ESO201A : THERMODYNAMICS
2021-22 Ist semester
IIT Kanpur

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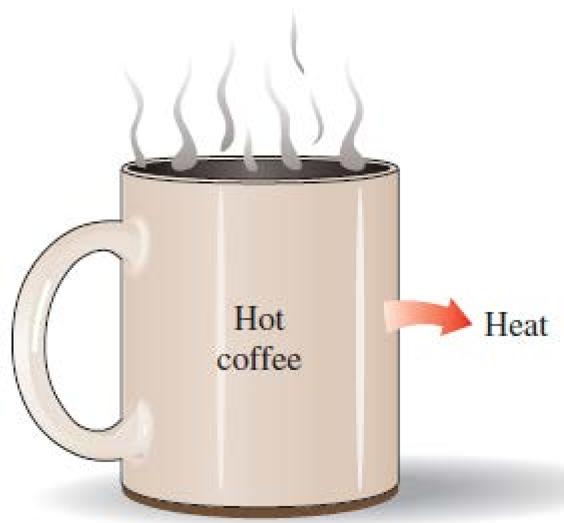
Lecture 13

Introduction to Second law of thermodynamics :

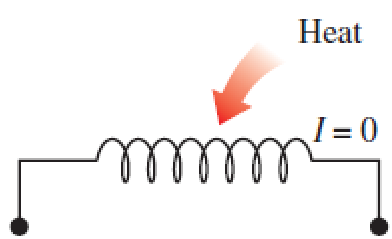
It is observed that processes occur only in a certain direction

Processes occur in a certain direction, and not in the reverse direction.

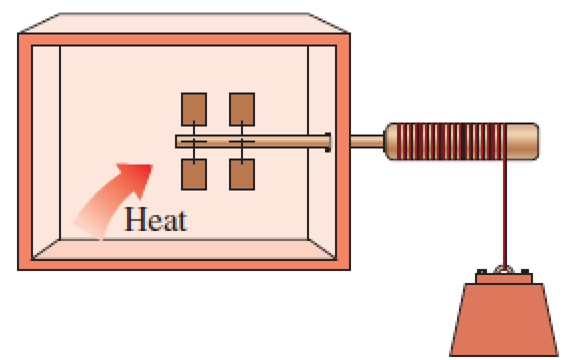
Examples :



A cup of hot coffee does not get hotter in a cooler room.



Transferring heat to a wire will not generate electricity.



Transferring heat to a paddle wheel will not cause it to rotate.

Ref. Cengel and Boles, 8th Edition (2015)

Introduction to Second law of thermodynamics :

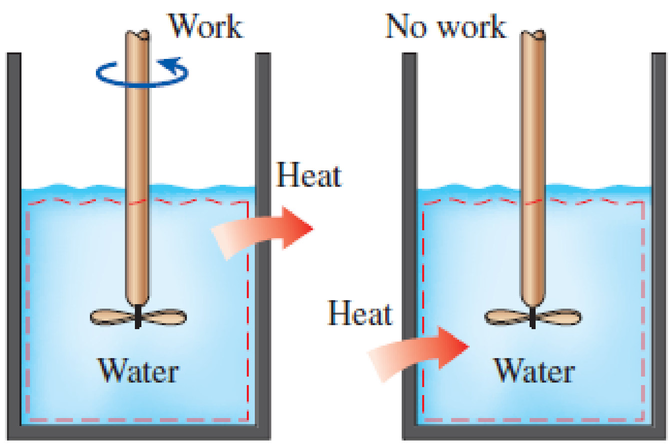
In reversing of the processes (see last slide) first law is not violated.

Still these processes are never observed to occur in reverse direction !

This suggests that there exists a general principle of nature which governs the direction of a process

This principle is called “Second law of thermodynamics”.

Heat engines :



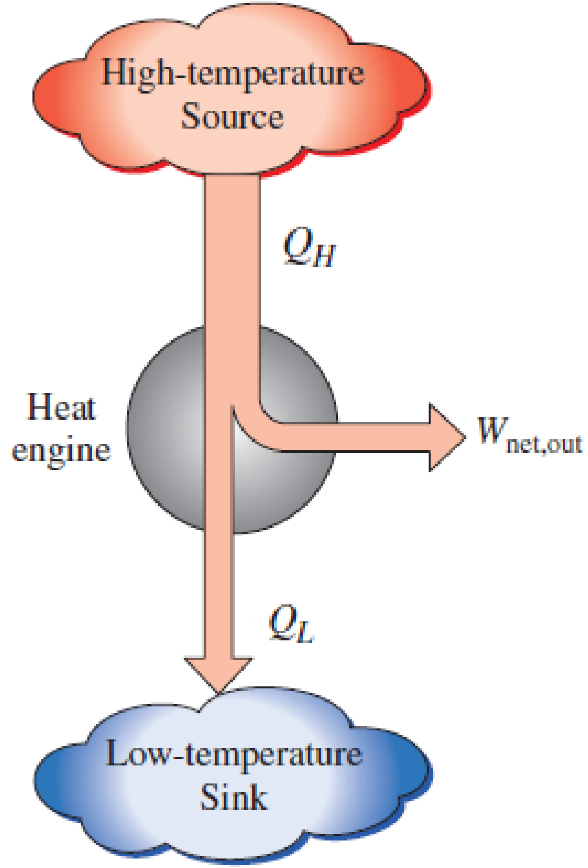
Ref. Cengel and Boles, 8th Edition (2015)

As can be seen in the above example, work can be converted into heat directly and completely, but the reverse is not true

Converting heat into work requires special devices known as “**Heat engines**”

Heat engine employs a “working fluid” which undergoes a cyclic process

Heat engines :

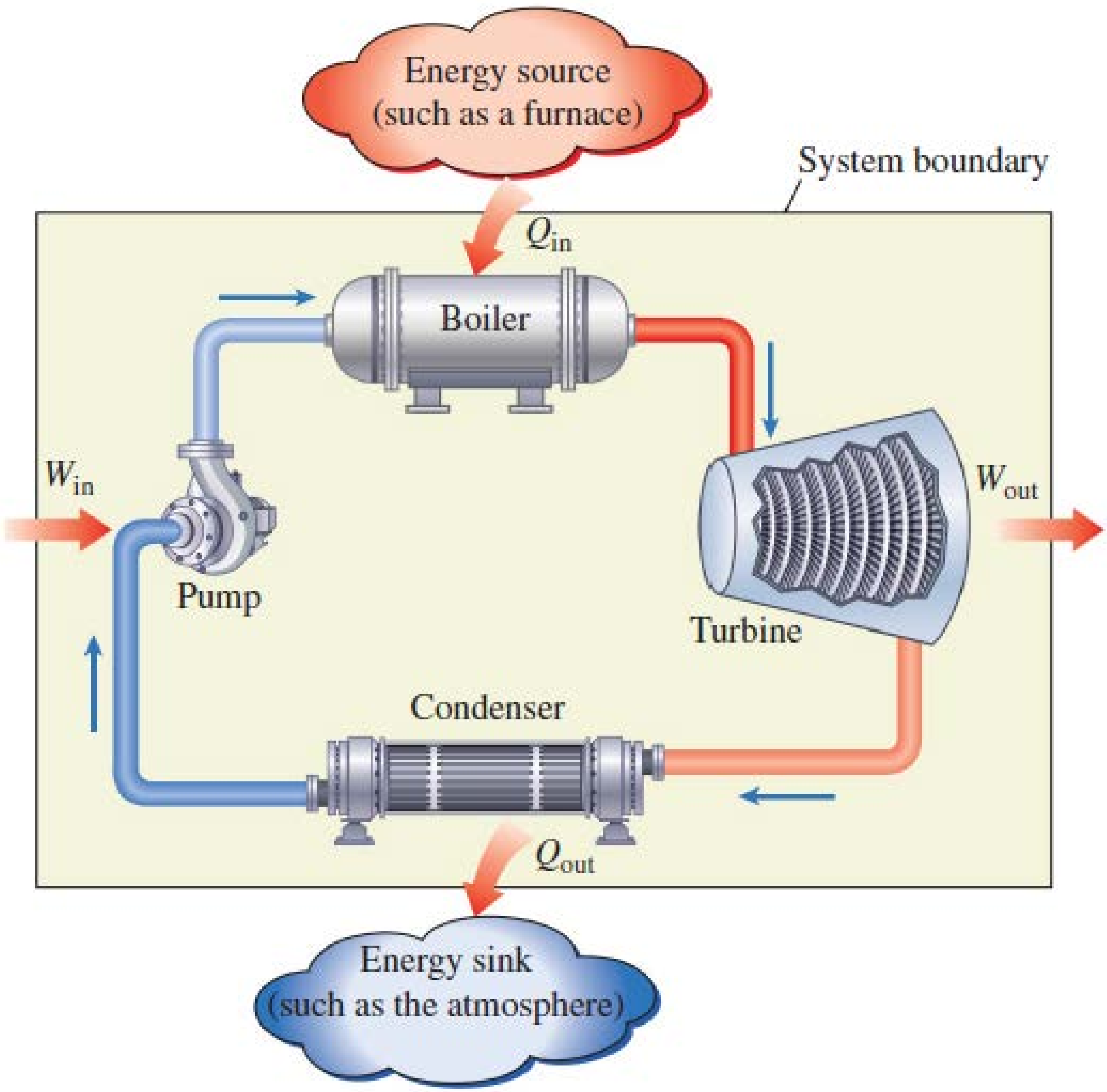


1. They receive heat from a high-temperature source (solar energy, oil furnace, nuclear reactor, etc.).
2. They convert part of this heat to work (usually in the form of a rotating shaft).
3. They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.).
4. They operate on a cycle.

Ref. Cengel and Boles, 8th Edition (2015)

Example :

Steam power plant

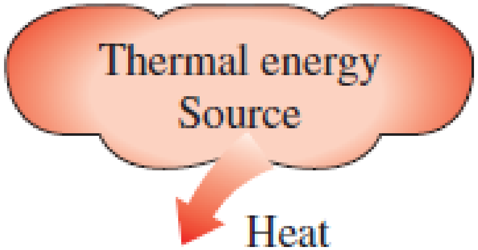


Ref. Cengel and Boles, 8th Edition (2015)

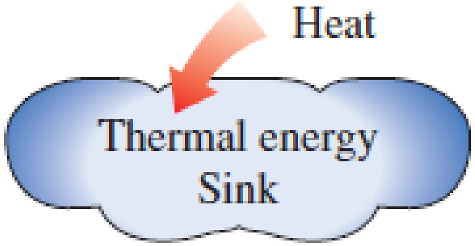
Thermal energy reservoirs :

These are large bodies which absorb or lose heat with negligible changes in temperature. Thus the temperature of thermal energy reserviors can be taken as constant during heat transfer with other systems. Examples : Atmospheric Air, rivers, lakes

Thermal energy reservoir that supplies energy in the form of heat is called as a "source"



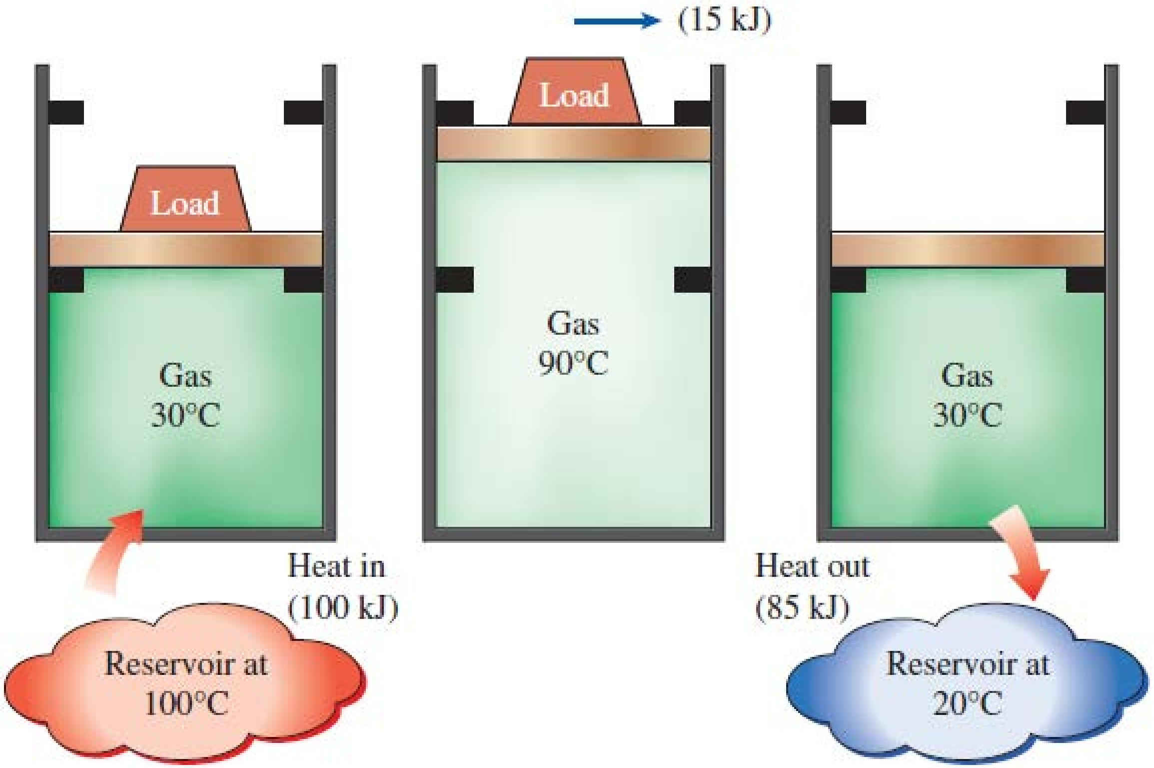
Thermal energy reservoir that absorbs energy in the form of heat is called as "sink"



Ref. Cengel and Boles, 8th Edition (2015)

Cyclic processes :

State of the gas
is characterized by
internal energy
and volume



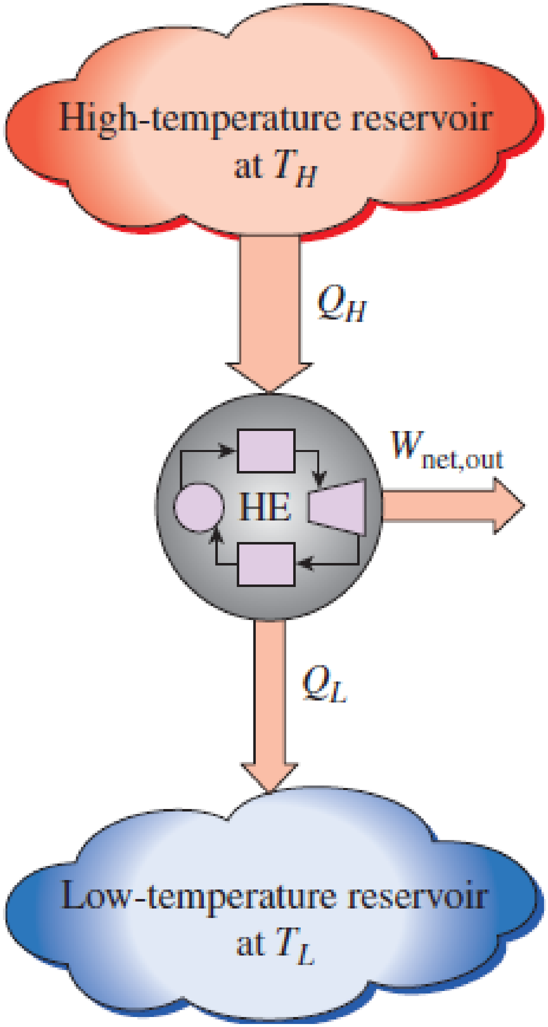
Step 1: Gas is heated by contacting with a high temperature reservoir. Some work is done in lifting the weight (U1 , V1) → (U1+85, V2)

Step 2: Load is removed and gas is returned to the original state by contacting with a low temperature reservoir (U1+85, V2) → (U1, V1)

Rejection of heat to low temperature reservoir is necessary to complete the cycle by returning the working fluid to original state

Ref. Cengel and Boles, 8th Edition (2015)

Thermal efficiency of heat engine :



$$W_{net,out} = Q_H - Q_L$$

It is not possible to have Q_L = 0

Some heat must be rejected !!

Thermal efficiency of a heat engine is

$$\eta_{th} = \frac{W_{net,out}}{Q_H} \quad \text{or} \quad \eta_{th} = 1 - \frac{Q_L}{Q_H}$$

Q_H = magnitude of heat transfer between the cyclic device and the high-temperature medium at temperature T_H

Q_L = magnitude of heat transfer between the cyclic device and the low-temperature medium at temperature T_L

Ref. Cengel and Boles, 8th Edition (2015)

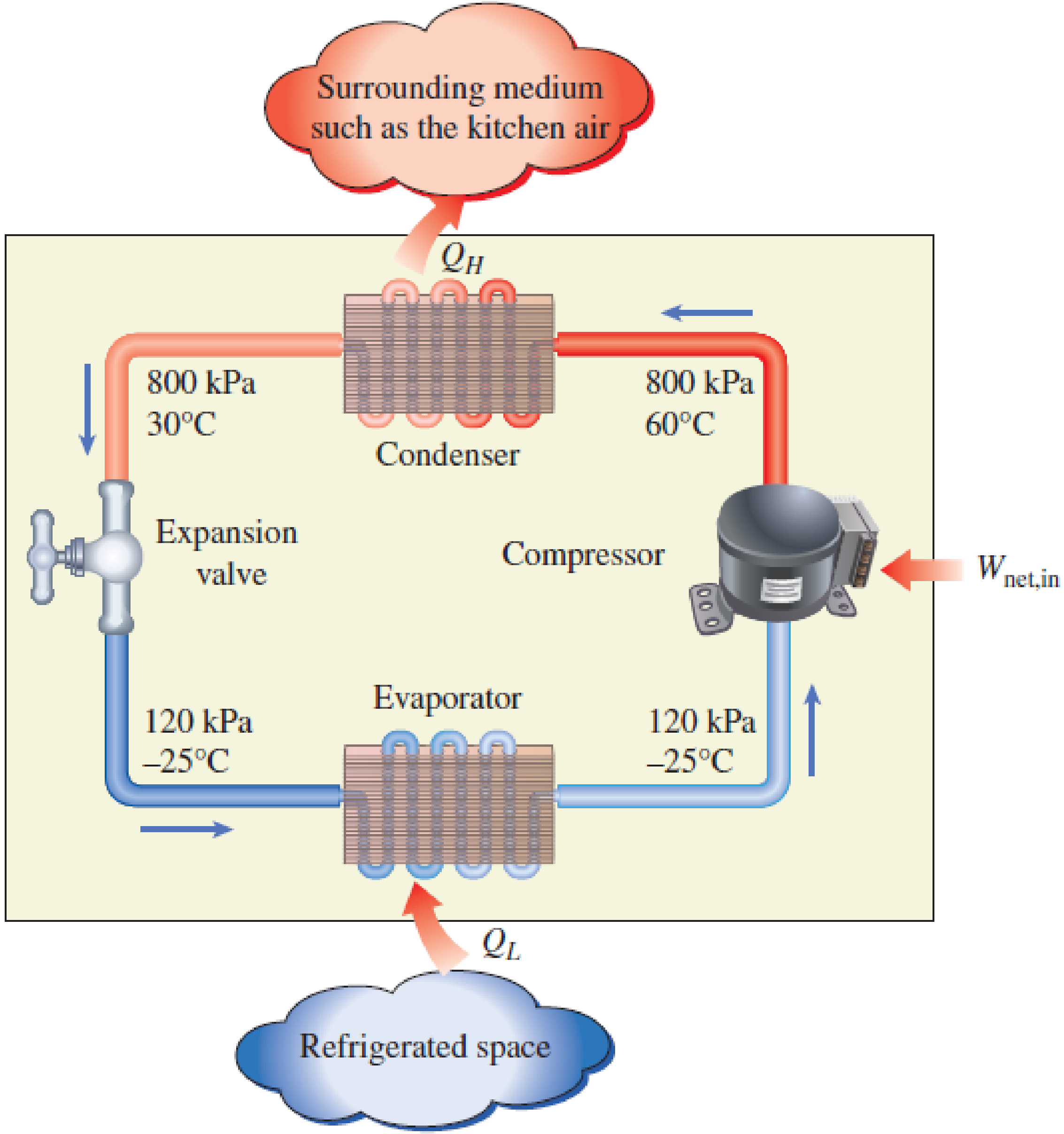
Kelvin—Planck statement (Second law of thermodynamics):

It is impossible for any device that operates on a cycle to absorb heat from a single reservoir and produce a net amount of work

$$\Downarrow$$

This is consistent with our experience that ‘random’ energy transfer in the form of heat cannot be completely converted into ‘directed’ energy transfer in the form of work.

Refrigerators :



Vapor compression refrigeration cycle and typical operating conditions

Ref. Cengel and Boles, 8th Edition (2015)

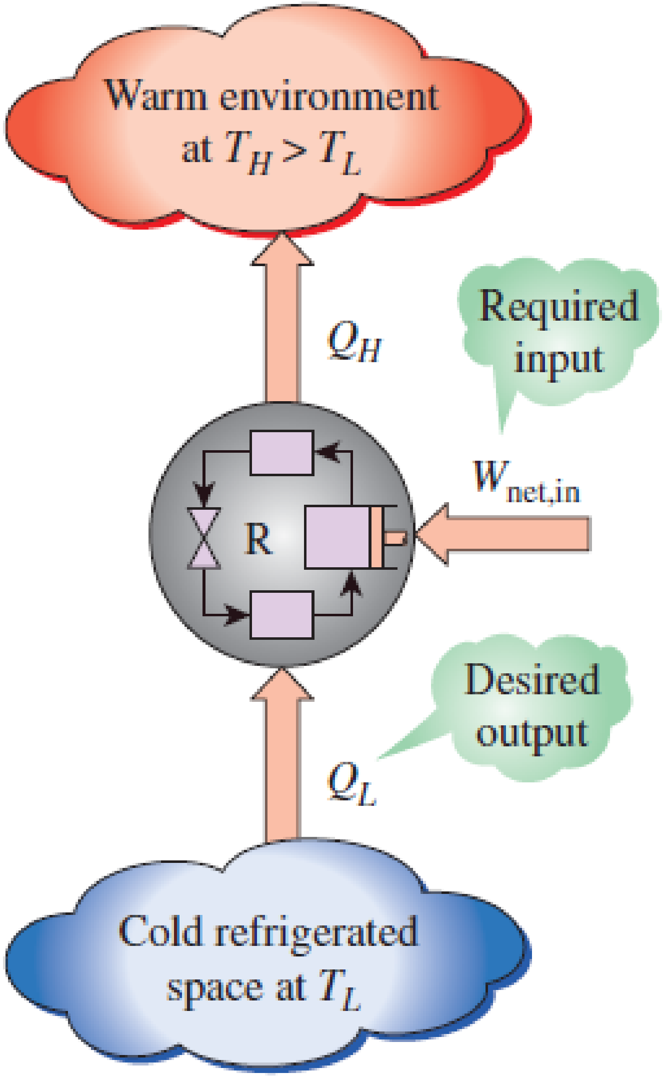
Refrigerators :

Coefficient of performance (COP_R)

$$\mathrm{COP_R} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{\mathrm{net,in}}}$$

$$W_{\mathrm{net,in}} = Q_H - Q_L$$

$$\mathrm{COP_R} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$



Ref. Cengel and Boles, 8th Edition (2015)

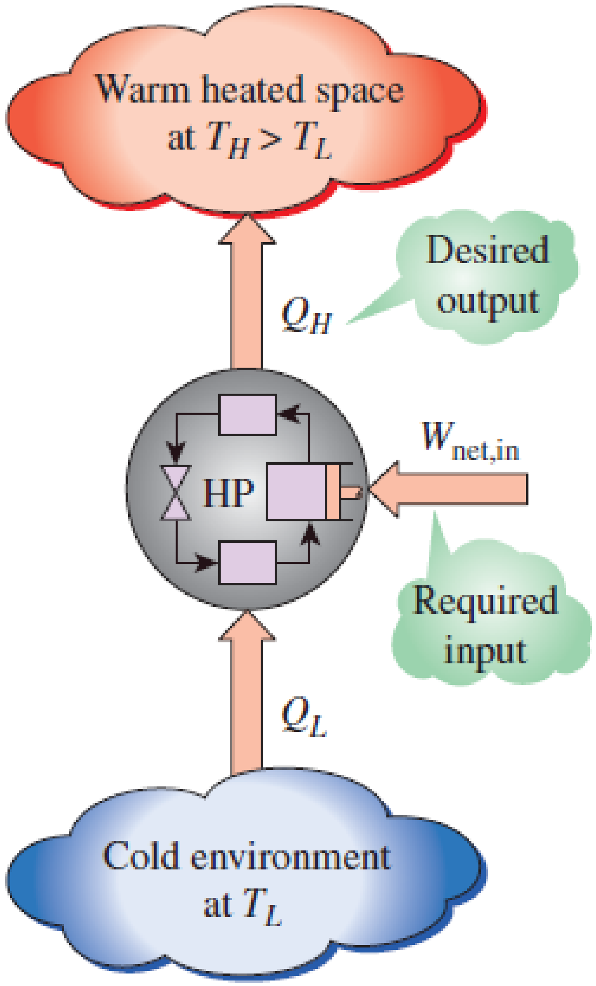
Heat pumps :

Coefficient of performance (COP_{HP})

$$\text{COP}_{\text{HP}} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_H}{W_{\text{net,in}}}$$

$$W_{\text{net,in}} = Q_H - Q_L$$

$$\text{COP}_{\text{HP}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - Q_L/Q_H}$$



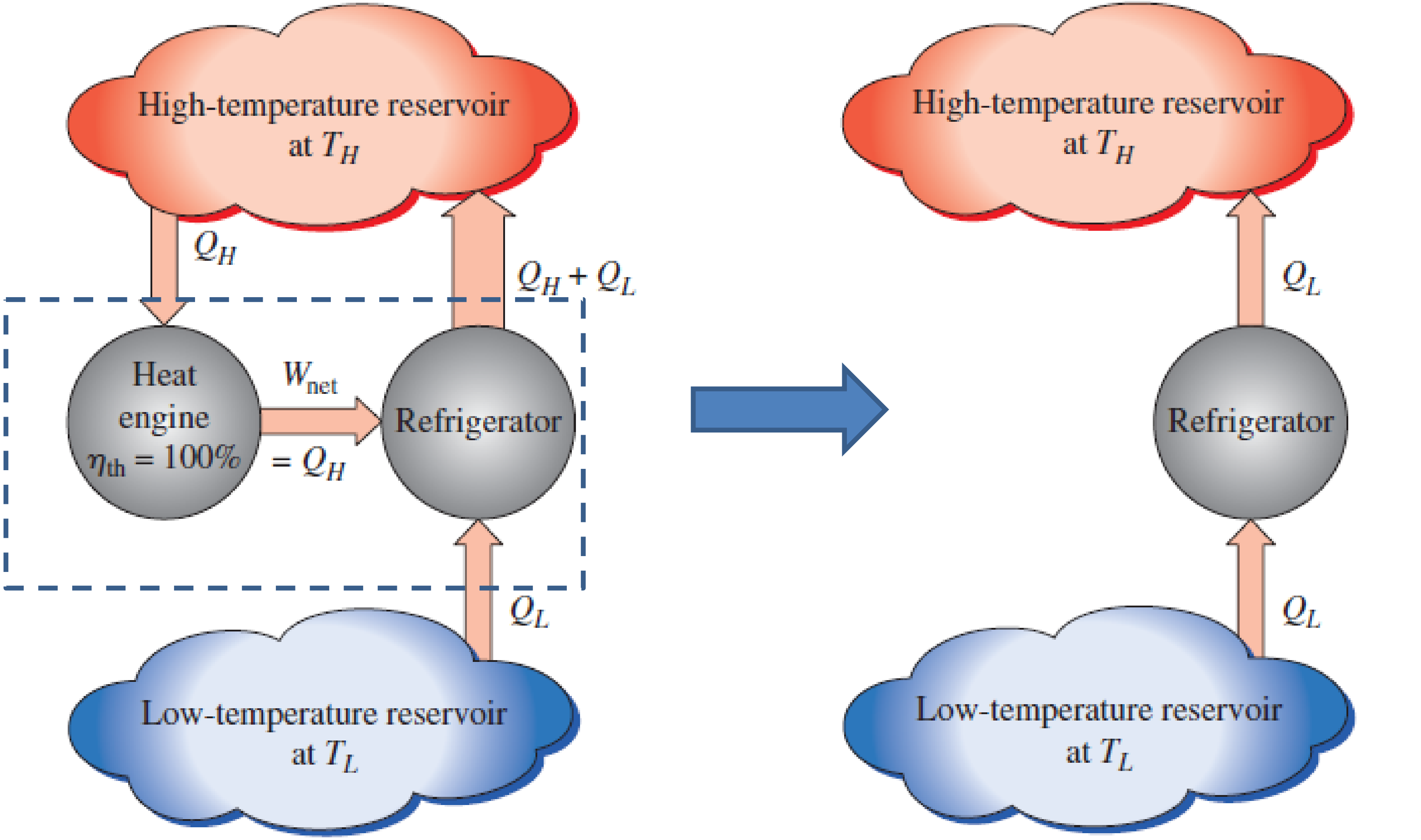
Ref. Cengel and Boles, 8th Edition (2015)

Clausius statement (Second law of thermodynamics) :

It is impossible to construct a device that operates on a cycle and produces no effect other than the transfer of heat from a low temperature body to a higher temperature body.

This is consistent with our experience that energy transfer in the form of heat does not occur from a low temperature body to a high temperature body.

Equivalence of Kelvin-Planck and Clausius statements :



(a) A refrigerator that is powered by a 100 percent efficient heat engine

(b) The equivalent refrigerator

Heat engine in (a) violates Kelvin-Planck statement. In (a) we use a refrigerator that takes in the work output of heat engine. The combined equipment inside the dashed box in (a) is equivalent to a refrigerator as shown in (b). This refrigerator in (b) violates Clausius statement.

Ref. Cengel and Boles, 8th Edition (2015)

Equivalence of Kelvin-Planck and Clausius statements :

The last slide shows that **violation of Kelvin-Planck statement leads to violation of Clausius statement.**

Similarly, it can be shown that **violation of Clausius statement leads to violation of Kelvin-Planck statement.**

Hence the two statements are **equivalent.** Both of these statements are different ways of expressing the same general principle in nature which is **"Second law of thermodynamics".**