UTM
UNIVERSITI TEKNOLOGI MALAYSIA
OPENCOURSEWARE

Thermodynamics I
Chapter 5
Second Law of Thermodynamics

Mohsin Mohd Sies

Fakulti Kejuruteraan Mekanikal, Universiti Teknologi Malaysia

Second Law of Thermodynamics (Motivation)

Energy has quality apart from quantity. This results in a preferred direction of processes.

This preferred direction is described by the 2^{nd} Law.

The 2^{nd} Law can be understood by practical insights into the workings of heat engines.

2nd LAW of THERMODYNAMICS

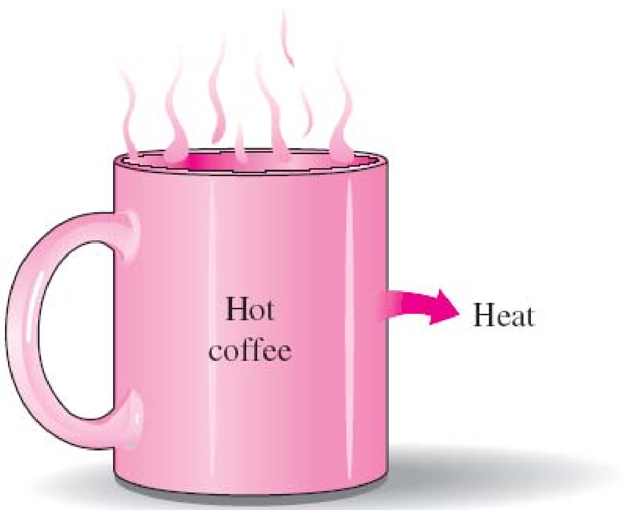
1st Law – Energy Conservation
- amount, quantity

2nd Law – Direction of process
- quality

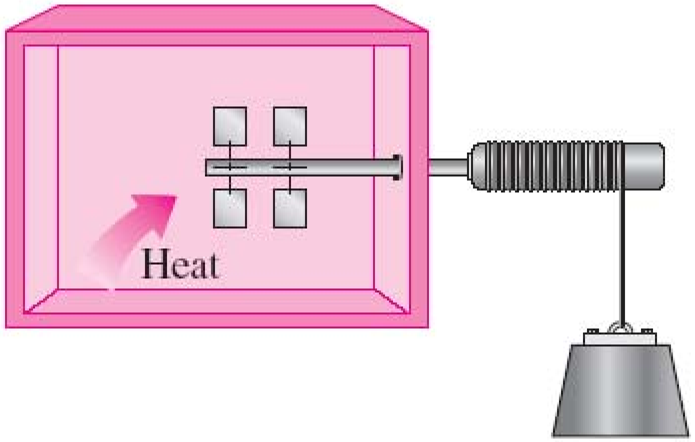
For a process to occur, 1st and 2nd Laws must be obeyed

Work – High quality energy (100% work can turn into heat)
Heat – Low quality energy (not 100% heat can turn into work)

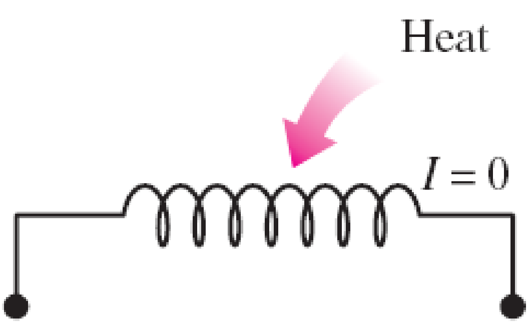
Observations



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



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



Transferring heat to a wire will not generate electricity.

These processes cannot occur even though they are not in violation of the first law.

MAJOR USES OF THE SECOND LAW

1. The second law may be used to identify the direction of processes.
2. The second law also asserts that energy has *quality* as well as quantity. The first law is concerned with the quantity of energy and the transformations of energy from one form to another with no regard to its quality. The second law provides the necessary means to determine the quality as well as the degree of degradation of energy during a process.
3. The second law of thermodynamics is also used in determining the *theoretical limits* for the performance of commonly used engineering systems, such as heat engines and refrigerators, as well as predicting the *degree of completion* of chemical reactions.

Heat Reservoir

A body which can receive/reject heat without resulting in temperature change

Source - reservoir supplies heat (heat leaves reservoir)

Sink - reservoir receives heat (heat enters reservoir)

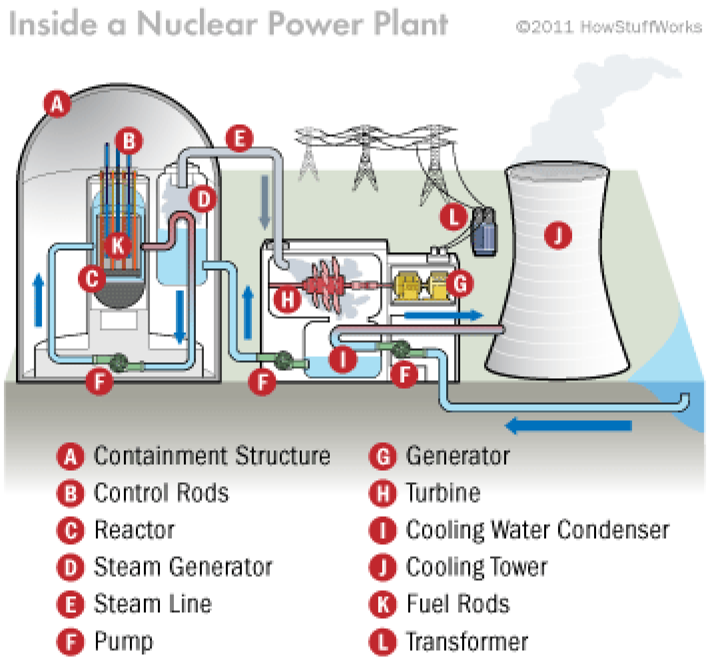
Heat Engine

A device that converts *heat* into *work*

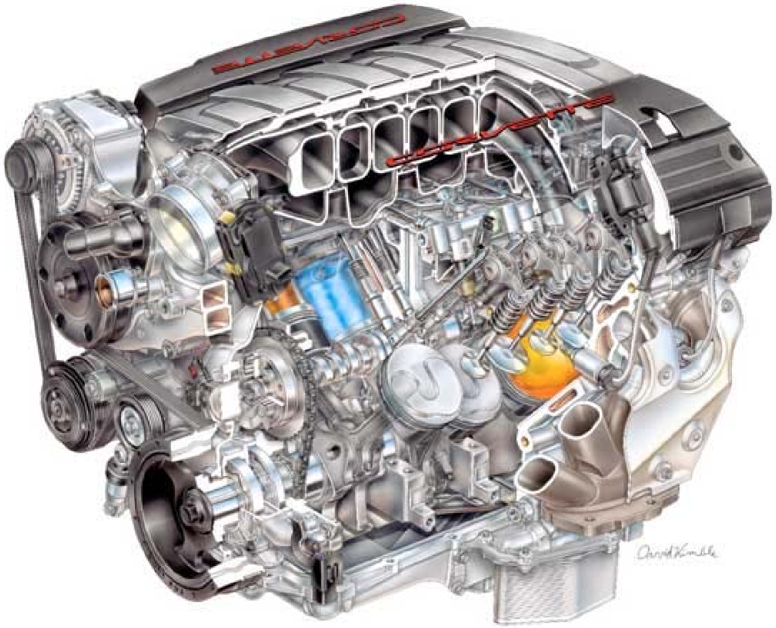
Characteristics

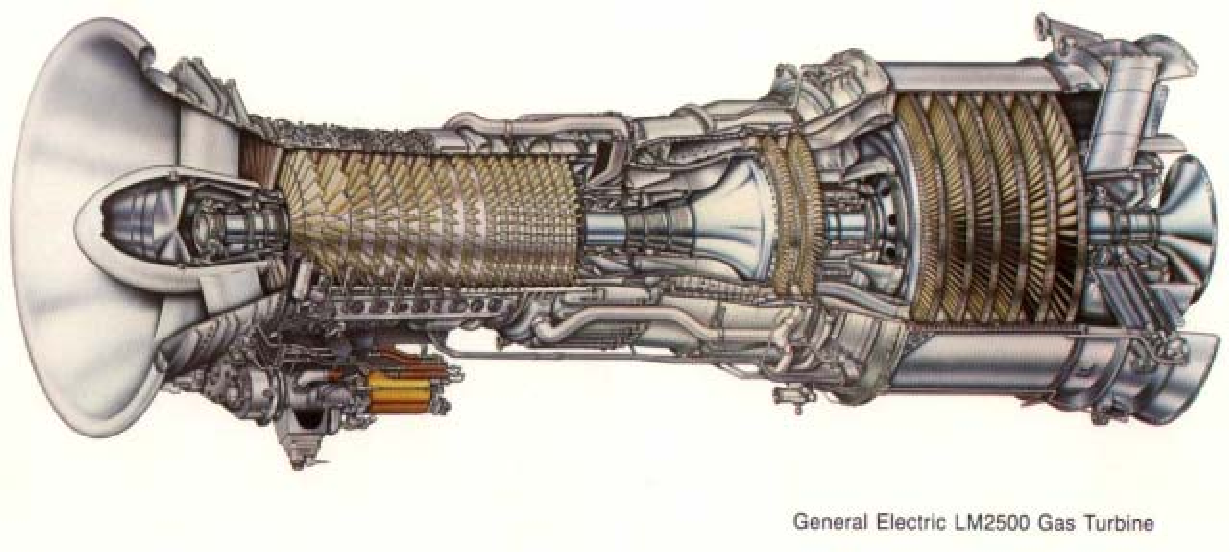
- Receives heat from a heat source at high temperature, T_H
- Only part of the heat is converted into work
- The rest is rejected to another heat sink at low temperature, T_L
- Engine works in a cycle (continuously)

Examples of Heat Engines

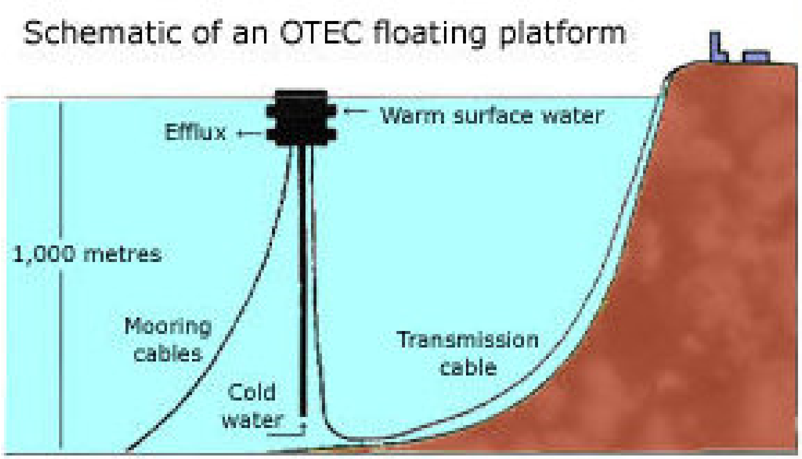


Examples of Heat Engines

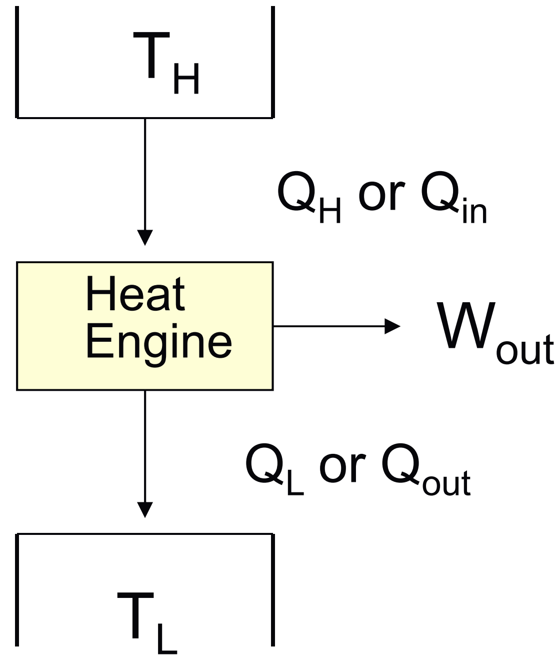




Examples of Heat Engines



High Temperature Heat Source



Low Temperature Heat Sink

$$Thermal\ Efficiency = \eta = \frac{Net\ Work\ Output}{Heat\ Supplied} = \frac{W_{out,net}}{Q_{\text{in}}}$$

$$\text{Efficiency} \equiv \frac{\text{Purpose Achieved}}{\text{Effort Supplied}}$$

2 factors limit efficiency

- Irreversibilities
- Side effect of heat transfer

Irreversibility

- Friction
- Electrical resistance
- Mixing of different substances
- Free expansion
- Non-isothermal heat transfer
- Etc.

Irreversible Process

Process where the above factors are present

Side Effect of Heat Transfer

Heat Transfer

- Expansion (Work Output)
- Temperature Increase (Energy Diverted)

If the diverted energy is not thrown away, engine temperature will finally reach heat source temperature, causing Q_H to stop (since no more delta_T), stopping the engine altogether.

Side Effect of Heat Transfer

- For the engine to keep operating
  - Need to cool the engine
  - Need to reject heat, Q_L.
- Rejected heat Q_L,
  - Cannot be recycled (Q_L at T_L cannot flow on its own to T_H to become heat source again)
- Efficiency will always be less than 100% (even if there's no friction and other irreversibilities)

Reversible Process

- After forward and reverse processes are done (system back to initial state), there is no change on the universe (system and surrounding)
- Reversible because there is no irreversibilities
- Internally reversible - irreversibilities assumed to exist only outside the system
- Externally reversible - irreversibilities assumed to exist only inside the system

2nd Law of Thermodynamics

Kelvin-Planck Statement (Heat Engine)

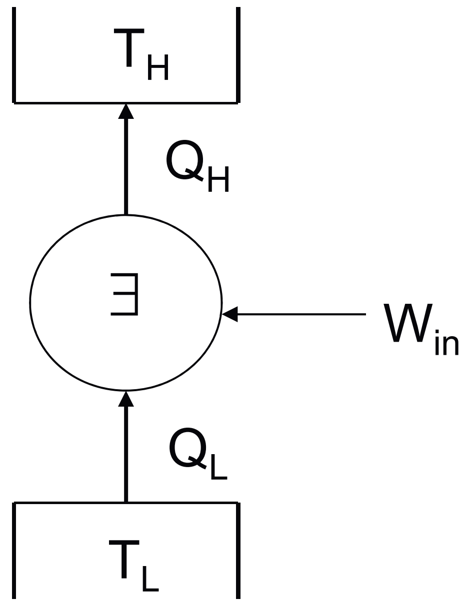
"It is impossible for a device that works in a cycle (continuously) to receive heat supply from one heat reservoir and produces the same amount of work"

Clausius Statement (Heat Pump)

"It is impossible to construct a device that works in a cycle which does not produce any other effect except the transfer of an amount of heat from a cold to a hot body"

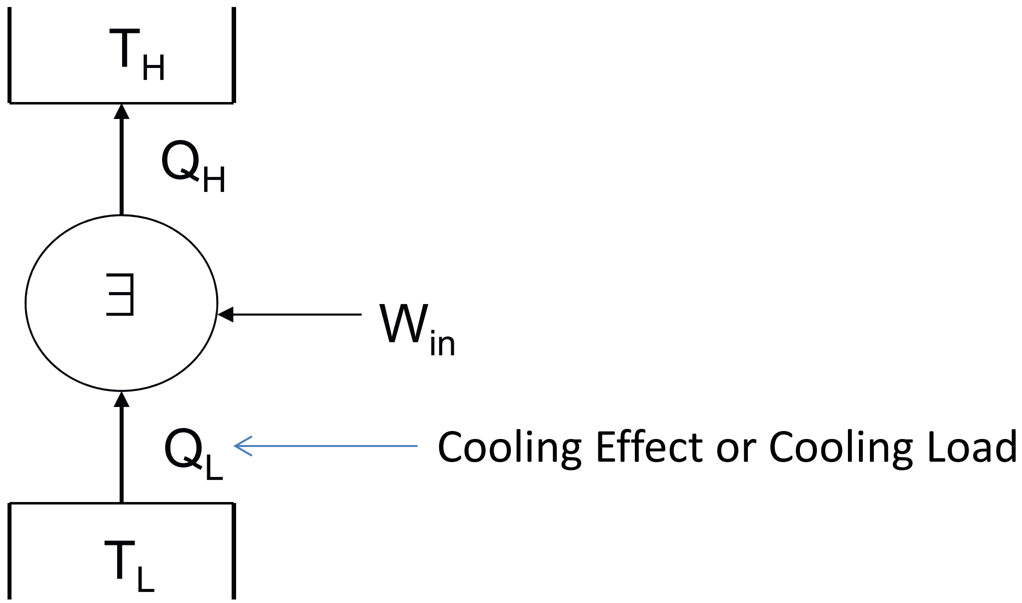
Refrigerator & Heat Pump (Reversed Heat Engine)

- To force heat at T_L to flow to T_H (work must be supplied)



Refrigerator

- To achieve cooling effect by taking away heat (Q_L) from cold space

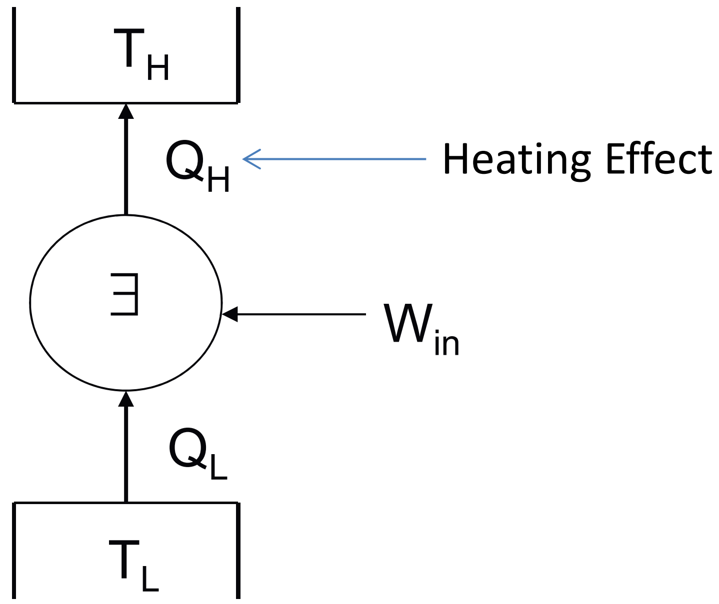


Coefficient of Performance for Refrigerators

$$COP_R = \frac{Q_L}{W_{in}}$$

Heat Pump

- To achieve heating effect by supplying heat (Q_H) to hot space using heat from cold surrounding



Coefficient of Performance for Heat Pumps

$$COP_{HP} = \frac{Q_H}{W_{in}}$$

Reversible vs Real Heat Engines

Reversible Heat Engine/Reversed H.E

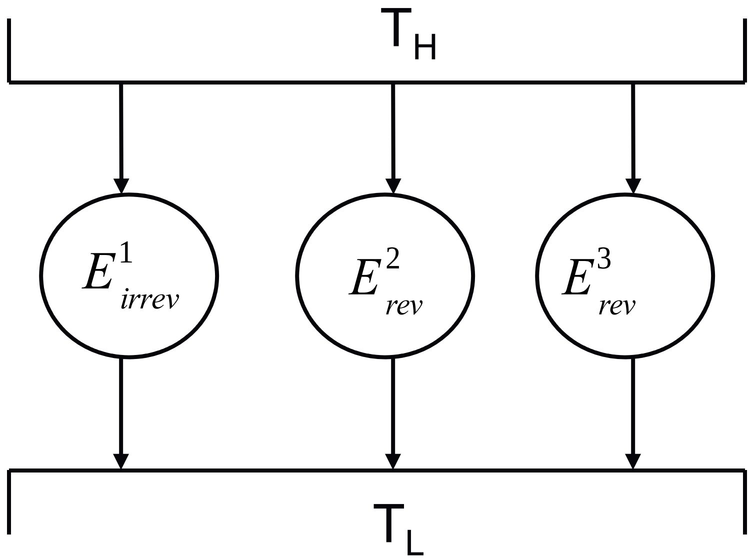
No irreversibilities in the engine (friction etc.)

All processes within the cycle are reversible processes (heat transfer done isothermally, etc.)

Real Heat Engine

- There exist irreversibilities (friction etc.)

Carnot Principles



3 heat engines between the same T_H, T_L

$(a)\quad \eta_{irrev} < \eta_{rev}$

$(b)\quad \eta_{rev,\,2} = \eta_{rev,\,3}$

$(c)\quad \eta_{rev} < 1$ (due to heat rejection requirement)

Thermodynamic Temperature Scale

- From Carnot Principle (b)

$$\eta_{rev} = f(T_H, T_L)$$

also $\eta_{rev} = 1 - \frac{Q_L}{Q_H}$

so $\frac{Q_L}{Q_H} = 1 - \eta_{rev} = 1 - f(T_H, T_L)$

$$\frac{Q_L}{Q_H} = g(T_H, T_L)$$

take $g(T_H, T_L) = \frac{T_L}{T_H}$

thus $\boxed{\left[\frac{Q_L}{Q_H}\right]_{rev} = \frac{T_L}{T_H}}$

Maximum Performance

General **Ideal/Max/Carnot/Reversible**

$$\frac{Q_H - Q_L}{Q_H} = \eta = \frac{T_H - T_L}{T_H}$$

$$\frac{Q_L}{Q_H - Q_L} = COP_R = \frac{T_L}{T_H - T_L}$$

$$\frac{Q_H}{Q_H - Q_L} = COP_{HP} = \frac{T_H}{T_H - T_L}$$

Same T_H, same T_L

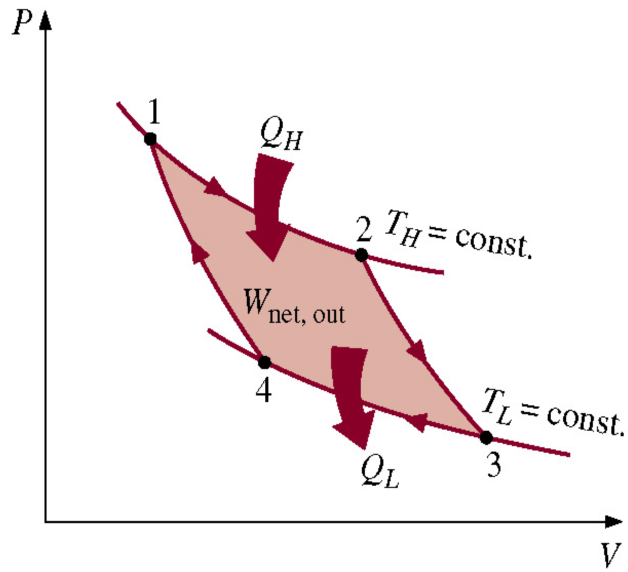
$$COP_{HP,\,rev} = COP_{R,\,rev} + 1$$

$$\eta, COP = \eta_{max}, COP_{max} \quad (\text{Ideal})$$

$$< \eta_{max}, COP_{max} \quad (\text{Real})$$

$$> \eta_{max}, COP_{max} \quad (\text{Impossible})$$

Carnot Cycle (Reversible Heat Engine)

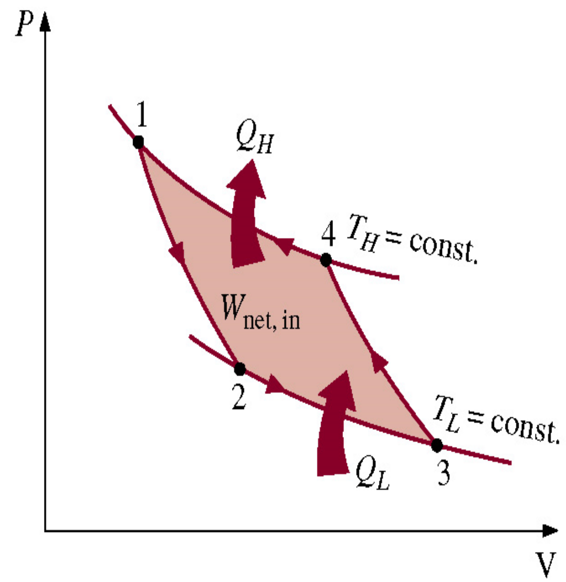


2 isothermal processes (heat transfers)
2 reversible adiabatic processes

$$\eta_{carnot} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

Reversed Carnot Cycle (for refrigerators/heat pumps)

- Same processes, but reversed direction



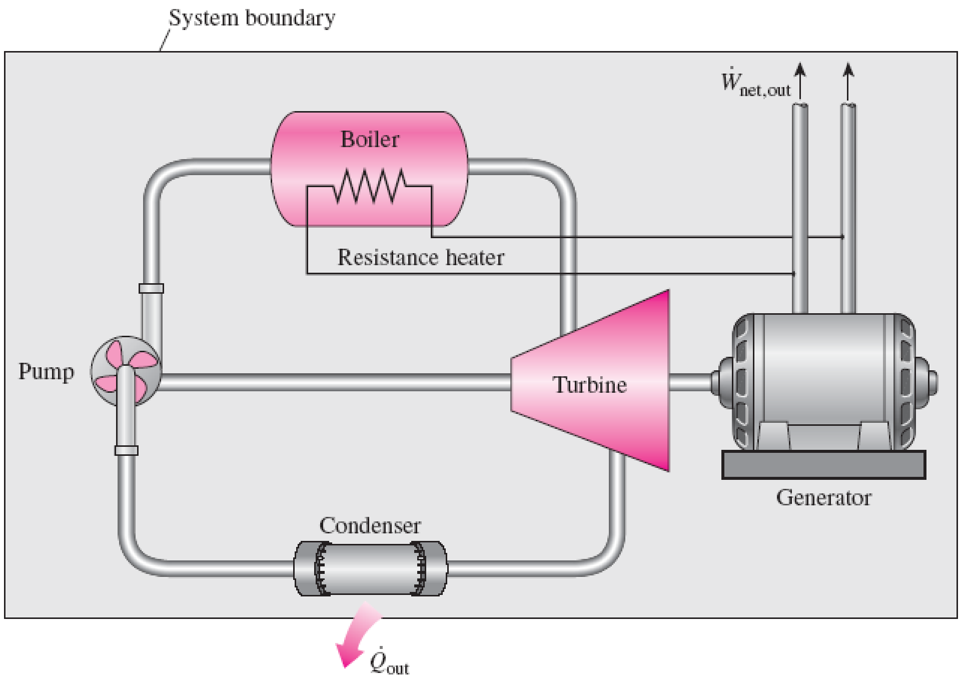
Refrigerators

$$COP_{R,rev} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

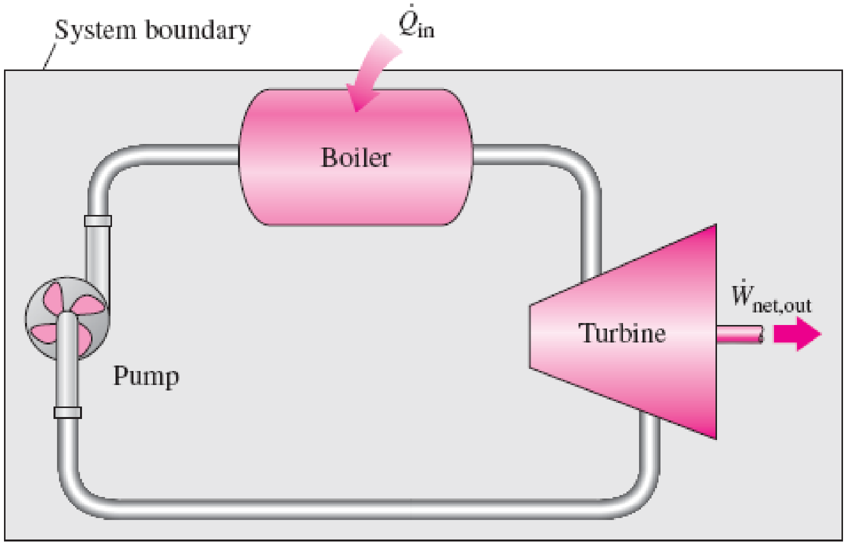
Heat Pumps

$$COP_{HP,rev} = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$

PERPETUAL-MOTION MACHINES



A perpetual-motion machine that violates the first law (PMM1).



A perpetual-motion machine that violates the second law of thermodynamics (PMM2).

Perpetual-motion machine: Any device that violates the first or the second law.

A device that violates the first law (by *creating* energy) is called a PMM1.

A device that violates the second law is called a PMM2.

Despite numerous attempts, no perpetual-motion machine is known to have worked. ***If something sounds too good to be true, it probably is***.

Terms

- Heat Reservoir
- Source
- Sink
- Heat Engine
- Irreversibility
- Thermal Efficiency
- Reversed Heat Engine
- Coefficient of Performance
- Carnot
- Kelvin-Planck, Clausius
- Heat Pump
- Refrigerator
- Perpetual Motion Machine