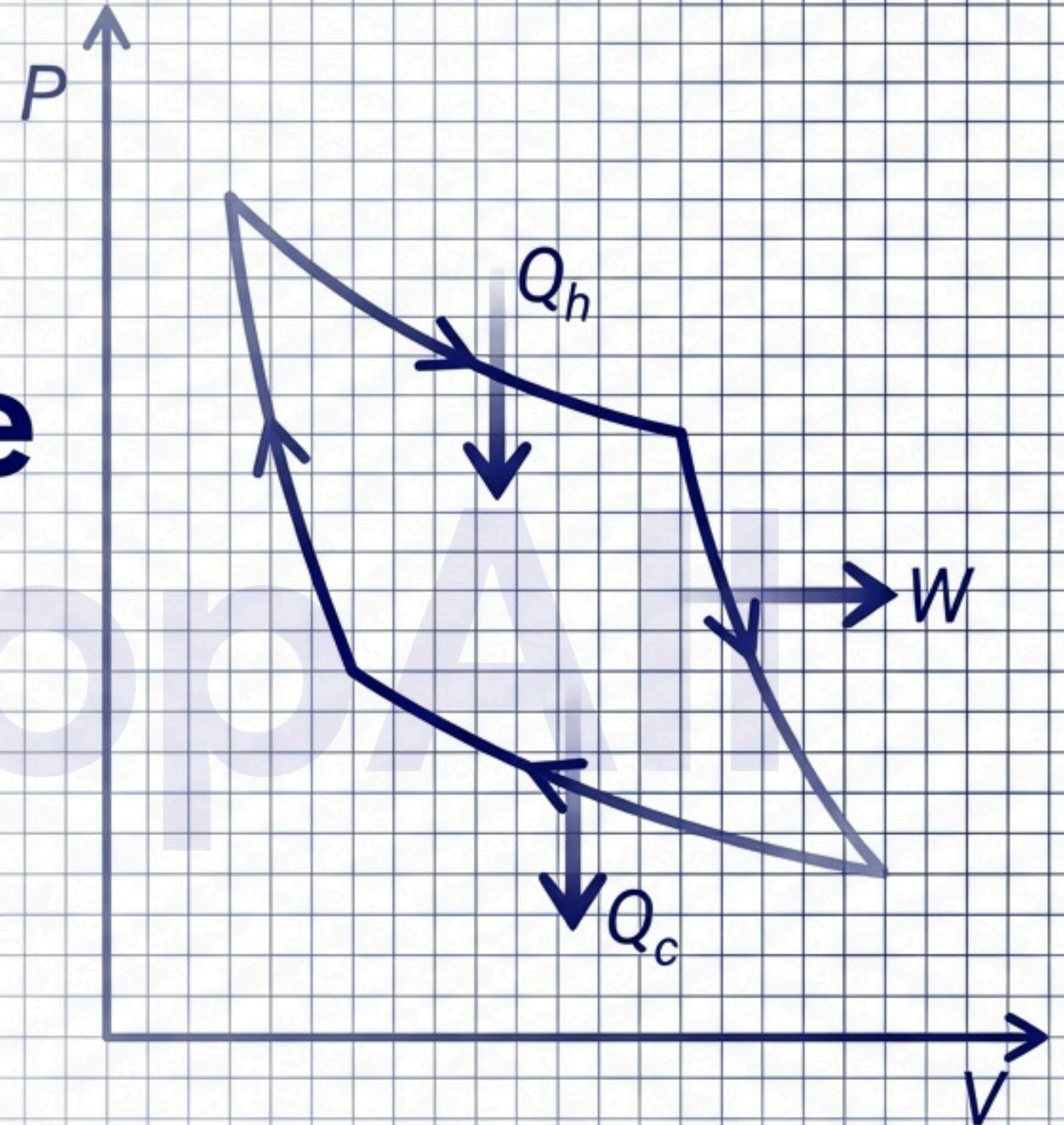


11.11 Carnot Engine

The Theoretical Limit of Heat Engine Efficiency

Master the perfectly reversible cycle, the maximum efficiency limit, and the logical proof of Carnot's theorem.

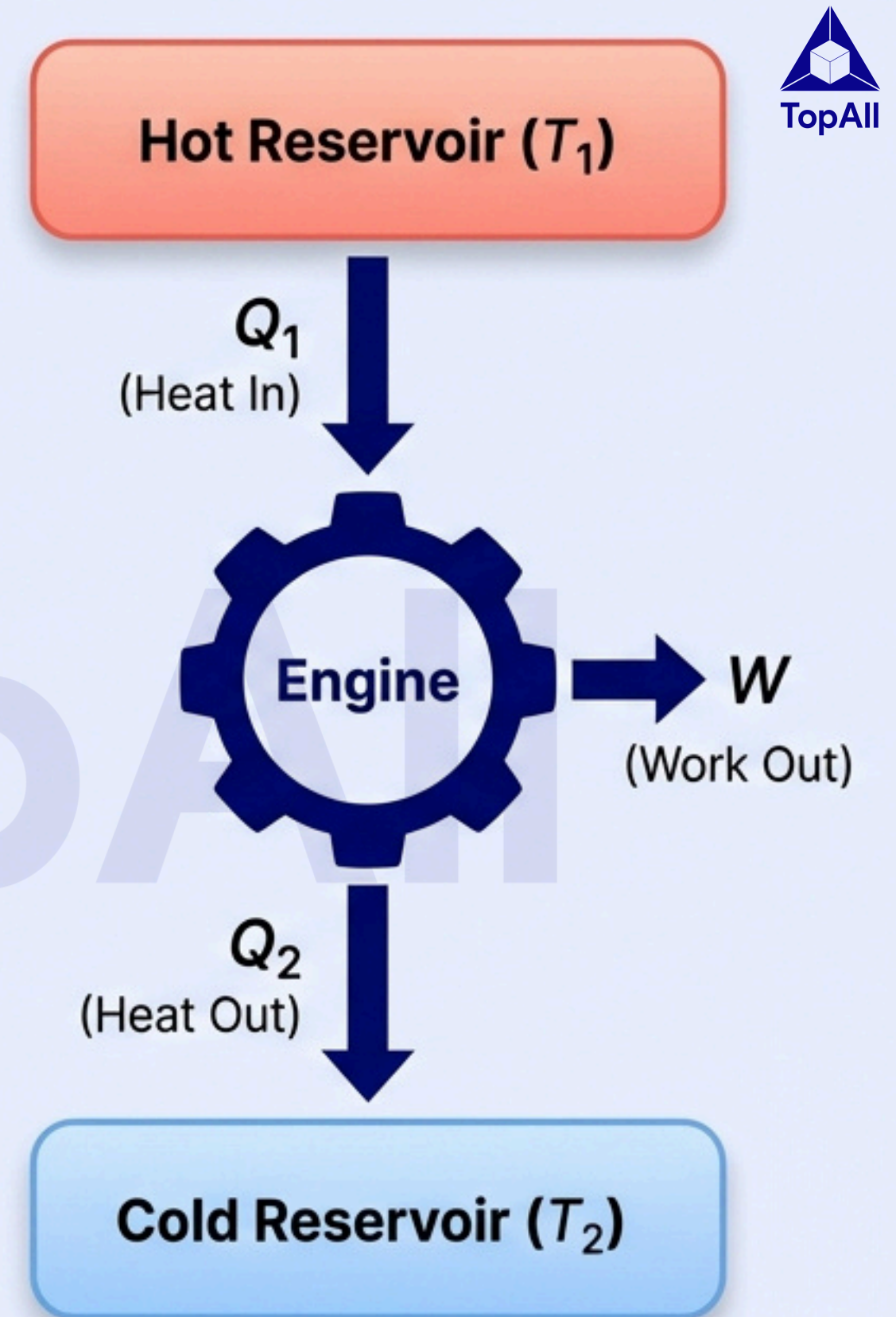


The Ideal Reversible Engine

Conceived by Sadi Carnot in 1824, this is a theoretical, perfectly reversible heat engine operating between two constant temperatures.

- Operates strictly between a Hot Reservoir (T_1) and a Cold Reservoir (T_2).
- Entirely free of dissipative effects (no friction, no viscosity).
- Represents the absolute highest possible efficiency any heat engine can achieve.

EXAM TIP: Real engines are always irreversible; the Carnot engine is the theoretical maximum.



The 4 Steps of the Carnot Cycle

Perfect reversibility requires alternating isothermal (constant temperature) and adiabatic (zero heat transfer) processes.

1. Isothermal Expansion

Absorbs heat Q_1 from the hot reservoir at a constant temperature T_1 .

2. Adiabatic Expansion

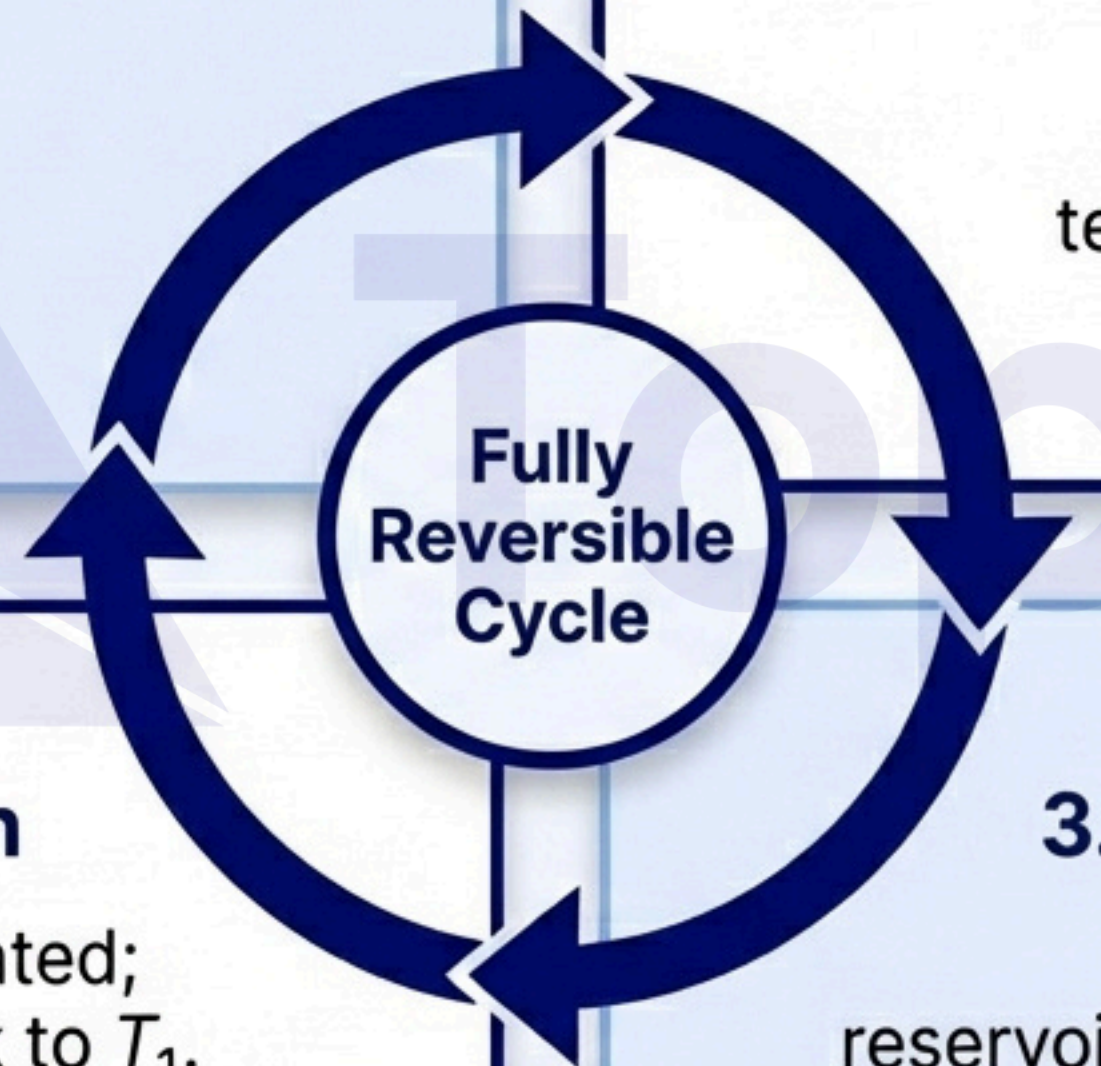
Gas expands while insulated; temperature drops from T_1 to T_2 .

4. Adiabatic Compression

Gas is compressed while insulated; temperature rises from T_2 back to T_1 .

3. Isothermal Compression

Releases heat Q_2 to the cold reservoir at a constant temperature T_2 .



Fully
Reversible
Cycle



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Let's Test Them Now.**

$$E=mc^2$$



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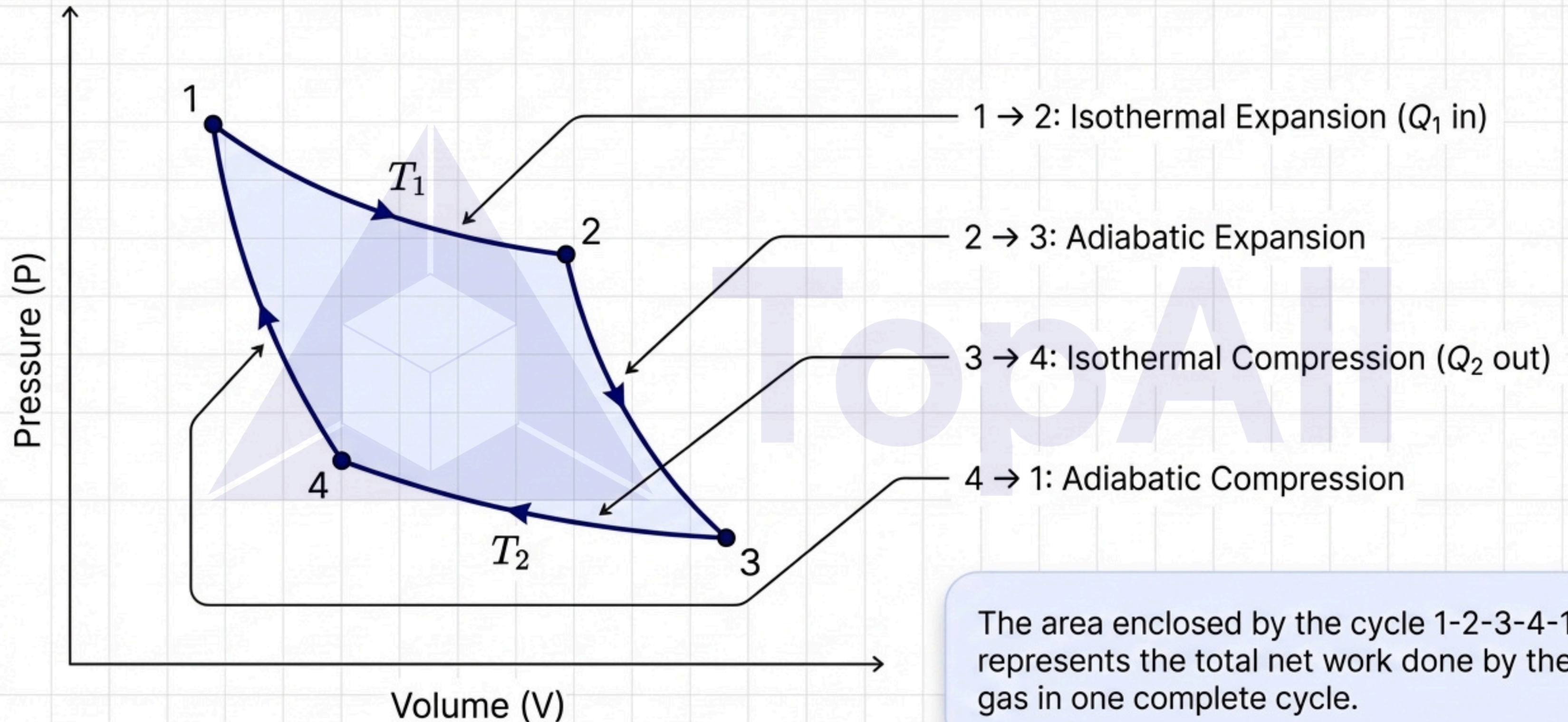
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Visualizing the Cycle (P-V Diagram)

FIG. 11.9



Calculating Carnot Efficiency

Eq. 11.27

$$\eta = 1 - \frac{T_2}{T_1}$$

Efficiency depends ONLY on the temperatures of the hot (T_1) and cold (T_2) reservoirs.

Eq. 11.28

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

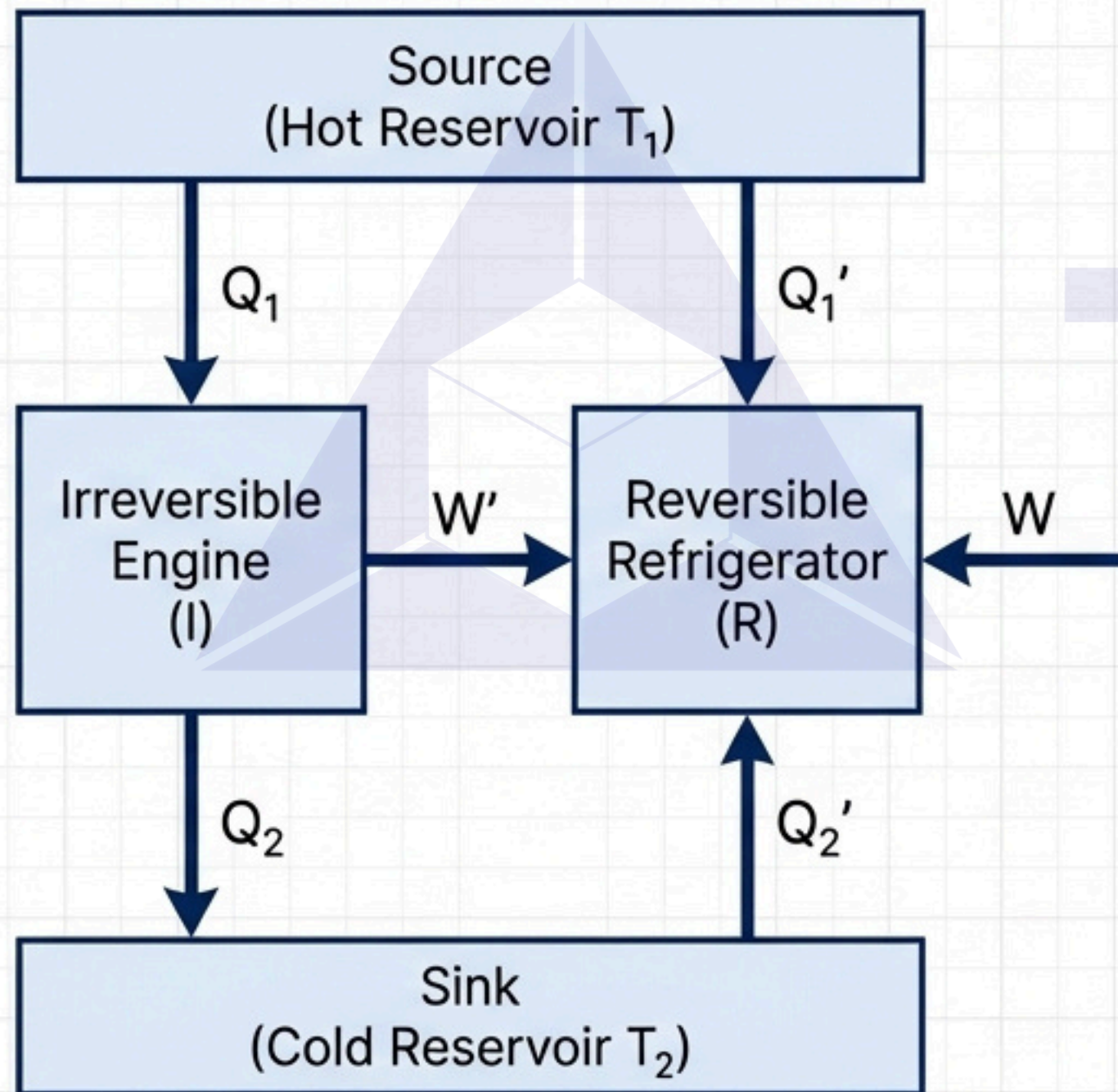
Universal Carnot Relation: The ratio of heat exchanged equals the ratio of absolute temperatures.

- **Temperatures must ALWAYS** be in **Kelvin (K)**.
- **Efficiency** (η) is entirely **independent of the working substance** (e.g., the type of ideal gas used).

Carnot's Theorem & The Second Law

No engine working between two temperatures can have an efficiency greater than the Carnot engine.  TopAll

FIG. 11.10



Logical Flow Diagram

Assume: Engine I is more efficient than Carnot Engine R ($\eta_I > \eta_R$).

Action: Couple I (running as an engine) to R (running in reverse as a refrigerator).

Result: The combined system extracts net heat from the cold sink and converts it *entirely* into work.

Conclusion: This violates the **Kelvin-Planck statement** of the Second Law. Therefore, $\eta_I > \eta_R$ is **impossible**.

Chapter Summary

- ✓ **Perfect Reversibility:** The Carnot cycle uses exactly 2 isothermal and 2 adiabatic processes.
- ✓ **Formula Focus:** $\eta = 1 - T_2/T_1$. (Always convert your temperatures to Kelvin!)
- ✓ **Absolute Limit:** No engine can out-perform a Carnot engine operating between the same two temperatures.
- ✓ **Substance Independent:** Efficiency relies solely on the reservoir temperatures, not the specific gas used inside the engine.

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