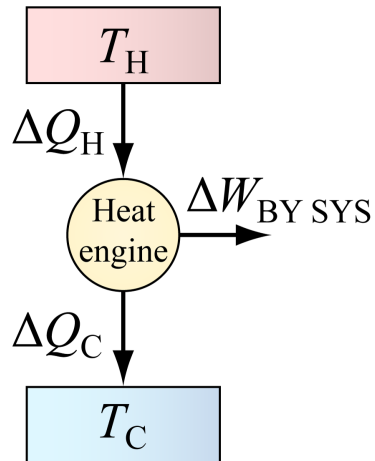


Heat engines and heat pumps (for SAT Subject Test in Physics)

Heat engines



$$\Delta U_{\text{SYS}} = \Delta Q_{\text{OUTSIDE INTO SYS}} + \Delta W_{\text{OUTSIDE ON SYS}}$$

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

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

$$0 = (\Delta Q_{\text{H}} - \Delta Q_{\text{C}}) - \Delta W_{\text{BY SYS}}$$

$$\Delta Q_{\text{H}} = \Delta Q_{\text{C}} + \Delta W_{\text{BY SYS}}$$

$$e := \frac{\Delta W_{\text{BY SYS}}}{\Delta Q_{\text{H}}} = \frac{\Delta Q_{\text{H}} - \Delta Q_{\text{C}}}{\Delta Q_{\text{H}}} = 1 - \frac{\Delta Q_{\text{C}}}{\Delta Q_{\text{H}}}$$

Ideality

Device returns to same state at end of each cycle:

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

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

$$\Delta S_{\text{SYS}} = \frac{\Delta Q_{\text{REV, INTO SYS}}}{T}$$

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

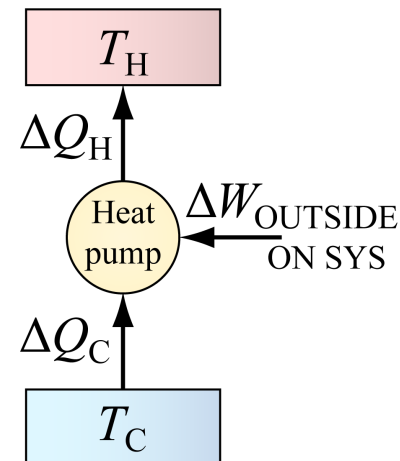
Ideal heat engines

A Carnot heat engine has efficiency

$$e_{\text{IDEAL}} = 1 - \frac{T_{\text{C}}}{T_{\text{H}}}$$

which no heat engine can exceed.

Heat pumps



$$\Delta U_{\text{SYS}} = \Delta Q_{\text{OUTSIDE INTO SYS}} + \Delta W_{\text{OUTSIDE ON SYS}}$$

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

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

$$0 = (\Delta Q_{\text{C}} - \Delta Q_{\text{H}}) + \Delta W_{\text{OUTSIDE ON SYS}}$$

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

$$\Delta S_{\text{SYS,H}} = \frac{\Delta Q_{\text{H}}}{T_{\text{H}}}$$

and

$$\Delta S_{\text{SYS,C}} = \frac{(-\Delta Q_{\text{C}})}{T_{\text{C}}}$$

Thus,

$$\Delta S = \frac{\Delta Q_{\text{H}}}{T_{\text{H}}} - \frac{\Delta Q_{\text{C}}}{T_{\text{C}}} = 0$$

This condition is achieved by a Carnot cycle.

Ideal heat pumps

A Carnot heat pump has coefficient of performance

$$\text{c. o. p. HEATING, IDEAL} = \frac{T_{\text{H}}}{T_{\text{H}} - T_{\text{C}}}$$

or

$$\text{c. o. p. COOLING, IDEAL} = \frac{T_{\text{C}}}{T_{\text{H}} - T_{\text{C}}}$$

which no heat pump can exceed.