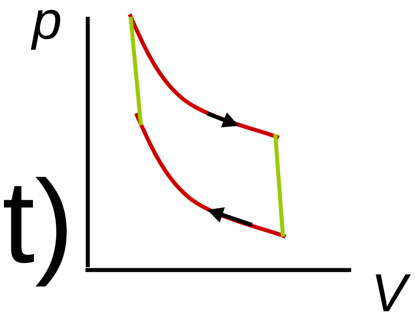
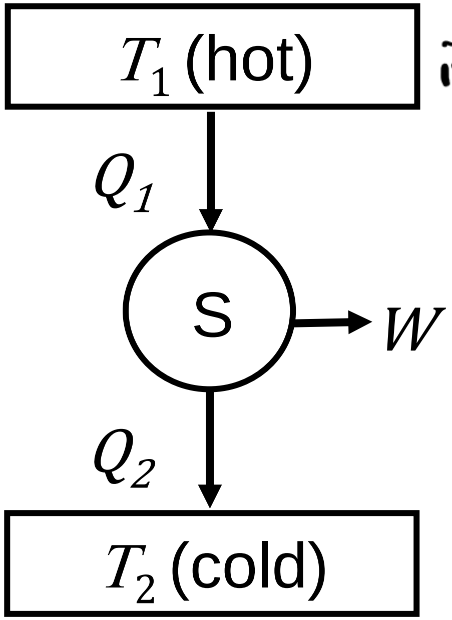


Diagram is too specific – only describes gas in a box.
More general diagram (S is the engine):



isotherm

isotherm

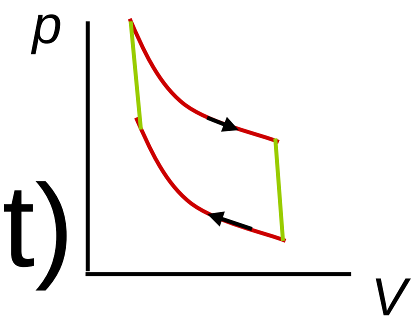
Since heat is taken in at fixed temp., the system must move along an *isotherm*.

Since it has to get from one isotherm to the other *without* taking in heat, it must move along an *adiabatic curve*.

reversible

Carnot cycle:
Adiabatics & isotherms are quasistatic (& assume no hysteresis) ⇒ thermody equilibrium through process
All processes are reversible ⇒ cycle is reversible

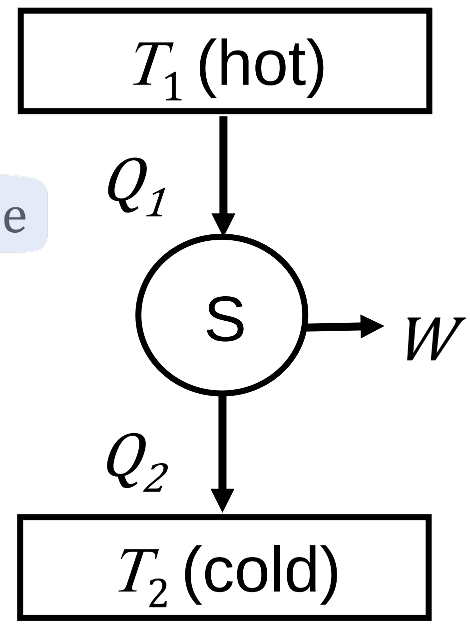
Heat engine
(a vital thought experiment)



For complete cycle:

$$\oint \mathrm{d}U = 0 = Q_1 - Q_2 + W$$

$$Q_1 - Q_2 = \text{heat supplied to working substance}$$
$$W = \text{work done } \textbf{on} \text{ working substance}$$

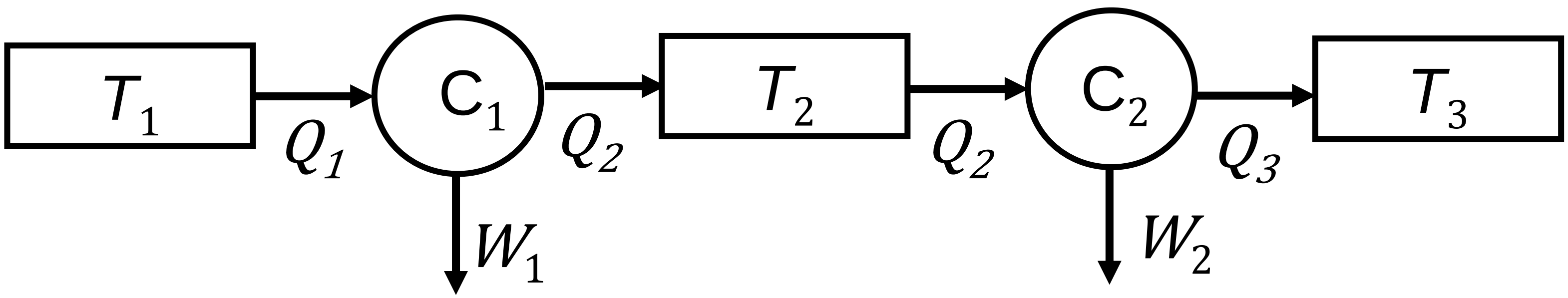


Work done by engine $= -W = Q_1 - |Q_2|$

Efficiency:

$$\eta = \frac{\text{work out}}{\text{heat in}} = \frac{Q_1 - |Q_2|}{Q_1} = 1 - \frac{|Q_2|}{Q_1}$$

Relating Q to T

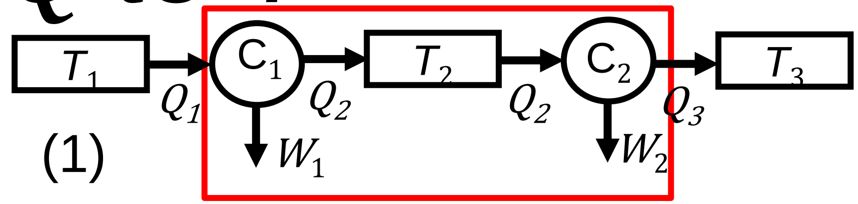


$$\frac{Q_1}{Q_2} = f_1(T_1, T_2) \;\&\; \frac{Q_2}{Q_3} = f_2(T_2, T_3)$$

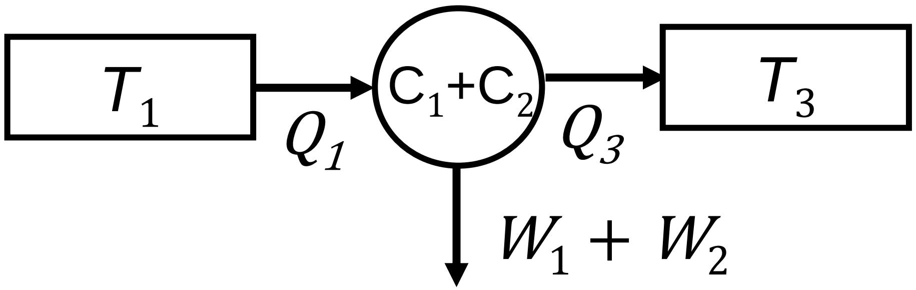
Multiply the two equations:

$$\frac{Q_1}{Q_3} = f_1(T_1, T_2) \cdot f_2(T_2, T_3) \qquad (1)$$

Relating Q to T



$$\frac{Q_1}{Q_3} = f_1(T_1, T_2) \cdot f_2(T_2, T_3) \qquad (1)$$



$$\frac{Q_1}{Q_3} = f_3(T_1, T_3)$$

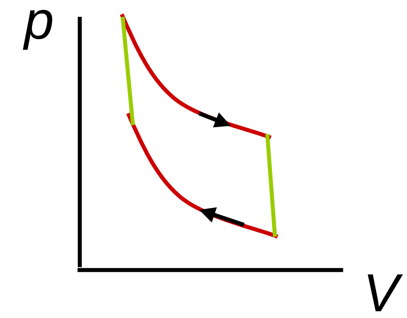
Here, T_2 does not appear, hence, must cancel from eqn. (1).

Therefore, requires that $f_1(T_1, T_2) = \frac{T_1}{T_2}$

and $f_2(T_2, T_3) = \frac{T_2}{T_3}$

So $\frac{Q_1}{Q_3} = \frac{T_1}{T_3}$

Refrigerators
Heat Pumps



heat engine

Driven backwards, Carnot engine will extract heat at colder *T* and reject at higher *T* at expense of mechanical work (=refrigerator or heat pump!)

Blundell & Blundell p129