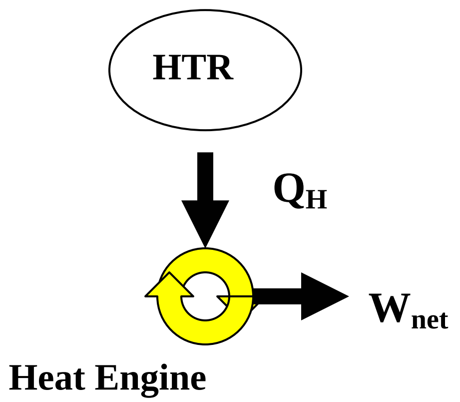
HEAT ENGINES

Two diagrams show the difference between a heat engine (device to produce heat from work) that satisfies the 1st Law BUT DOES NOT satisfy the 2nd Law (a) and one that satisfieS both the 1st and 2nd Laws (b)

(a)



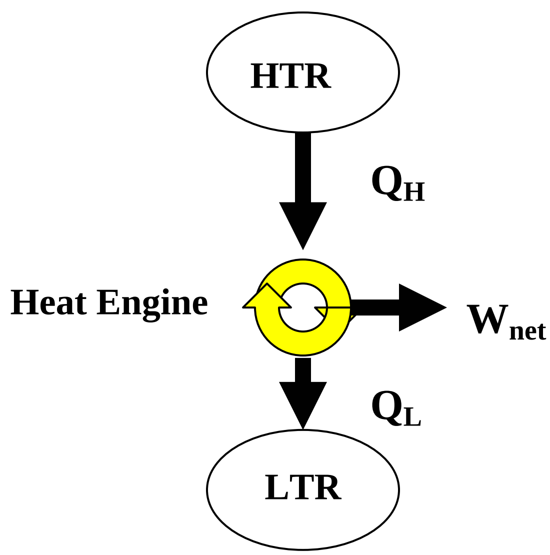
✓ **Satisfies 1st Law:**

$\mathbf{Q_{in} = W_{net}}$

η = 1 (by <u>only</u> 1st Law)

✗ **Violates Kelvin-Planck statement of 2nd Law.**

(b)



✓ **Satisfies 1st Law**

$\mathbf{W_{net} = Q_H - Q_L}$

✓ **Satisfies 2nd Law since heat is rejected to LTR: $Q_L > 0$**

$\boldsymbol{\eta = 1 - (Q_L/Q_H)}$

Equivalent formulas for efficiency of a heat engine

$$\eta = \frac{W_{net}}{Q_{net}} = \frac{w_{net}}{q_H} = \frac{\dot{W}_{net}}{\dot{Q}_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{q_L}{q_H} = 1 - \frac{\dot{Q}_L}{\dot{Q}_H}$$

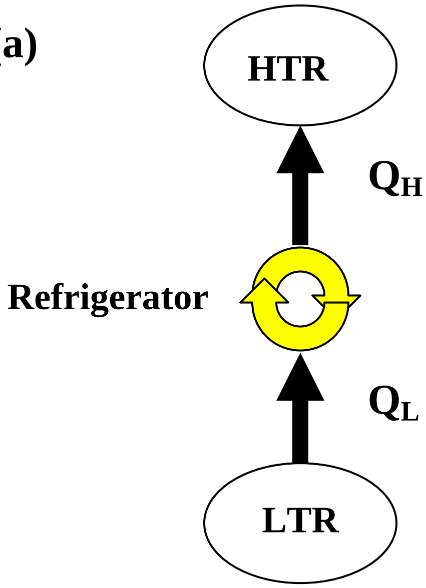
<u>Solving heat engine efficiency problems:</u>

1. given η, find W_{net} or Q_H, by finding either W or Q from the 1st Law and use efficiency formula to find the unknown (W or Q).
2. given W find Q, or given Q find W from 1st Law and use formula to calculate η

REFRIGERATORS

Two diagrams show the difference between a heat engine (device to produce heat from work) that satisfies the 1st Law BUT DOES NOT satisfy the 2nd Law (a) and one that satisfieS both the 1st and 2nd Laws (b)

(a)



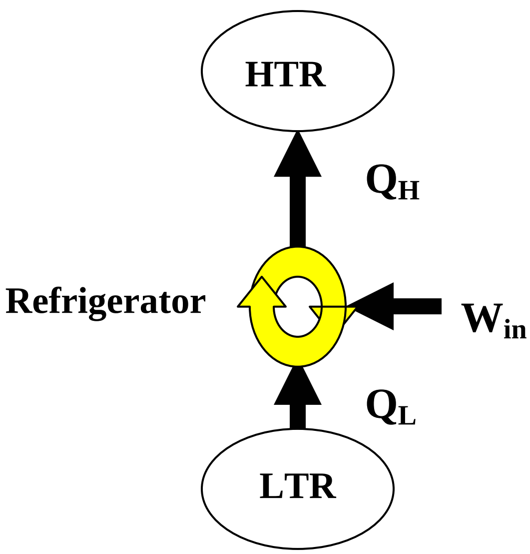
✓ **Satisfies 1st Law:**

$Q_H = Q_L$

COP_R undefined (div 0)

✘ **Violates Clausius' statement of 2nd Law.**

(b)



✓ **Satisfies 1st Law:**

$W_{in} = Q_L - Q_H$

$COP_R = Q_L/W_{in}$

✓ **Satisfies 2nd Law since work input, $W_{in} > 0$**

***Heat pump is same as refrigerator EXCEPT**

$COP_{HP} = Q_H/W_{in}$

Equivalent formulas for COP_R and COP_{HP}

REFRIGERATOR

$$COP_R = \frac{Q_L}{W_{in}} = \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{q_L}{w_{in}} = \frac{1}{\left(\frac{Q_H}{Q_L} - 1\right)} = \frac{1}{\left(\frac{\dot{Q}_H}{\dot{Q}_L} - 1\right)} = \frac{1}{\left(\frac{q_H}{q_L} - 1\right)}$$

HEAT PUMP

$$COP_{HP} = \frac{Q_H}{W_{in}} = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{q_H}{w_{in}} = \frac{1}{\left(1 - \frac{Q_L}{Q_H}\right)} = \frac{1}{\left(1 - \frac{\dot{Q}_L}{\dot{Q}_H}\right)} = \frac{1}{\left(1 - \frac{q_L}{q_H}\right)}$$

NOTE THAT:
Coefficient of Performance values are generally > 1

Also, it can be shown that:

$$\mathbf{COP_{HP} = COP_R + 1}$$

Since $COP_R + 1 = \left(\frac{Q_L}{Q_H - Q_L}\right) + 1 = \frac{Q_H}{Q_H - Q_L} = COP_{HP}$

AND $|Q_L| < |Q_H|$

Since $W_{in} = Q_L - Q_H$ (1^{st} law) and W_{in} is negative, then $(Q_L – Q_H)$ must be negative.

Solving refrigeration and heat pump COP problems:

1. Given COP, find W, or Q_L/Q_H using 1^{st} Law, and use COP formula to find second (unknown) Q_L/Q_H or W.
2. Given W or Q_L/Q_H, find unknown W or Q_L/Q_H from 1^{st} Law and calculate COP.