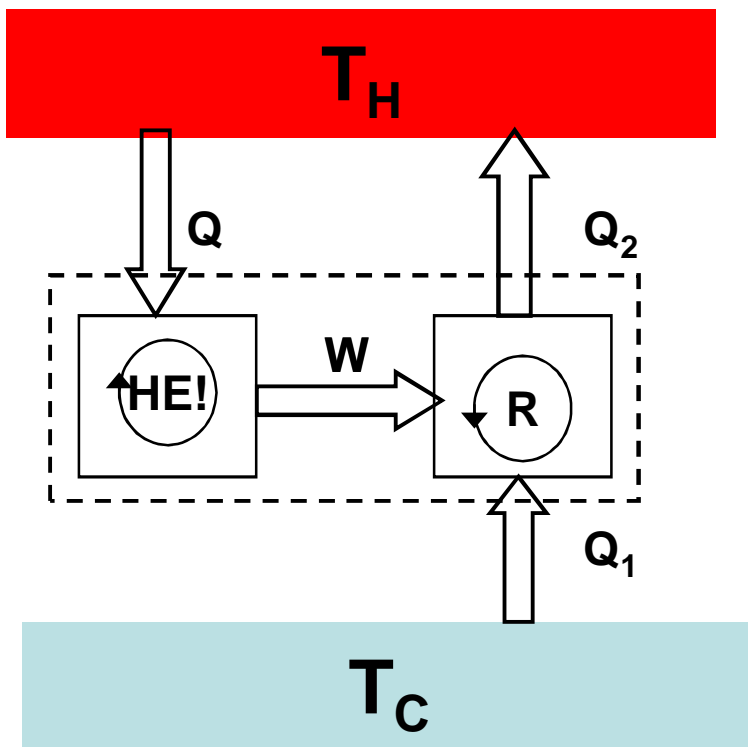


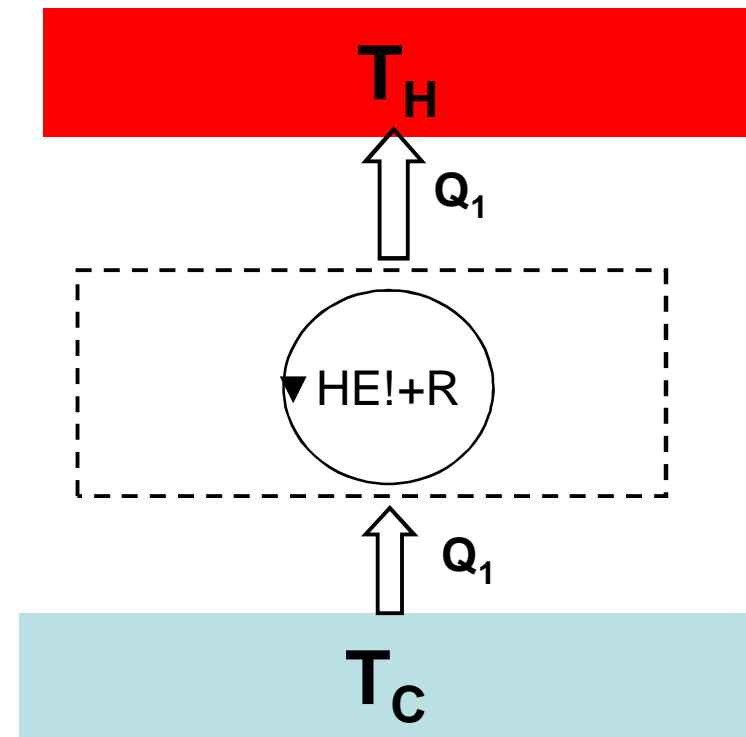
Equivalence of Kelvin-Planck and Clausius statements

- Violation of Clausius statement \rightarrow Violation of Kelvin-Planck statement
- Violation of Kelvin-Planck statement \rightarrow Violation of Clausius statement

Violation of KP \rightarrow Violation of Clausius

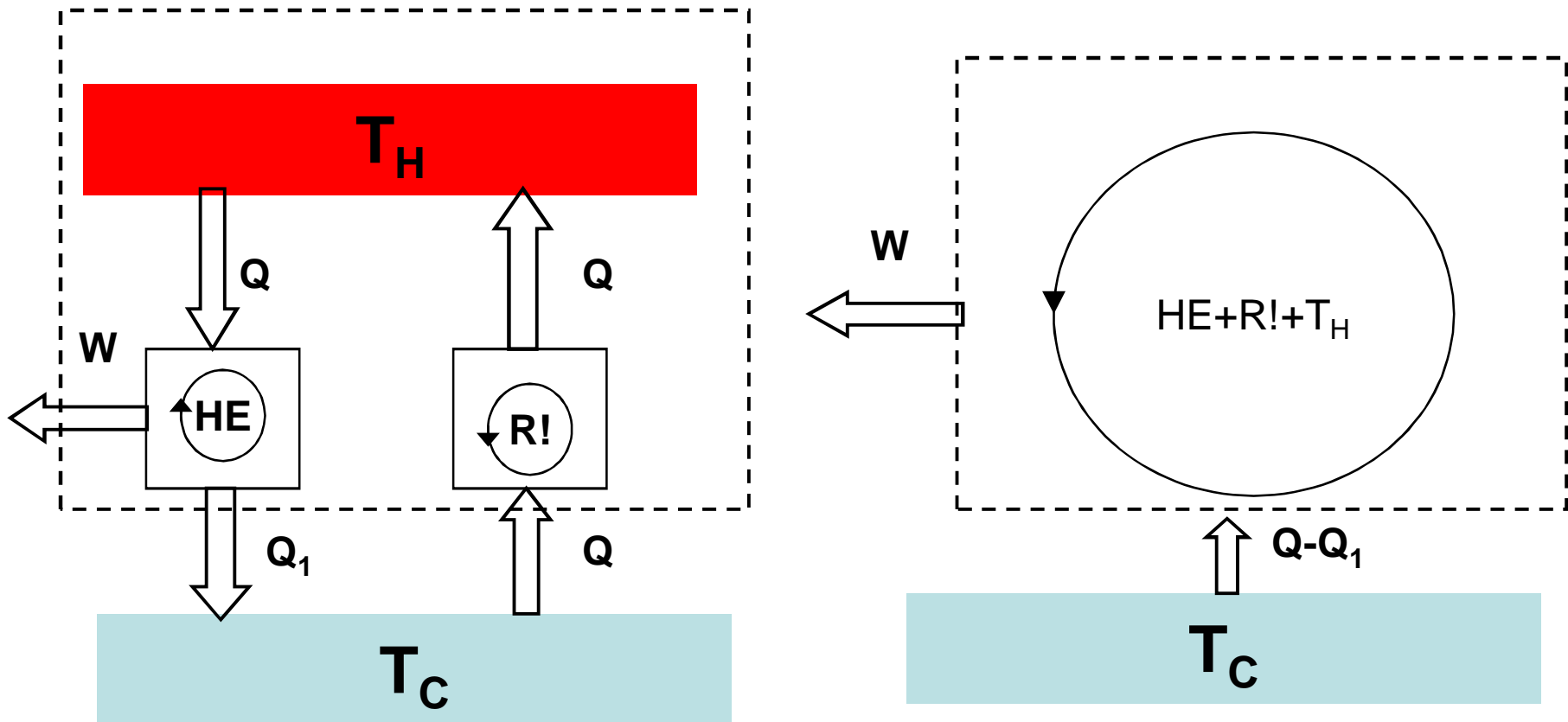


- $W=Q$ for HE!
- $Q_2=Q_1+W$ for R
- So, $Q_2-Q=Q_1$



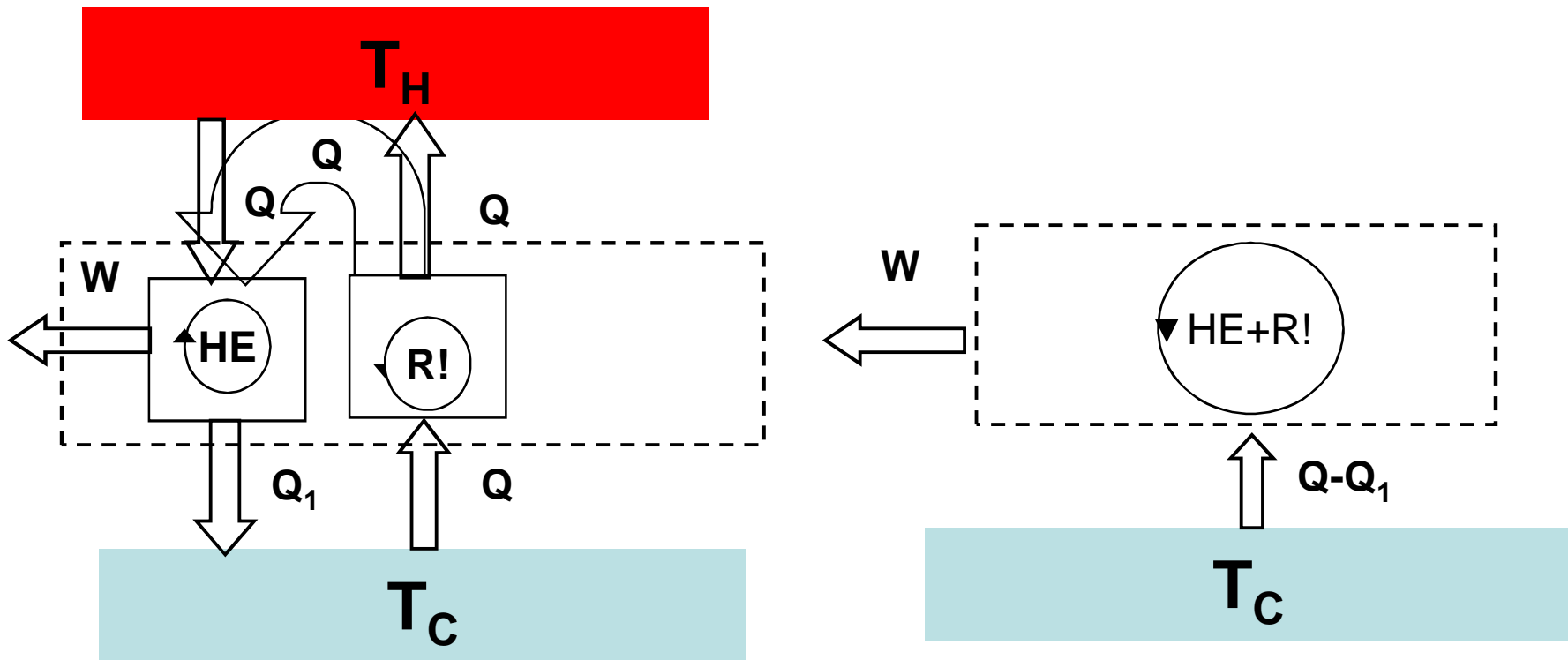
The net heat exchange of the **cyclic device (HE+R)** with the **hot reservoir** = $Q_2 - Q$

Violation of Clausius \rightarrow Violation of KP



KP statement requires the device in contact with the single reservoir (here at T_C) to be a cyclic device. Because nothing happens to the T_H reservoir ($Q_{in}=Q_{out}=Q$), the combined device (HE+R!+ T_H) is a cyclic device.

Violation of Clausius \rightarrow Violation of KP (Alternative)

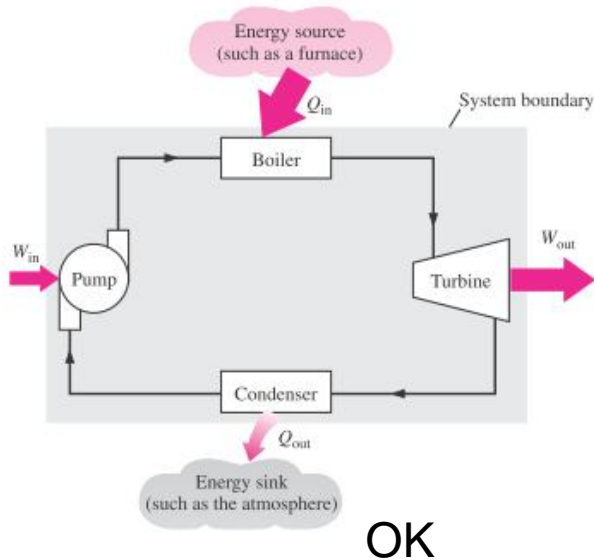


T_H can be eliminated and Q can be fed directly to H from R

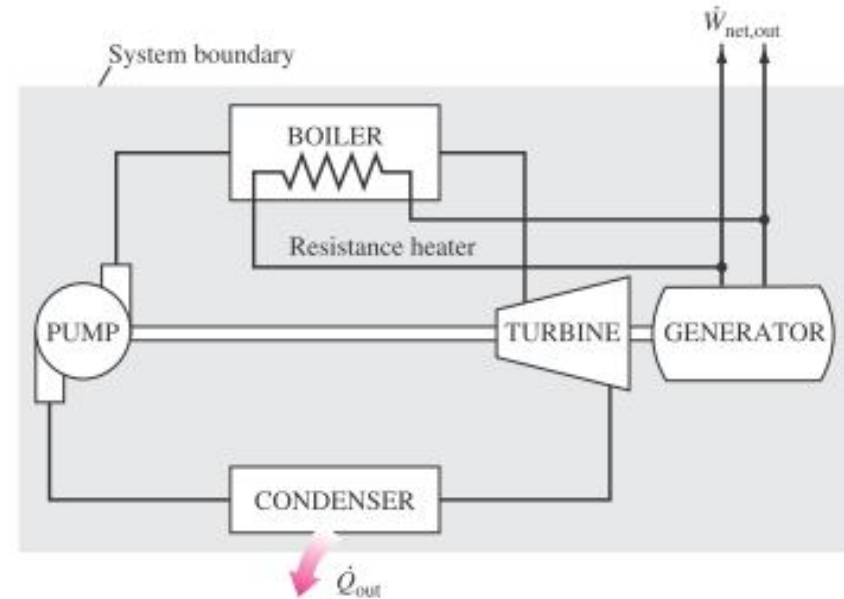
Perpetual motion machines (PMM)

- Any device that violates the first or the second law of thermodynamics is called a perpetual motion machine.
- Violates the First law: “perpetual machine of the first kind”: produces more energy than supplied.
- Violates the Second law: “perpetual motion machine of the second kind”: Allows the efficiency of cyclic heat engines to approach 100%.

Example of a PMM1



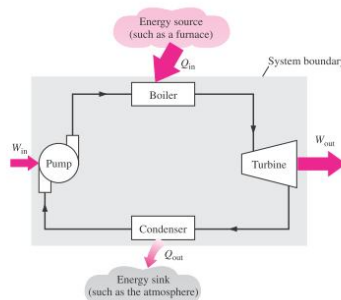
$$W_{net,out} = W_{out} - W_{in}$$



Not OK! Produces net energy output ($\dot{Q}_{out} + \dot{W}_{out}$) without energy input.

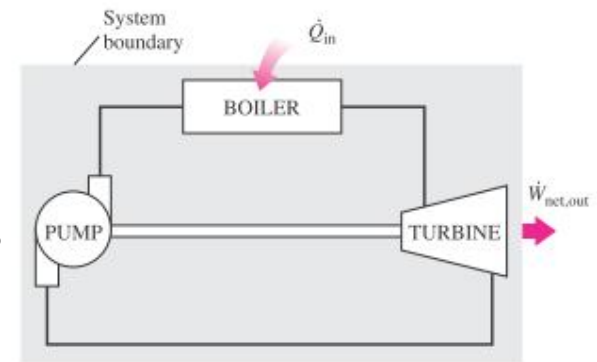
Identifying PMM2 by Kelvin-Planck/Clausius statement

- A PMM2 according to Kelvin-Planck statement is a device that:
 - ✓ Operates in a cycle.
 - ✓ Accepts heat from a single reservoir (surroundings).
 - ✓ Develops a **net** work output.
- Example: A power plant with no condenser



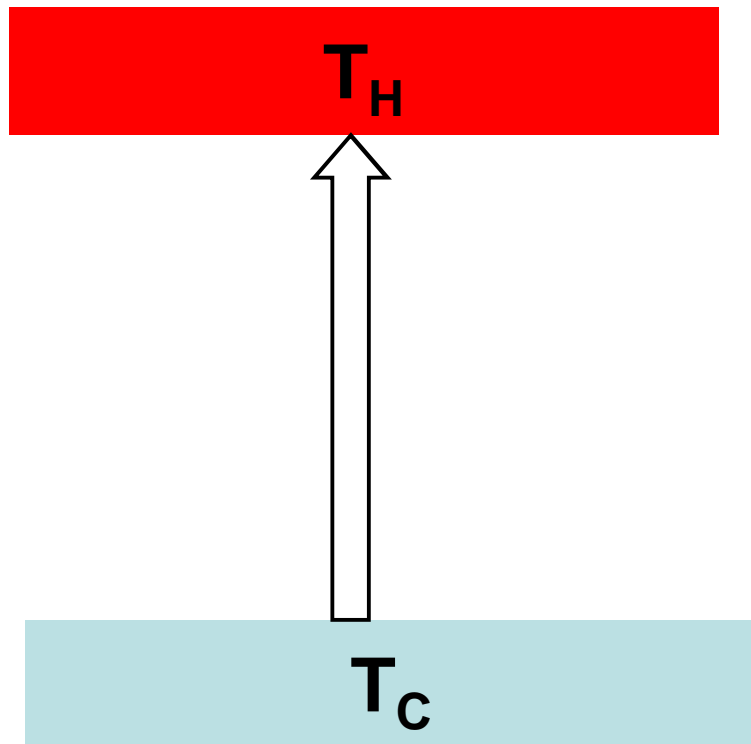
OK

Not
OK!
Violates
KP

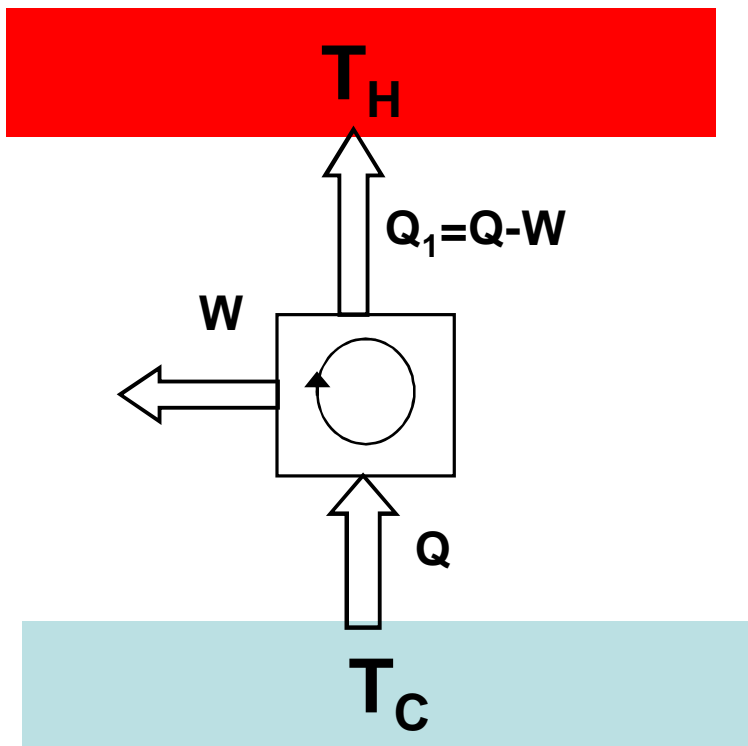


Identifying PMM2 by Clausius statement

- A PMM2 according to Clausius statement is a device whose operation has the sole effect of transfer of heat from a low temperature to high temperature body.

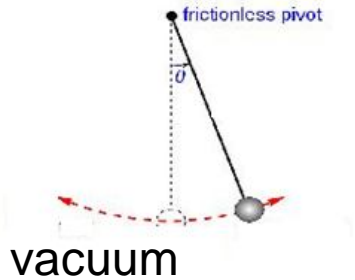


An impossible claim? PMM2?



How to make the most efficient heat engine

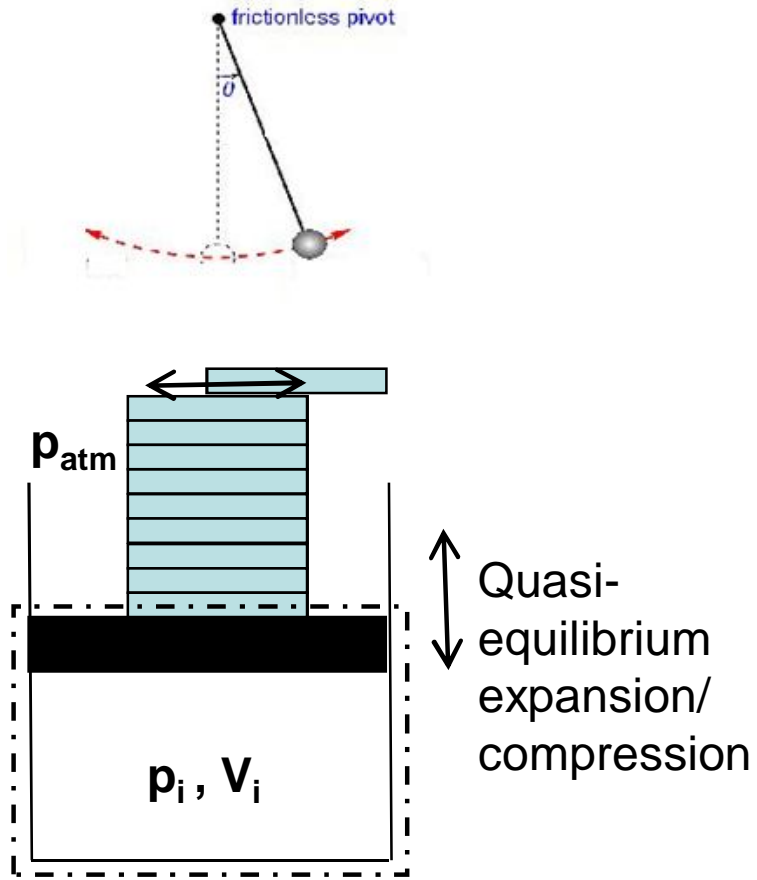
- Second law: no heat engine can have an efficiency of 100%.
- So, what is the maximum efficiency?
- It turns out (shown later) that maximum efficiency is realized when a heat engine runs on a cycle consisting of certain “idealized processes”.
- These “idealized processes” have the characteristic that work producing devices such as a turbine and work consuming devices such as pumps and compressors deliver the most work when run on these idealized processes.



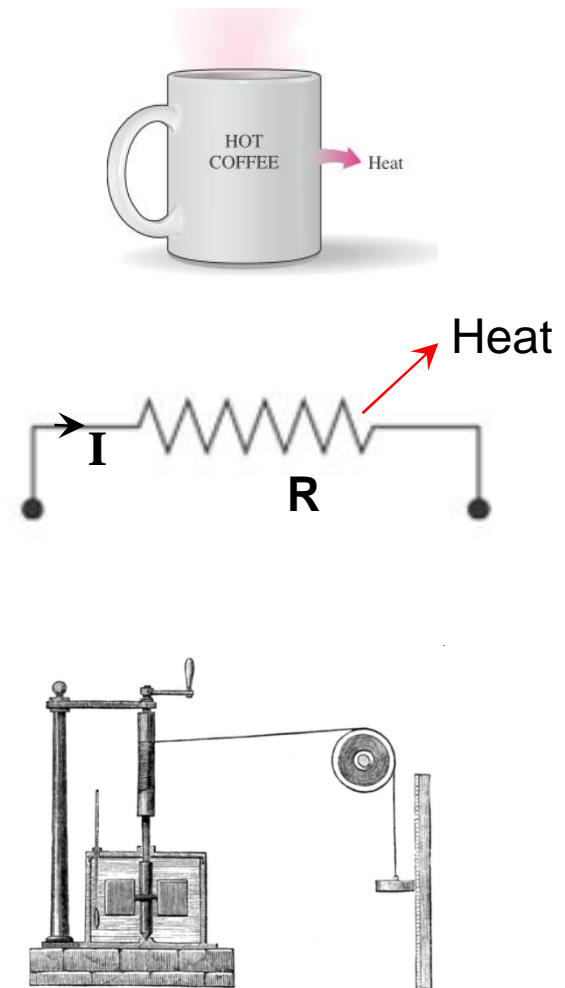
Reversible process

- Reversible processes can be reversed leaving no trace on the surroundings.
- If the original process and its reverse is combined into a cycle, after the cycle is executed,
 - both the system and surroundings will return to their original state.
 - no net heat and work exchange between the system and surroundings occurs during this cycle.

Reversible processes



Irreversible processes



Irreversible processes

- Processes that are not reversible are irreversible.
- **After an irreversible process is executed, it is impossible to restore both the system and the surroundings to the original state.**
- Factors that make a process irreversible (irreversibilities) include:
 1. Lack of equilibrium between parts of the system or with the surroundings:
 - A) Heat transfer through a finite temperature difference.
 - B) Lack of pressure equilibrium.
 2. Dissipative effects (friction, transfer of current through a resistor).

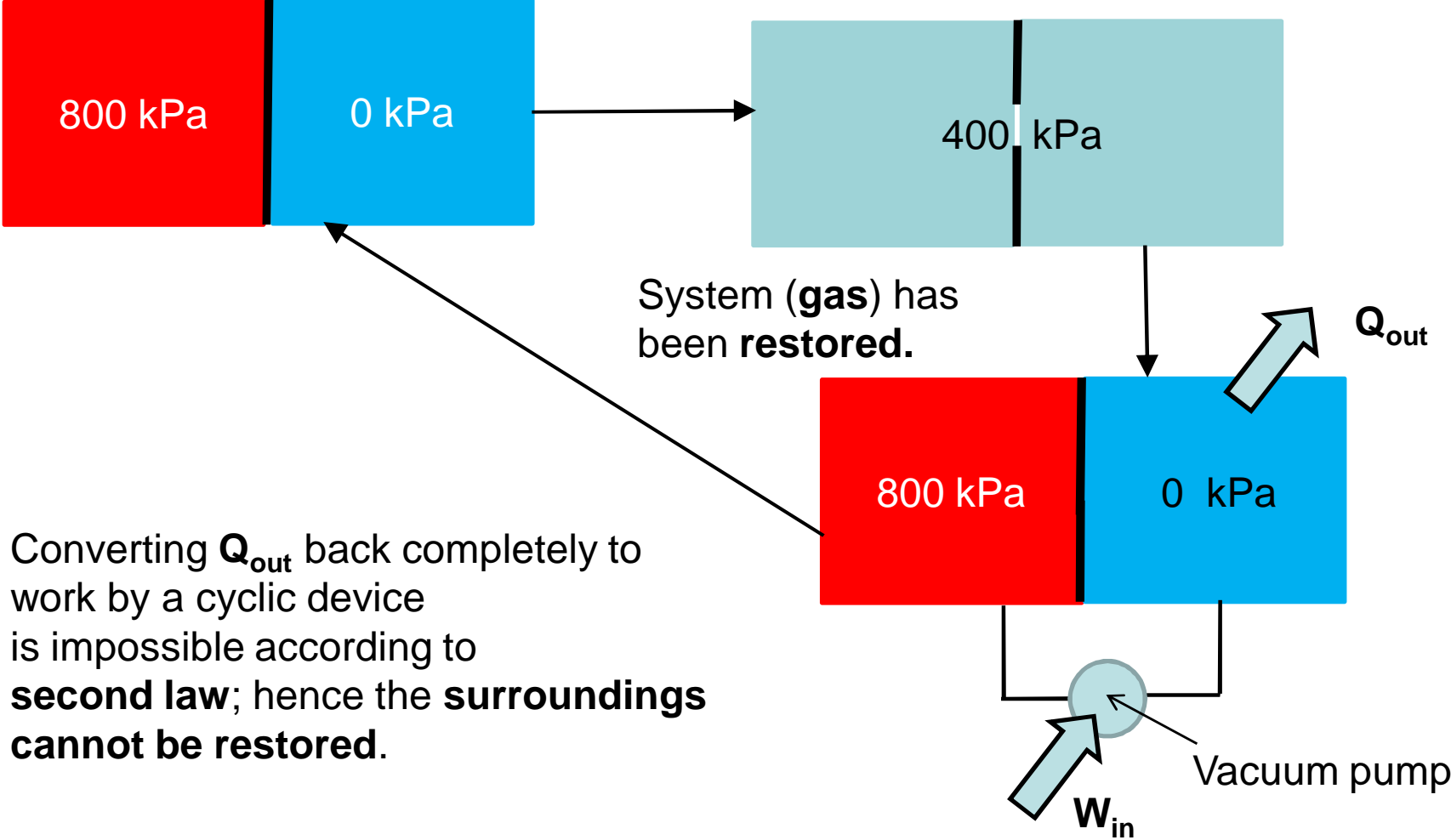
Example of irreversibility due to lack of equilibrium: unrestrained expansion of a gas



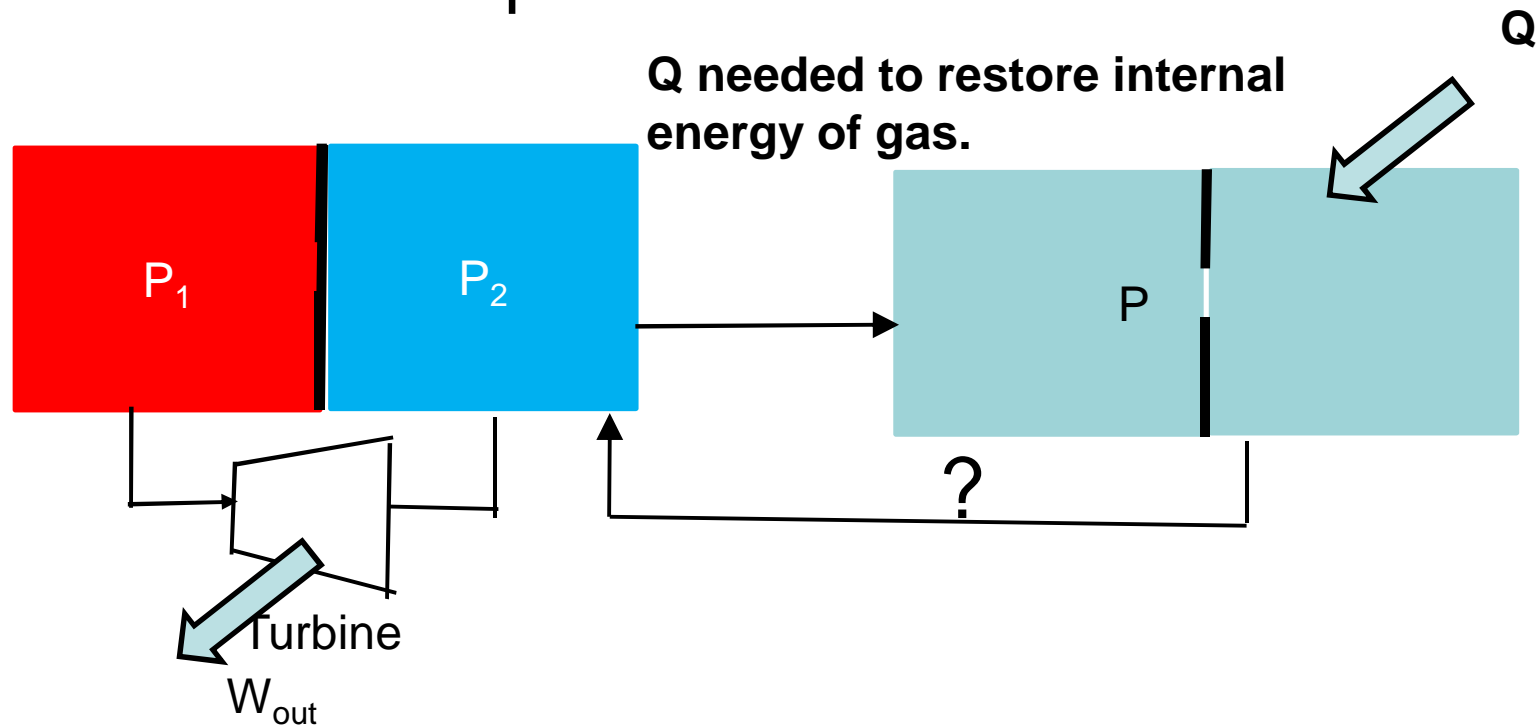
A membrane separates a gas in chamber A from vacuum in chamber B. The membrane is ruptured and the gas expands into chamber B until pressure equilibrium is established. The process is so fast and the container is insulated enough such that negligible heat transfer takes place between the gas and the surroundings during this process.

At the end of the unrestrained expansion process, the gas (system) has the same internal energy, as it had initially.

To show that unrestrained expansion is an irreversible process



Another method to show that unrestrained expansion is an irreversible process: constructing a PMM2 that uses the reversed process.



This is a PMM2 according to Kelvin-Planck statement:

- ✓ Operates in a cycle.
- ✓ Accepts heat from a single reservoir (surroundings).
- ✓ Develops a **net** work output.

To show that unrestrained expansion is an irreversible process

To reverse the process, we assume a vacuum pump running on electricity is available in the surroundings.

- The vacuum pump will evacuate chamber B and restore the gas to chamber A. The vacuum pump is then removed.
- But the vacuum pump has **increased the internal energy** of the gas by an amount equal to the **electrical work** consumed by it.



- **Therefore, only after an equal amount of heat has to be rejected by the gas to the surroundings will the gas be restored to its initial state.**

- The surroundings have expended work on the gas and absorbed the heat released by the gas to bring the system (gas) to its initial state.

- The heat released cannot be returned completely as work to the surroundings (a single thermal reservoir), since, any cyclic device that does the same will violate the second law (Kelvin Planck statement). Consequently the surroundings cannot be restored to its initial state.

- Therefore, unrestrained expansion is an irreversible process.