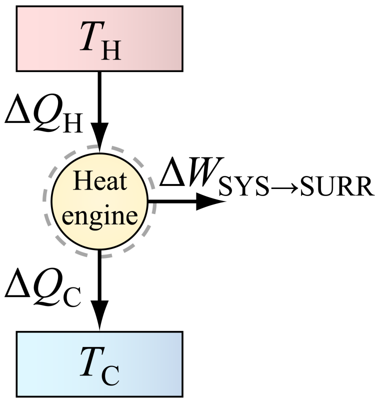
Heat engines and heat pumps (for SAT Subject Test in Physics)

Heat engines



$$\Delta U_{SYS} = \Delta Q_{SURR \to SYS} + \Delta W_{SURR \to SYS}$$

Heat engine returns to same state at end of each cycle:

$$\Delta U_{SYS} = 0$$

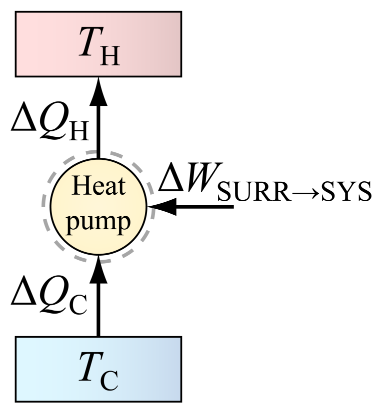
$$0 = (\Delta Q_H - \Delta Q_C) - \Delta W_{SYS \to SURR}$$

$$\Delta Q_H = \Delta Q_C + \Delta W_{SYS \to SURR}$$

$$e := \frac{\Delta W_{SYS \to SURR}}{\Delta Q_H} = \frac{\Delta Q_H - \Delta Q_C}{\Delta Q_H}$$

$$= 1 - \frac{\Delta Q_C}{\Delta Q_H}$$

Heat pumps



$$\Delta U_{SYS} = \Delta Q_{SURR \to SYS} + \Delta W_{SURR \to SYS}$$

Heat pump returns to same state at end of each cycle:

$$\Delta U_{SYS} = 0$$

$$0 = (\Delta Q_C - \Delta Q_H) + \Delta W_{SURR \to SYS}$$

$$\Delta Q_C + \Delta W_{SURR \to SYS} = \Delta Q_H$$

$$\text{c.o.p.} = \frac{\Delta Q_{GOAL}}{\Delta W_{SURR \to SYS}}$$

Ideality

Device returns to same state at end of each cycle:

$$\Delta S_{SYS} = 0$$

Recall that heat transfer can change the amount of entropy of a system. Particularly, for a reversible process,

$$\Delta S_{SYS} = \frac{\Delta Q_{REV,SURR \to SYS}}{T}$$

If an engine operates slowly enough throughout its cycle to be considered reversible (an *idealization* that is not always reasonable),

$$\Delta S_{SYS,H} = \frac{\Delta Q_H}{T_H}$$

and

$$\Delta S_{SYS,C} = \frac{(-\Delta Q_C)}{T_C}$$

Thus,

$$\Delta S_{SYS} = \frac{\Delta Q_H}{T_H} - \frac{\Delta Q_C}{T_C} = 0$$

This condition is achieved by a Carnot cycle.

Ideal **heat engines**

A Carnot heat engine has an efficiency of

$$e_{IDEAL} = 1 - \frac{T_C}{T_H}$$

which no heat engine's efficiency can exceed.

Ideal **heat pumps**

A Carnot heat pump has a coefficient of performance of

$$\text{c.o.p.}_{HEATING,IDEAL} = \frac{T_H}{T_H - T_C}$$

or

$$\text{c.o.p.}_{COOLING,IDEAL} = \frac{T_C}{T_H - T_C}$$

which no heat pump's coefficient of performance can exceed.