LEARNING OBJECTIVE

- Introduce the second law of thermodynamics.
- Identify valid processes as those that satisfy both the first and second laws of thermodynamics.
- Discuss thermal energy reservoirs, reversible and irreversible processes, heat engines, refrigerators, and heat pumps.
- Describe the Kelvin–Planck and Clausius statements of the second law of thermodynamics.
- Discuss the concepts of perpetual-motion machines.
- Apply the second law of thermodynamics to cycles and cyclic devices.
- Apply the second law to develop the absolute thermodynamic temperature scale.
- Describe the Carnot cycle.
- Examine the Carnot principles, idealized Carnot heat engines, refrigerators, and heat pumps.
- Determine the expressions for the thermal efficiencies and coefficients of performance for reversible heat engines, heat pumps, and refrigerators.

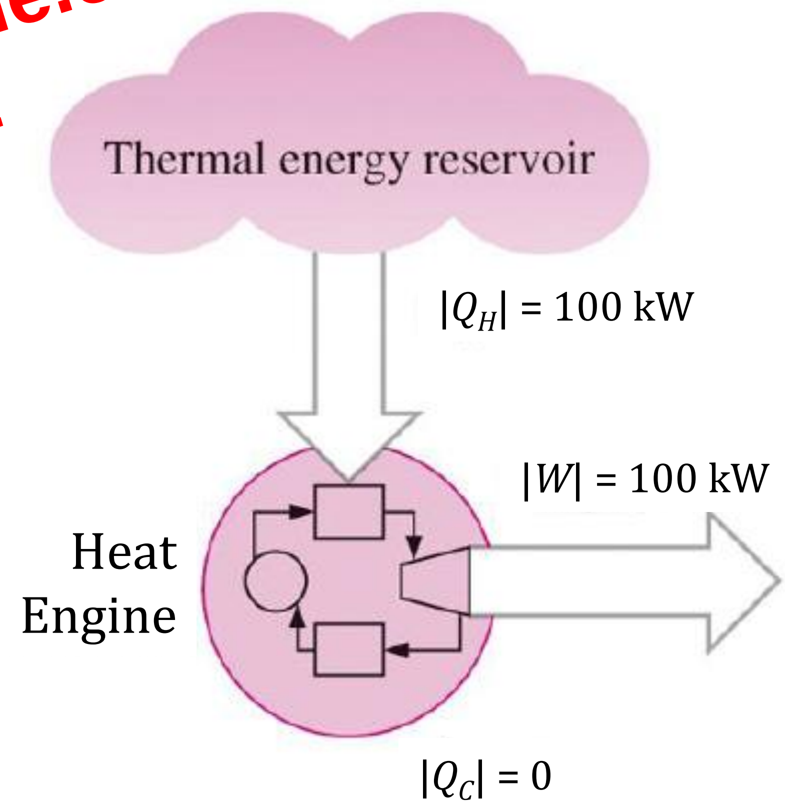
The Second Law of Thermodynamics

Kelvin–Planck Statement

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

No heat engine can have a thermal efficiency of 100%. For a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.

The impossibility of having a 100% efficient heat engine is not due to friction or other dissipative effects. It is a limitation that applies to both the idealized and the actual heat engines.

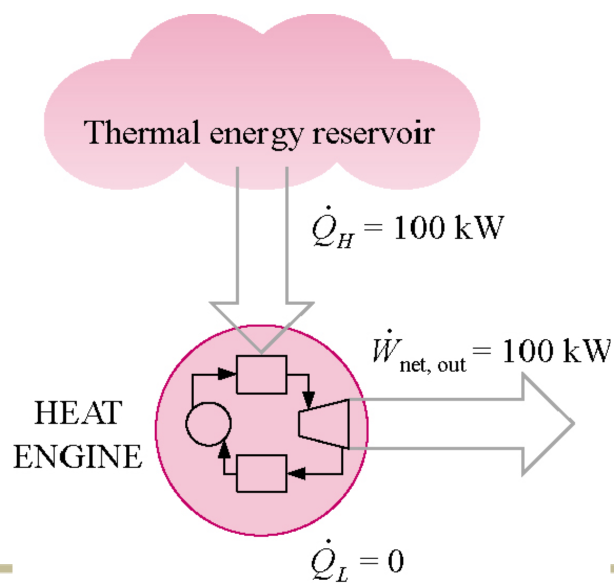


A heat engine that violates the Kelvin-Planck statement of the second law.

Kelvin–Planck Statement

It is impossible for any system to operate in a thermodynamic cycle & deliver a net amount of work to its surroundings while receiving energy by heat transfer from a single thermal reservoir.

The statement **does not rule out** the possibility of a system developing a net amount of work from a heat transfer drawn from a single reservoir. It only denies this possibility if the system undergoes a **thermodynamic cycle**.



Is this system undergo thermodynamic cycle?

EXERCISE

- What is your conclusion from the example on the previous slide?

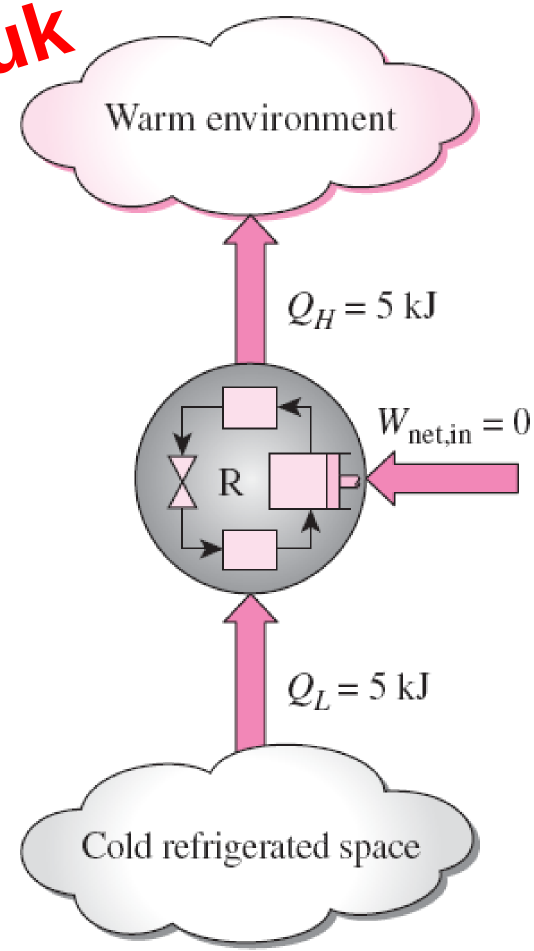
THE SECOND LAW OF THERMODYNAMICS: CLAUSIUS STATEMENT

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

It states that a refrigerator cannot operate unless its compressor is driven by an external power source, such as an electric motor.

This way, the net effect on the surroundings involves the consumption of some energy in the form of work, in addition to the transfer of heat from a colder body to a warmer one.

To date, no experiment has been conducted that contradicts the second law, and this should be taken as sufficient proof of its validity.

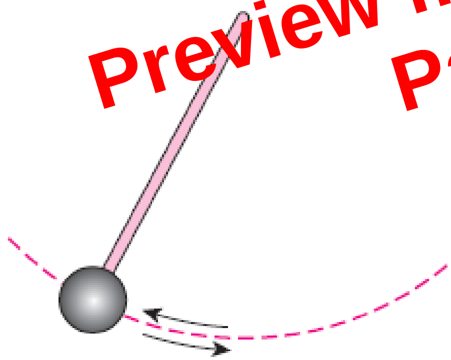


A refrigerator that violates the Clausius statement of the second law.

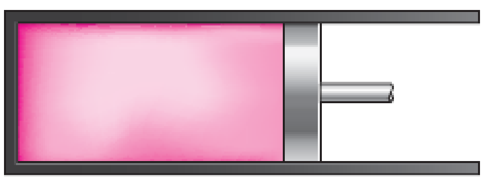
REVERSIBLE AND IRREVERSIBLE PROCESSES

Reversible process: *A process that can be reversed without leaving any trace on the surroundings.*

Irreversible process: A process that is not reversible.

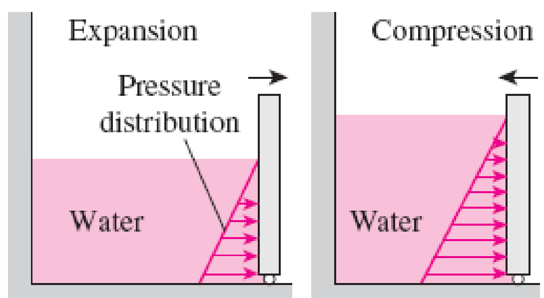


(a) Frictionless pendulum

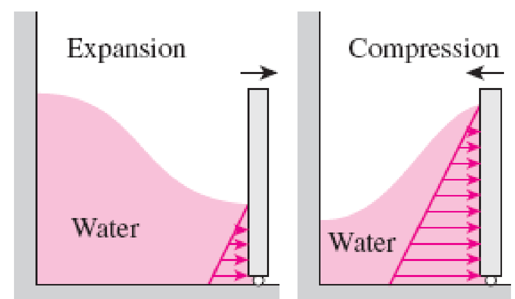


(b) Quasi-equilibrium expansion and compression of a gas

- All the processes occurring in nature are irreversible.
- ***Why are we interested*** **in reversible processes?**
- **(1)** they are easy to analyze and **(2)** they serve as idealized models (theoretical limits) to which actual processes can be compared.
- Some processes are more irreversible than others.
- We try to approximate reversible processes. **Why?**



(a) Slow (reversible) process



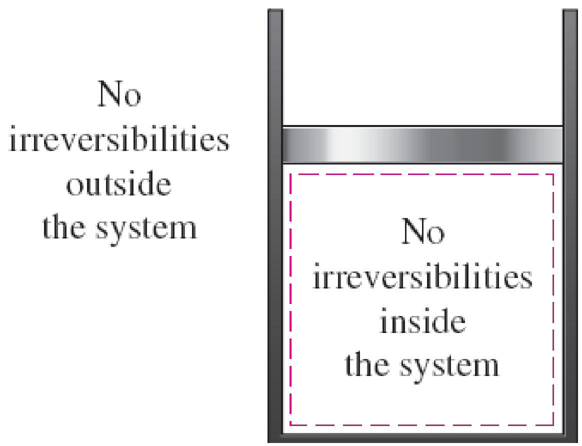
(b) Fast (irreversible) process

Two familiar reversible processes.

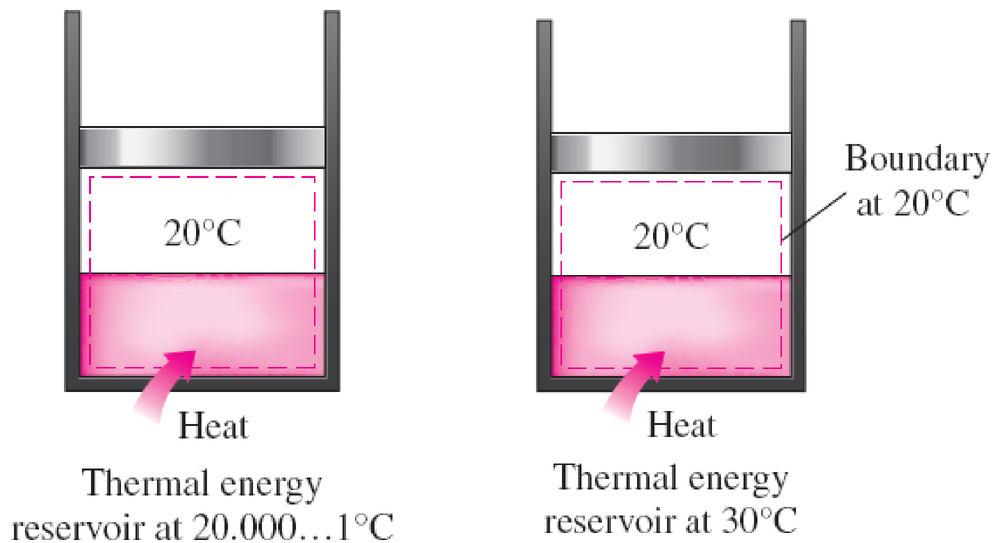
Reversible processes deliver the most and consume the least work.

INTERNALLY AND EXTERNALLY REVERSIBLE PROCESSES

- **Internally reversible process:** If no irreversibilities occur within the boundaries of the system during the process.
- **Externally reversible:** If no irreversibilities occur outside the system boundaries.
- **Totally reversible process:** It involves no irreversibilities within the system or its surroundings.
- A totally reversible process involves no heat transfer through a finite temperature difference, no nonquasi-equilibrium changes, and no friction or other dissipative effects.



A reversible process involves no internal and external irreversibilities.



(*a*) Totally reversible (*b*) Internally reversible

Totally and internally reversible heat transfer processes.