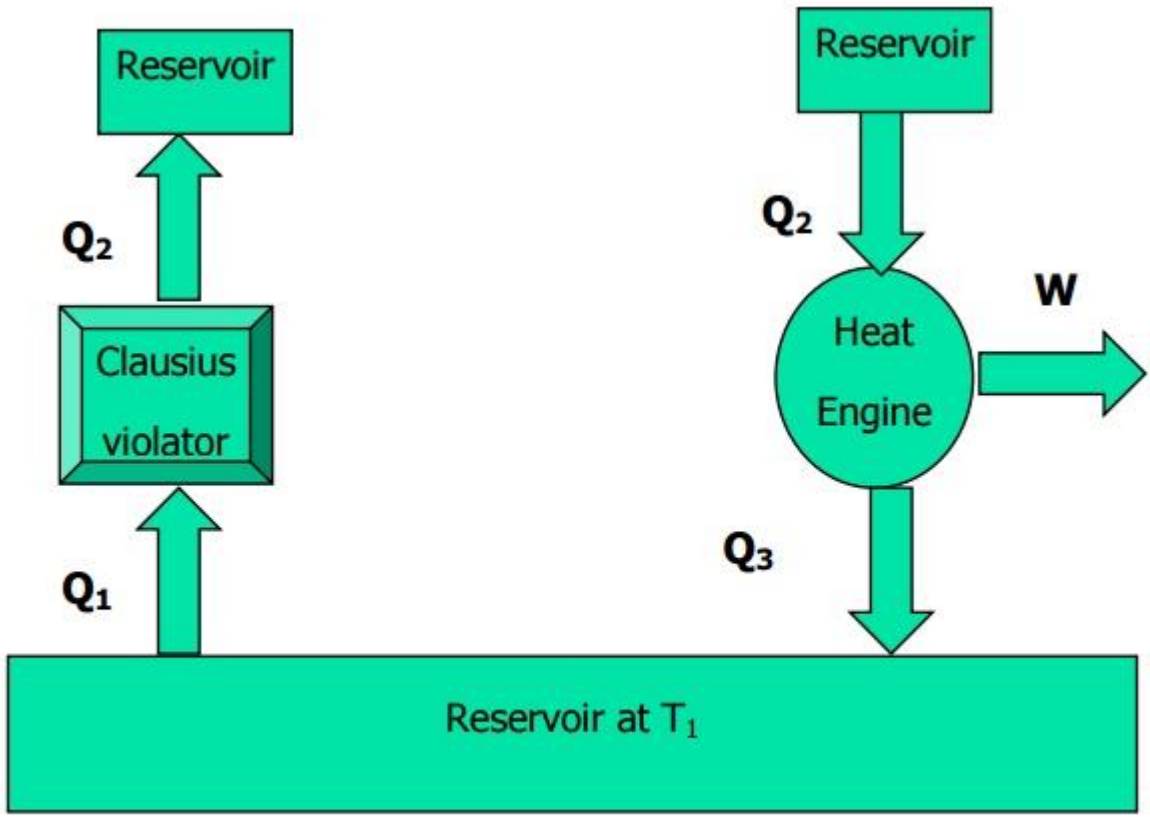

(a)

The **Kelvin-Planck** and **Clausius** statements are two equivalent expressions of the **Second Law of Thermodynamics**, which fundamentally describes the direction of natural processes and sets limits on the performance of heat engines and refrigerators.

1. Kelvin-Planck Statement

Statement:

"It is impossible to construct a heat engine that, operating in a cycle, produces no other effect than the absorption of heat from a single thermal reservoir and the performance of an equivalent amount of work."

Explanation:

- This statement implies that no heat engine can be 100% efficient if it operates between two thermal reservoirs. A heat engine must exchange heat with at least two reservoirs: one hot (heat source) and one cold (heat sink).
- Some heat absorbed from the hot reservoir must be rejected to the cold reservoir; it cannot be entirely converted into work.

Key Points:

- A perfect engine (which converts all heat into work) violates this statement because it would not reject any heat.
- Real engines always have efficiency less than 100%, as they must waste some energy by rejecting it to a low-temperature sink.

Illustration:

- Consider a steam engine. It absorbs heat (QinQ_{in}Qin) from a boiler (high-temperature source) and converts part of this heat into work (WWW), while the rest (QoutQ_{out}Qout) is expelled to the environment (low-temperature sink).

2. Clausius Statement

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 colder body to a hotter body without the input of external work."

Explanation:

- This statement directly addresses refrigerators and heat pumps, asserting that heat cannot spontaneously flow from a cold object to a hot one without external work.
- To transfer heat from cold to hot (against the natural direction), an external source of work is always required.

Key Points:

- The Clausius statement implies that natural heat transfer occurs from hot to cold. To reverse this (e.g., refrigeration), external work must be applied.
- Refrigerators and air conditioners work by absorbing heat from a cold interior and expelling it to the warmer outside, driven by external power (electricity).

Illustration:

- In a refrigerator, the system absorbs heat from inside the fridge (cold space) and releases it into the warmer room air. This process is not spontaneous; it requires a compressor to do work on the refrigerant, thus pushing heat from cold to hot.

Equivalence of Kelvin-Planck and Clausius Statements

Both statements are equivalent because they describe the same fundamental principle: energy transformations are limited by the need to maintain entropy balance and prevent violations of natural heat flow.

Proof of Equivalence:

- If one of these statements were violated, the other would also be violated.

- For example, if a perfect heat engine (violating Kelvin-Planck) existed, its work output could drive a refrigerator to transfer heat without external work, violating Clausius.