

Office hours today: after class (Remo), 3:30-4:30 (Zoom)

Midterm Q&A: Monday, 5-7pm (Zoom link on Canvas)

Learning Goals for today:

- To calculate heat based on the area under the curve on a T-S diagram.
- To geometrically evaluate the efficiency of an engine cycle displayed on a T-S diagram.
- To describe the Carnot Cycle and explain why it has the highest efficiency for any cycle between reservoirs of two fixed temperatures.

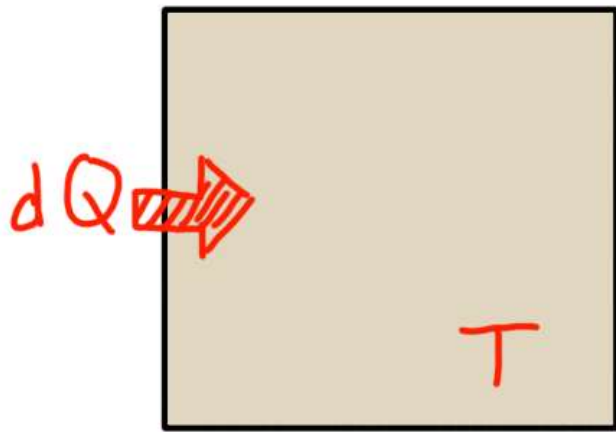


Last time
in Physics
157

$$dS = \frac{dQ}{T}$$

dQ

ENTROPY: macroscopic definition



$$dS = \frac{dQ}{T}$$

change in entropy

heat added

Amazing result:

we can prove this from the microscopic definition of S .

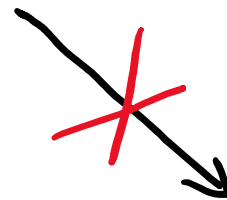
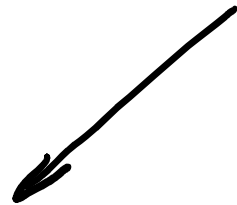
★ see bonus video ★

<https://www.youtube.com/watch?v=t7gyi8NhgYg>

2ND LAW OF THERMODYNAMICS:

Total entropy never decreases.

of whole system \rightarrow entropy for a part can increase

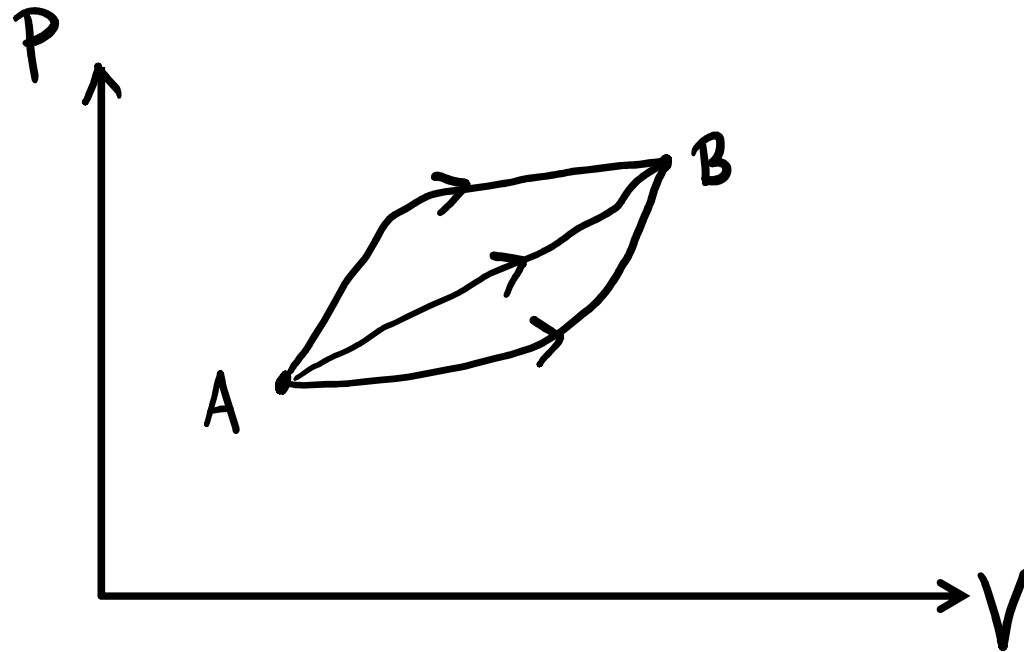


$$\Delta S_{\text{TOT}} > 0$$



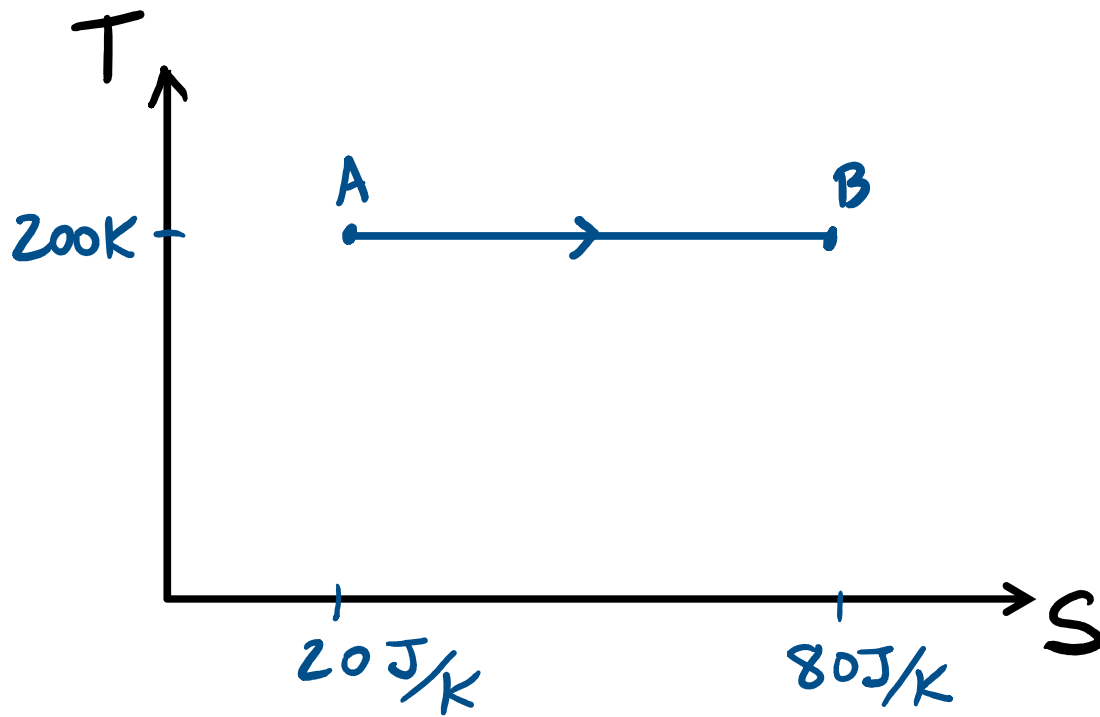
$$\Delta S_{\text{TOT}} < 0 \text{ violates 2nd law!}$$

Entropy is a state variable - like P, V, T, U



ΔS same for all paths, zero for cycle.

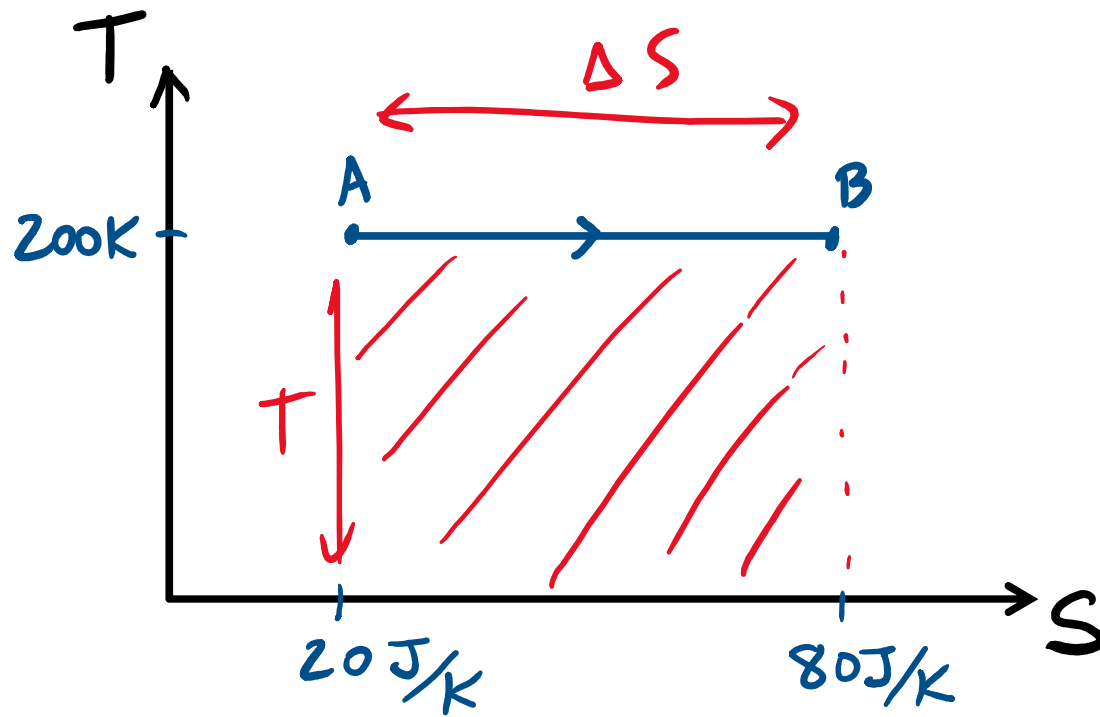
But: S for environment usually increases!



The entropy and temperature are plotted for a certain isothermal process. How much heat was added during the process?

- A) 4000 J
- B) 8000 J
- C) 10000 J
- D) 12000 J
- E) 16000 J

$$dS = \frac{dQ}{T}$$



The entropy and temperature are plotted for a certain isothermal process. How much heat was added during the process?

- A) 4000 J
- B) 8000 J
- C) 10000 J
- D) 12000 J**
- E) 16000 J

$$dS = \frac{dQ}{T} \Rightarrow dQ = TdS$$

$$T_{\text{constant so}} \quad Q = T\Delta S$$

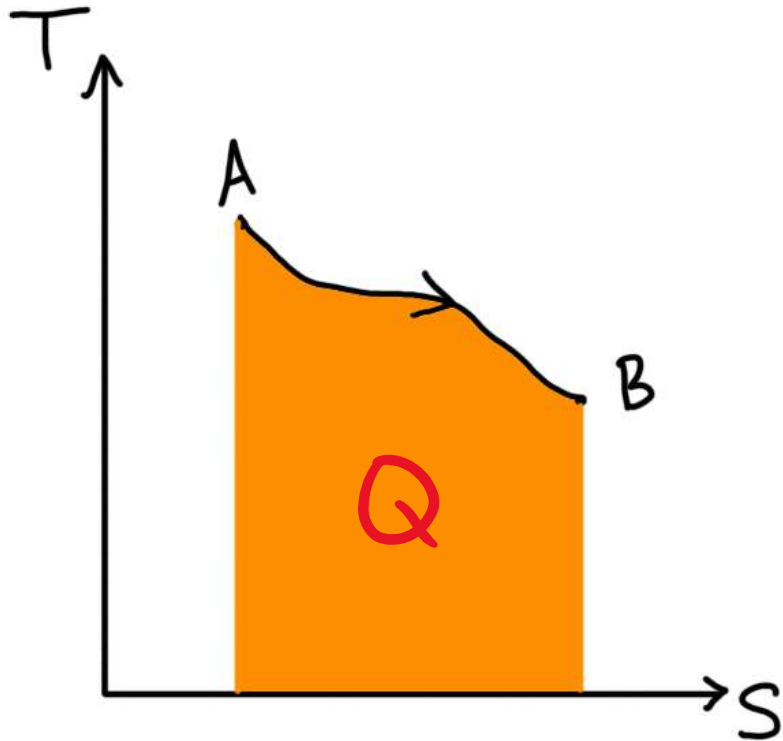
$$= 200\text{K} \cdot 60\text{J/K}$$

$$= 12,000\text{J}$$

Heat = area under curve on a T-S diagram

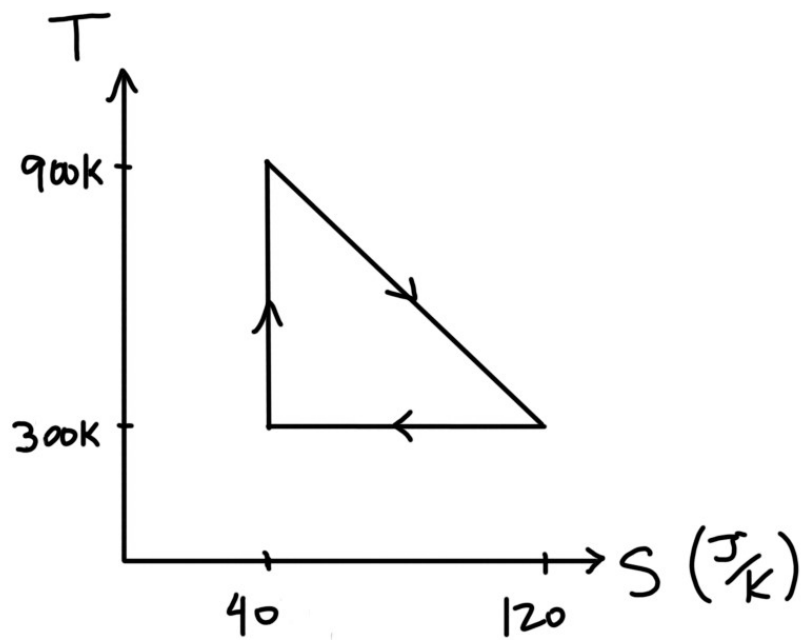
$$dQ = T dS$$

↖ area of small
rectangle



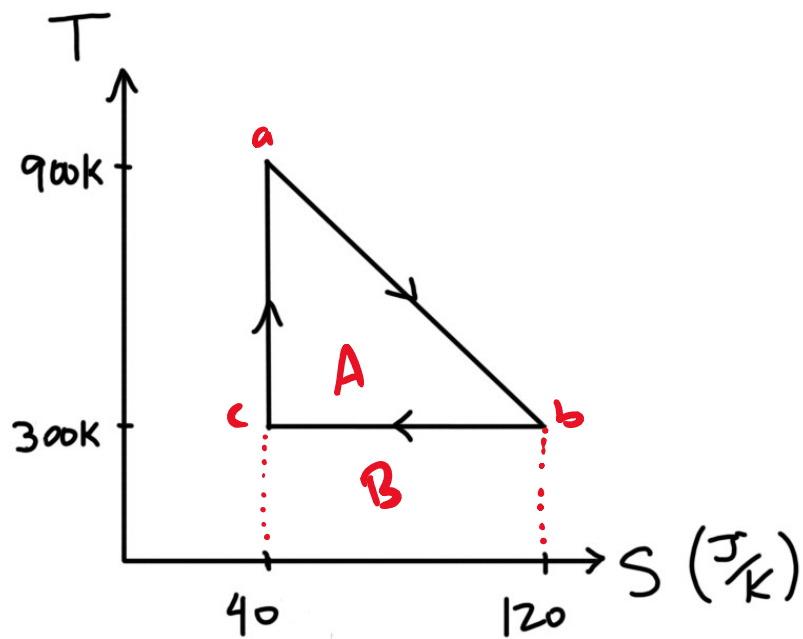
S increasing \Rightarrow $Q > 0$

S decreasing \Rightarrow $Q < 0$



What is the net heat that enters the gas during the cycle shown?

- A) 4kJ
- B) 8kJ
- C) 12kJ
- D) 24kJ
- E) 32kJ



What is the net heat that enters the gas during the cycle shown?

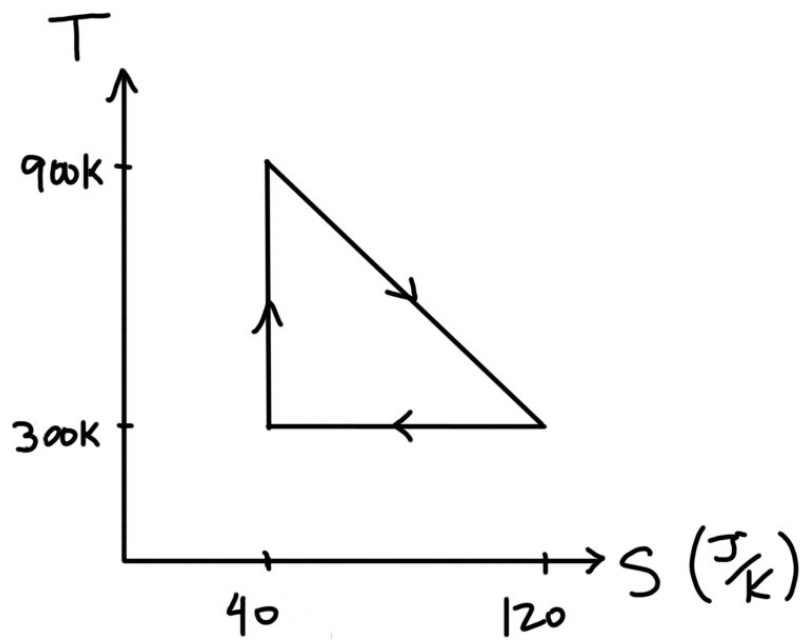
- A) 4kJ
- B) 8kJ
- C) 12kJ
- D) 24kJ**
- E) 32kJ

$$Q_{a \rightarrow b} = \text{area A} + \text{area B}$$

$$Q_{b \rightarrow c} = - \text{area B}$$

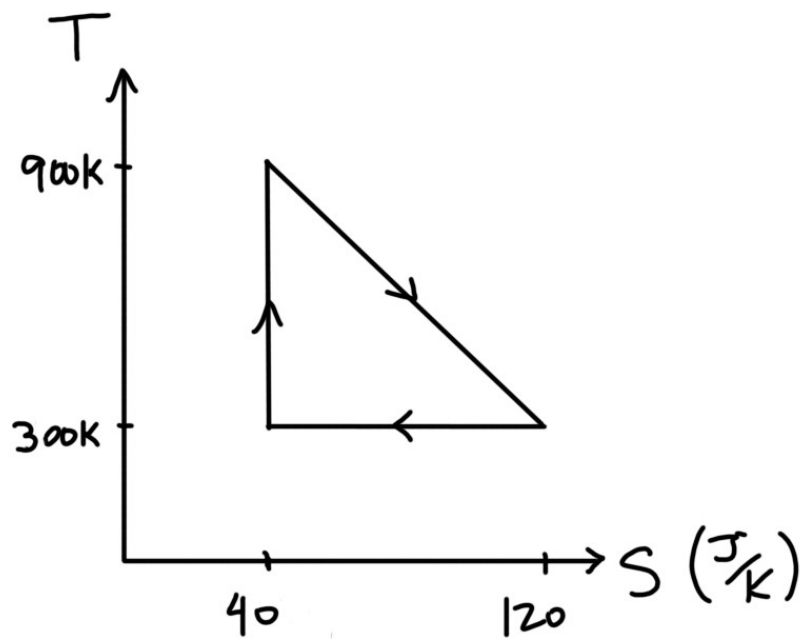
$$Q_{c \rightarrow a} = 0$$

$$\text{so } Q_{\text{net}} = \text{area A} = \frac{1}{2} \cdot 80 \cdot 600 \text{ J} = 24,000 \text{ J}$$



What is the net work done by the gas during the cycle shown?

- A) 4kJ
- B) 8kJ
- C) 12kJ
- D) 24kJ
- E) 32kJ

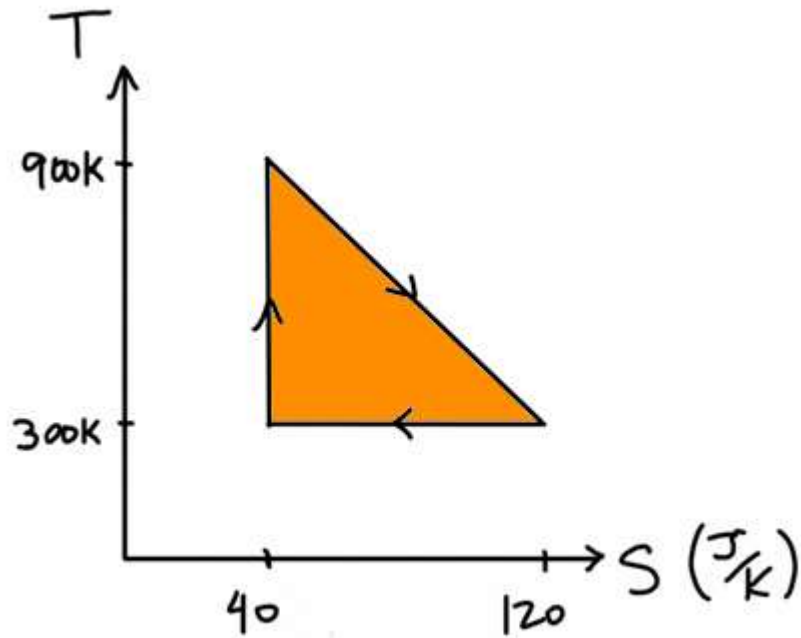


$\Delta U = 0$ for full cycle
so $W = Q = 24 \text{ kJ}$

What is the net work done by the gas during the cycle shown?

- A) 4kJ
- B) 8kJ
- C) 12kJ
- D) 24kJ
- E) 32kJ

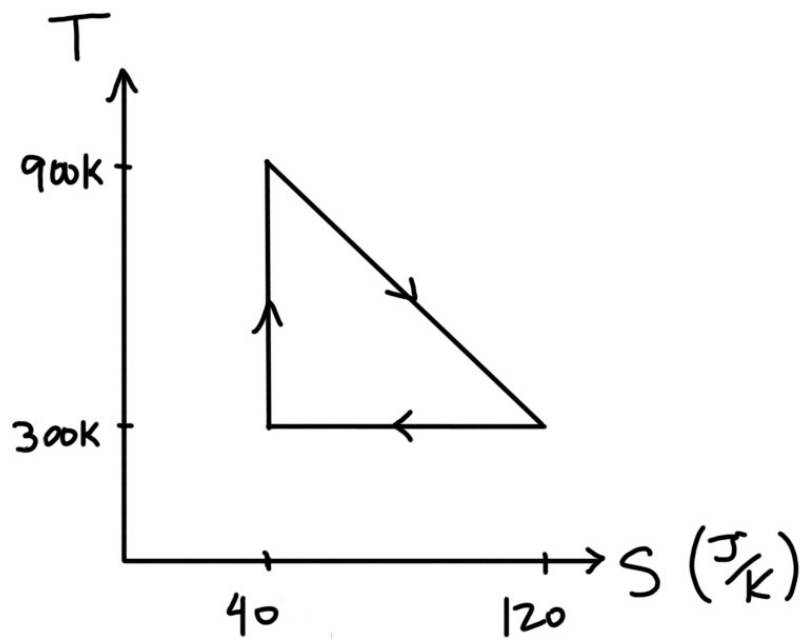
Net heat/work for a cycle from T-S diagram



$$Q_{\text{net}} = W_{\text{net}} = \text{area inside}$$

clockwise: $Q > 0$

counterclockwise: $Q < 0$



What is the efficiency of the engine described by the cycle shown?

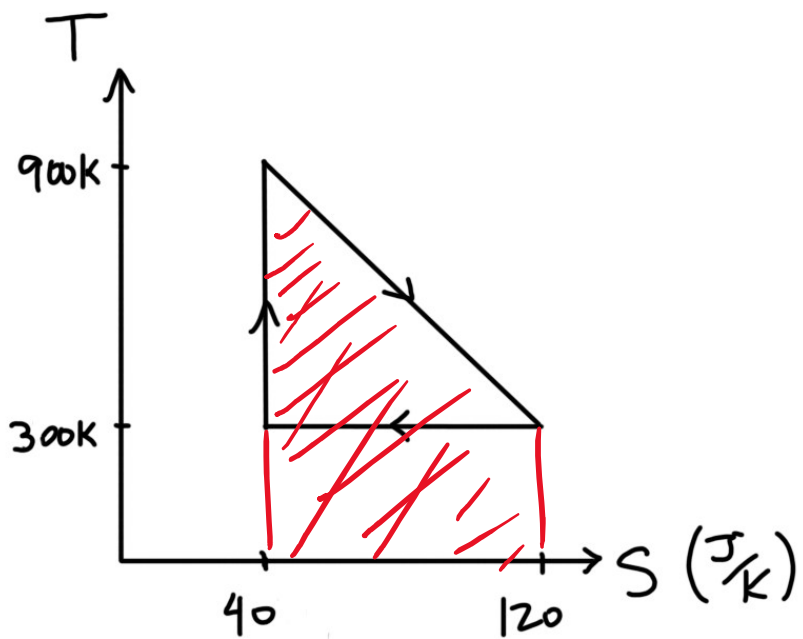
A) 0.333

B) 0.400

C) 0.500

D) 0.666

E) 1.000



What is the efficiency of the engine described by the cycle shown?

A) 0.333

B) 0.400

C) 0.500

D) 0.666

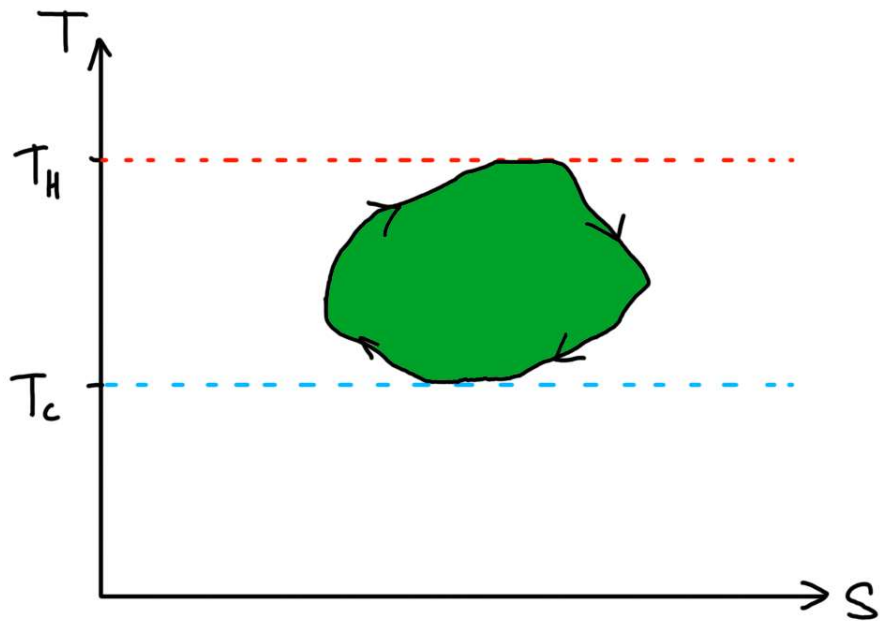
E) 1.000

$$W_{net} = Q_{net} = \text{area inside} = 24 \text{ kJ}$$

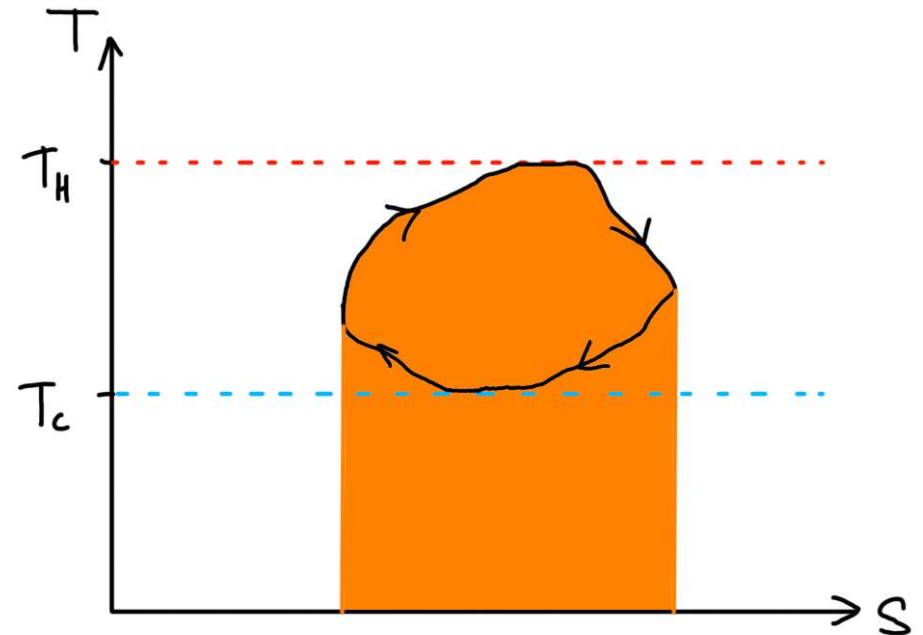
$$Q_{in} = \text{area under part going to right.} = \text{shaded area} = 48 \text{ kJ}$$

$$e = \frac{W_{net}}{Q} = \frac{1}{2}$$

Efficiency from a T-S diagram

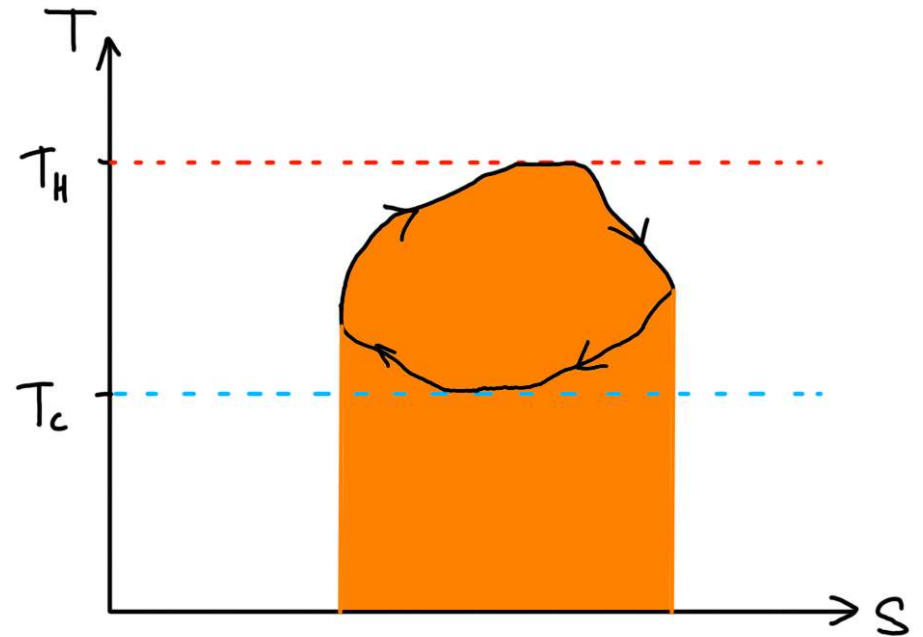
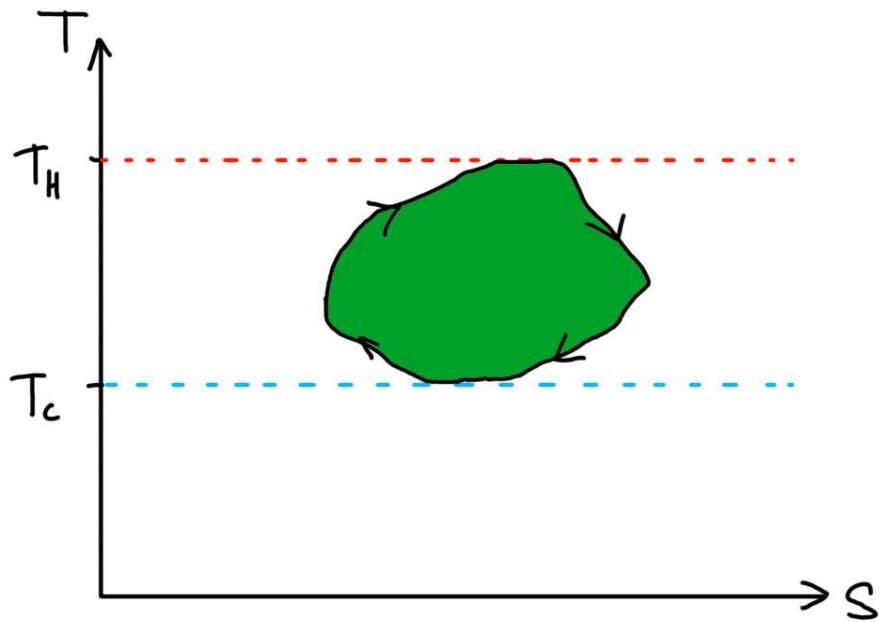


$W_{net} = \text{area enclosed}$

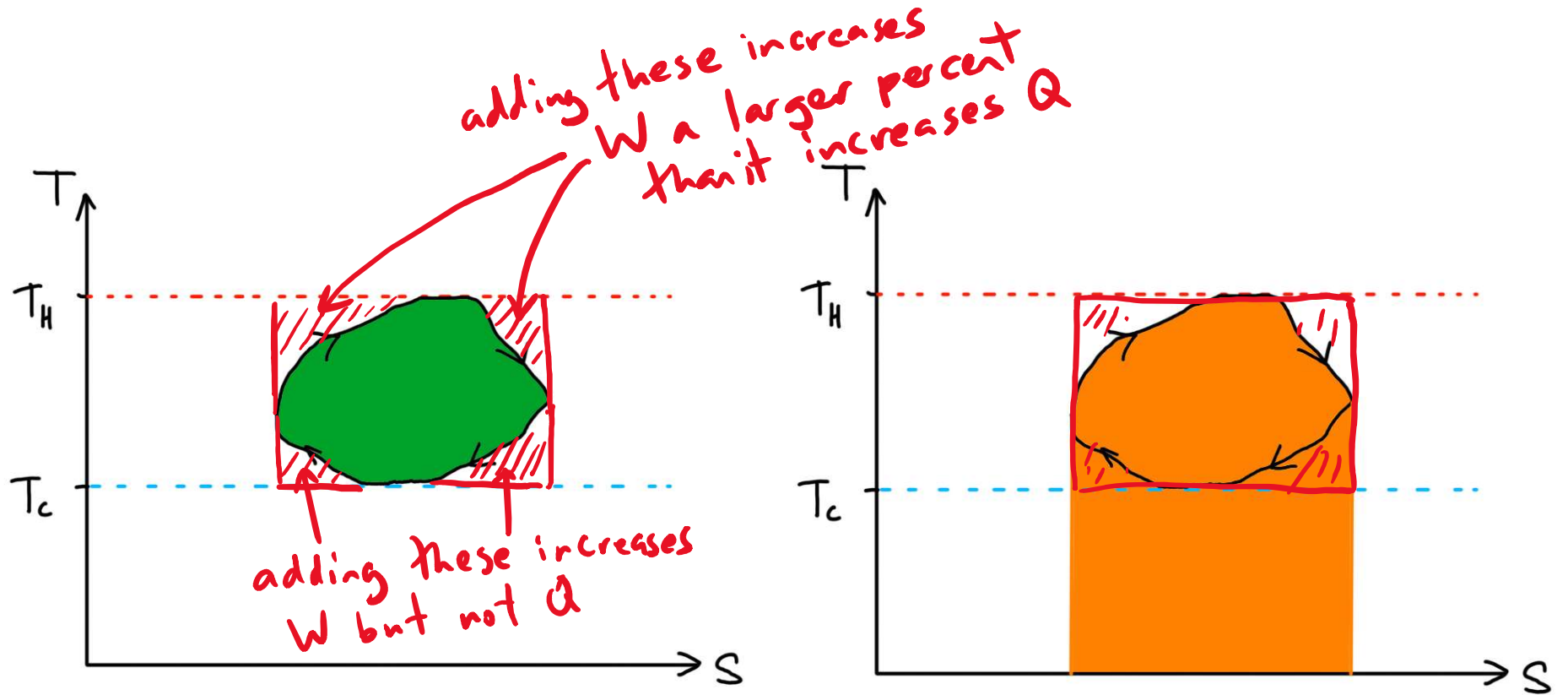


$Q_{in} = \text{area under } \Delta S > 0 \text{ parts}$

$$e = \frac{W_{net}}{Q_{in}} = \frac{\text{green}}{\text{orange}}$$

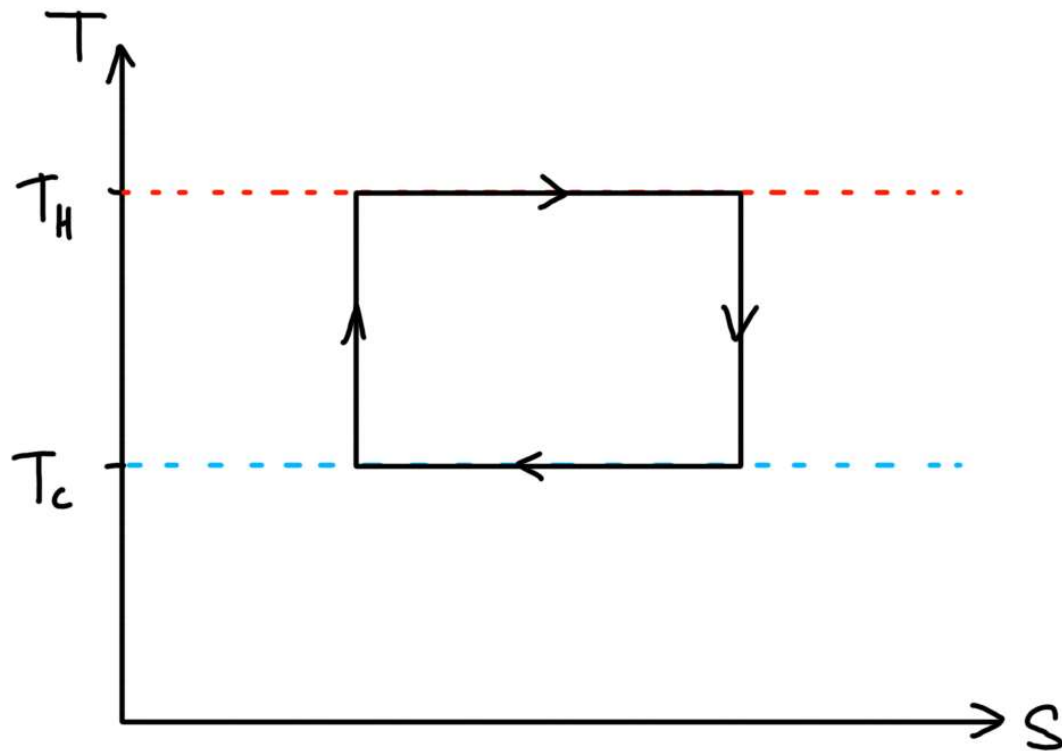


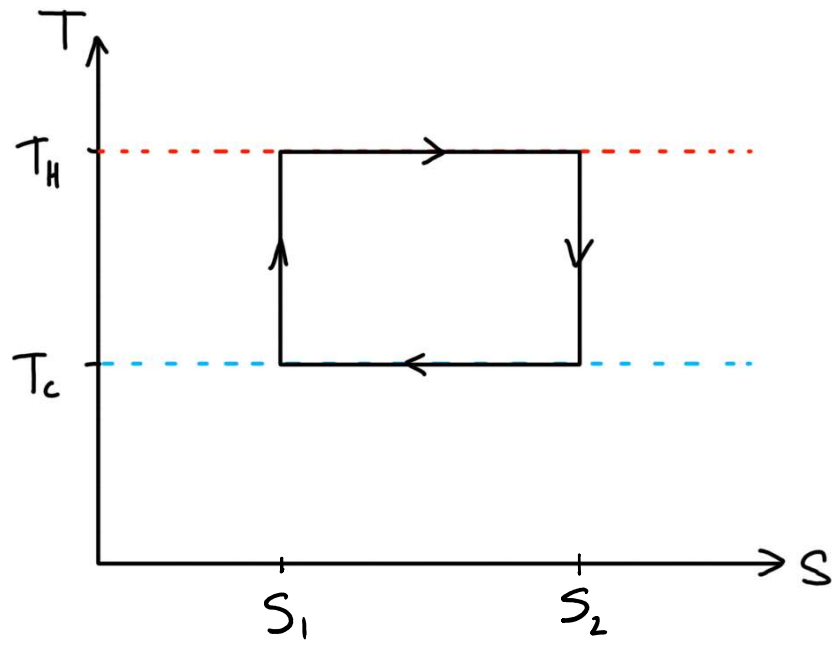
If we keep T_C and T_H fixed, what shape would give the maximum possible efficiency?



If we keep T_C and T_H fixed, what shape would give the maximum possible efficiency?

CARNOT CYCLE: maximum possible efficiency for fixed max & min temperatures T_H, T_C





What is the efficiency of the engine described by the Carnot cycle shown?

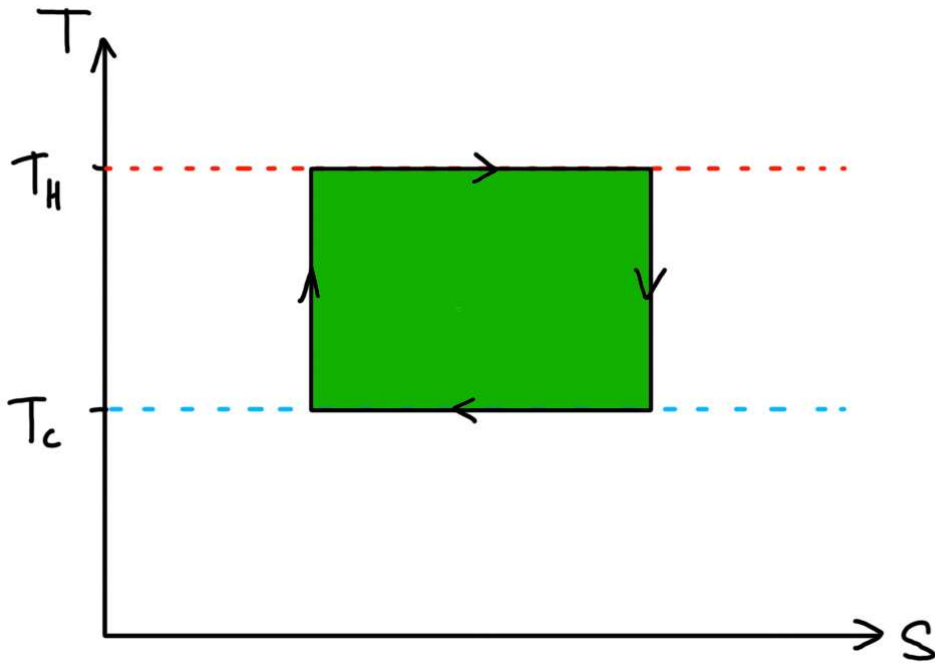
A) T_C / T_H

B) $(T_H - T_C) / T_H$

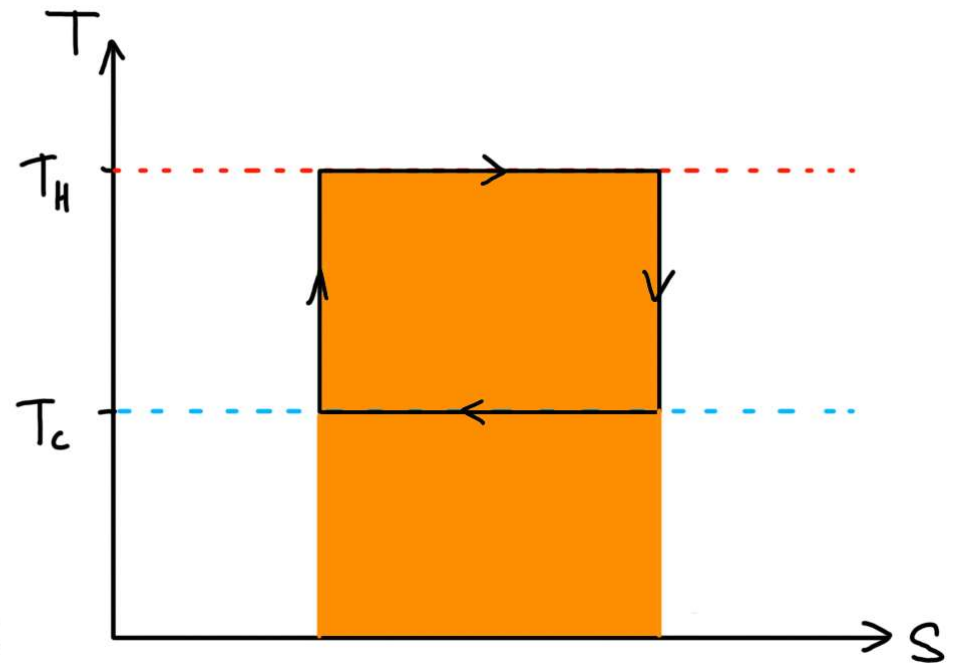
C) $T_H / (T_C + T_H)$

D) $T_C / (T_C + T_H)$

E) $(T_H - T_C) / (T_C + T_H)$



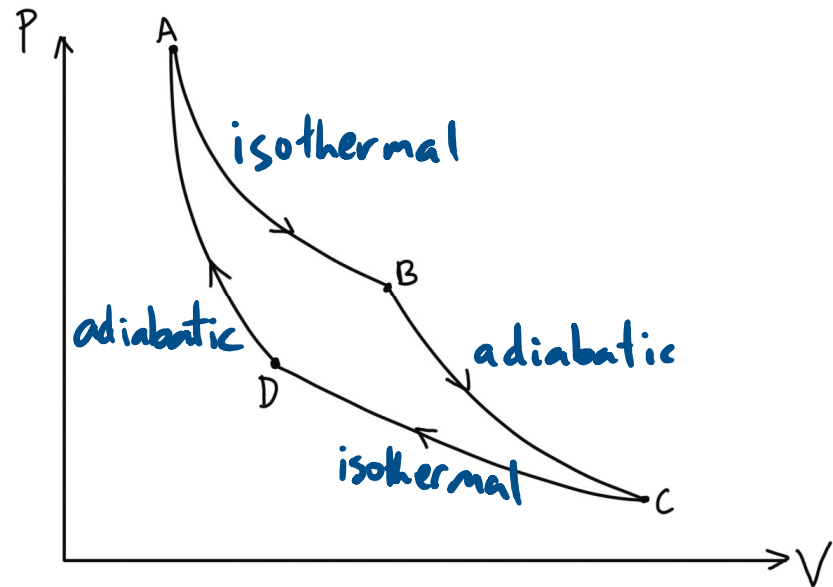
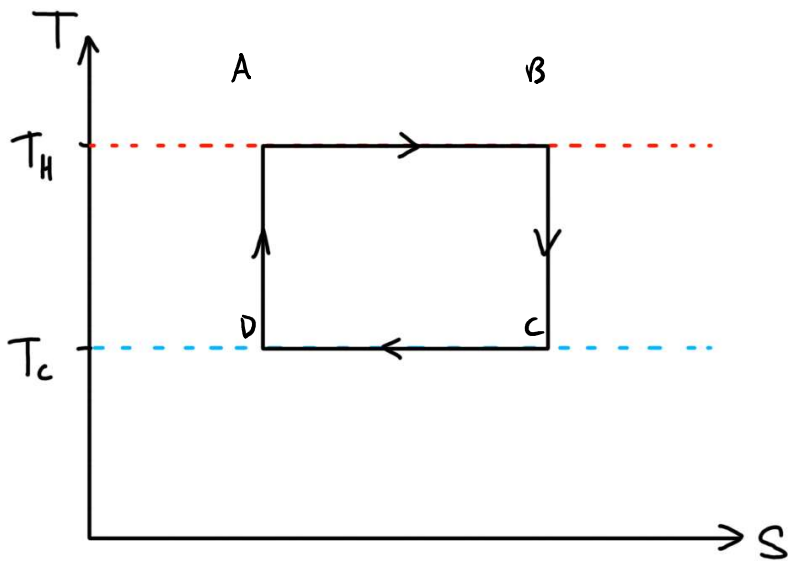
$$W = (T_H - T_C) \cdot \Delta S$$



$$Q_{in} = T_H \cdot \Delta S$$

$$e = \frac{W}{Q_{in}} = \frac{T_H - T_C}{T_H} = 1 - \frac{T_C}{T_H}$$

CARNOT CYCLE: maximum possible efficiency for fixed max & min temperatures T_H, T_C



efficiency $e = 1 - \frac{T_C}{T_H}$

not so useful in practice since isothermal processes must be very slow.

larger efficiency would violate 2nd Law of Thermodynamics