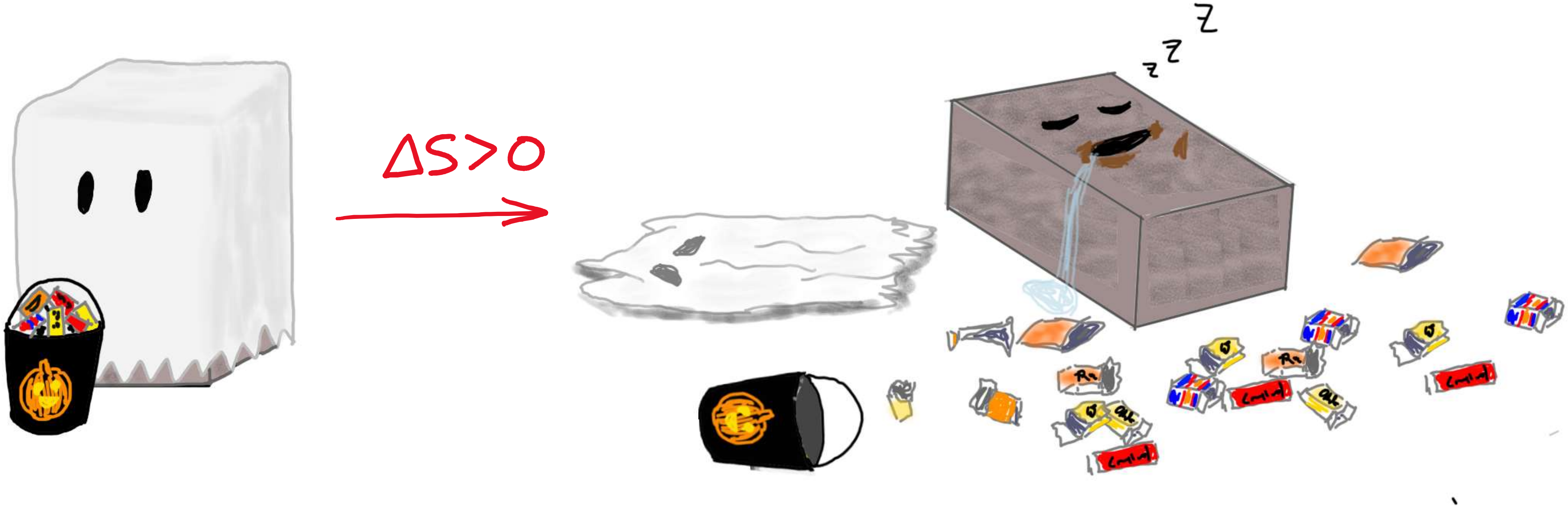
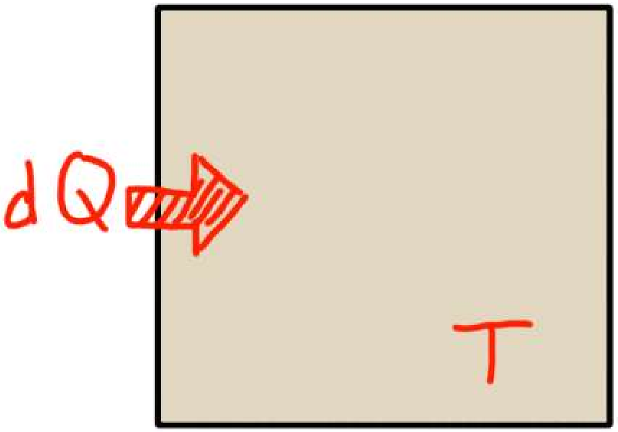
Last time in Physics 157...



ENTROPY : macroscopic definition



$$\underset{\text{change in entropy}}{dS} = \frac{dQ}{T}$$

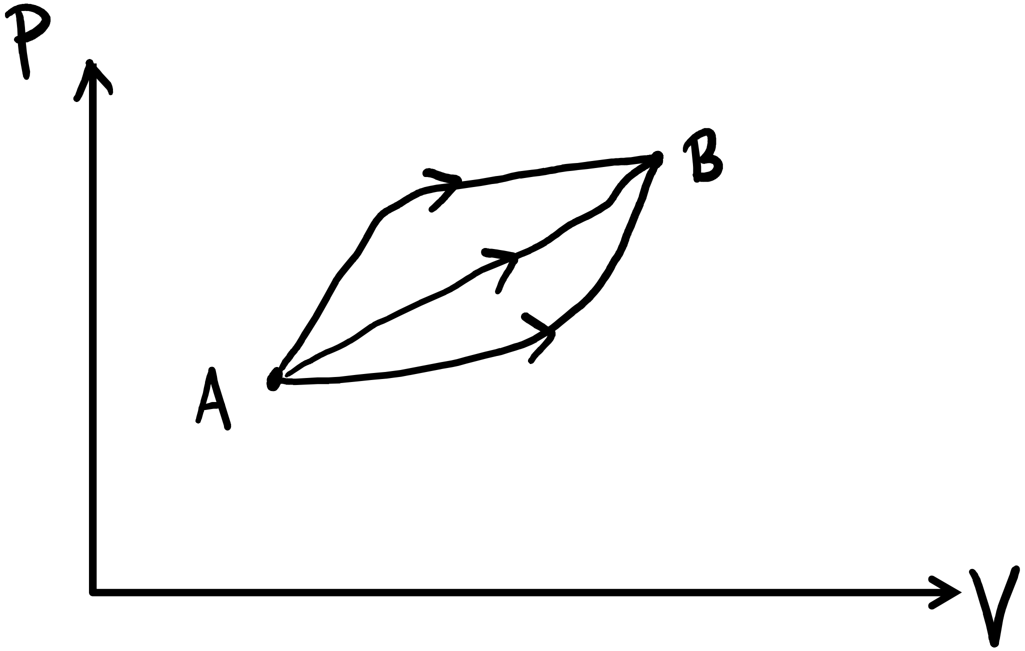
dQ ← heat added

Amazing result:

we can prove this from the microscopic definition of S.

★ see bonus video ★ https://www.youtube.com/watch?v=t7gyi8NhgYg

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



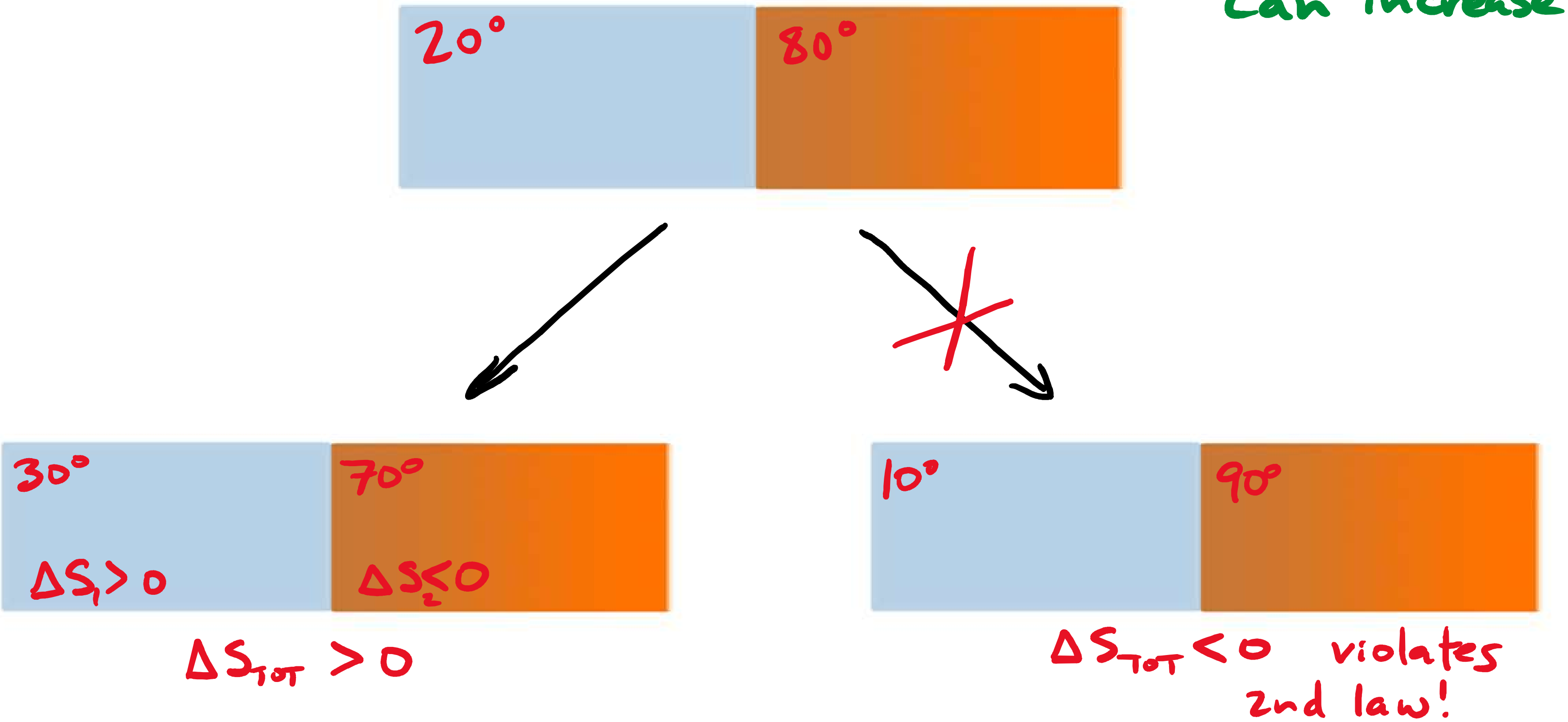
ΔS same for all paths, zero for cycle.

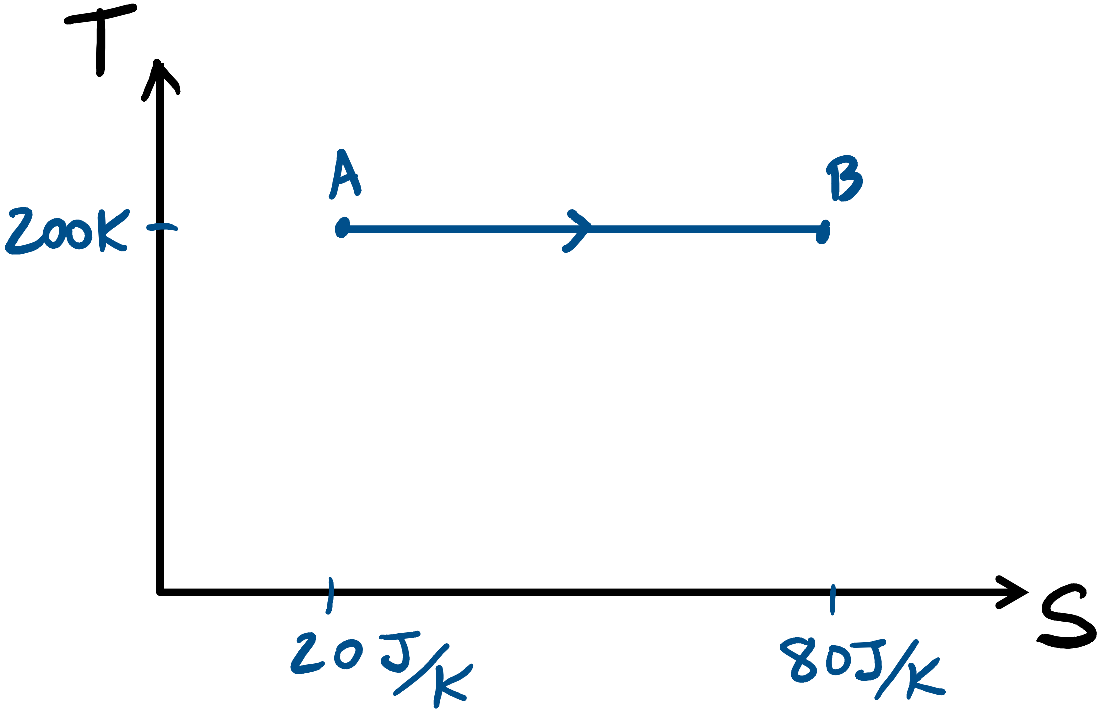
But: S for environment usually increases!

2ND LAW OF THERMODYNAMICS:

Total entropy never decreases.

of whole system → entropy for a part can increase





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

A) 4000 J

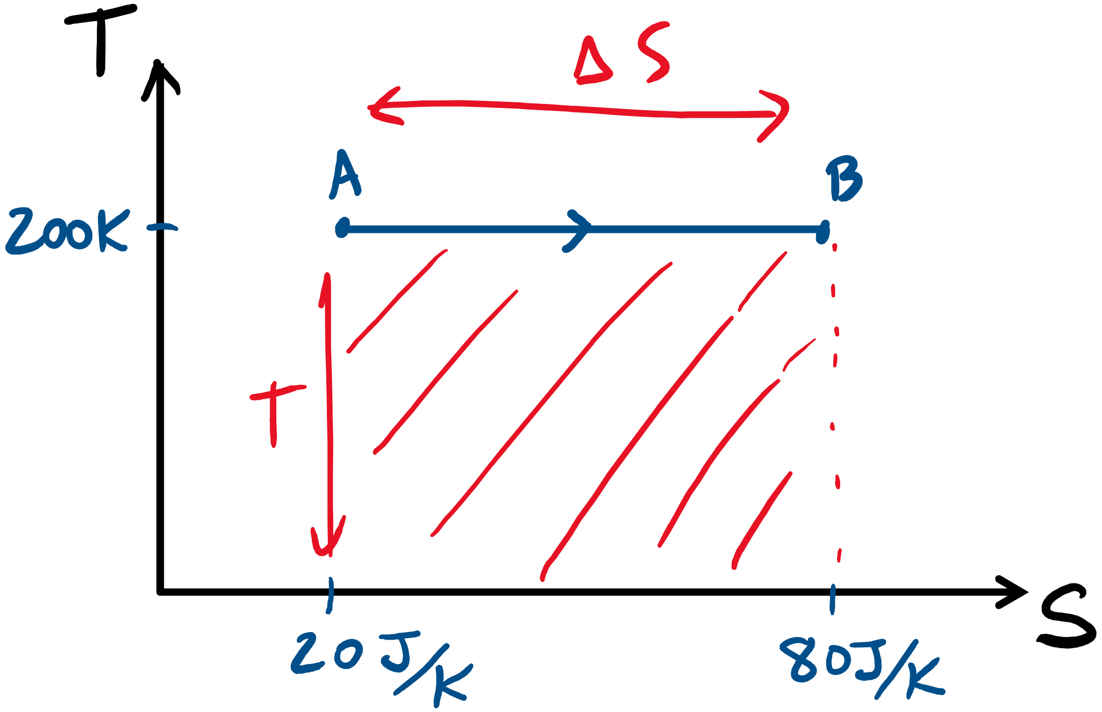
B) 8000 J

C) 10000 J

D) 12000 J

E) 16000 J

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



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

T constant so $Q = T\Delta S$

$= 200K \cdot 60 J/K$

$= 12{,}000 J$

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

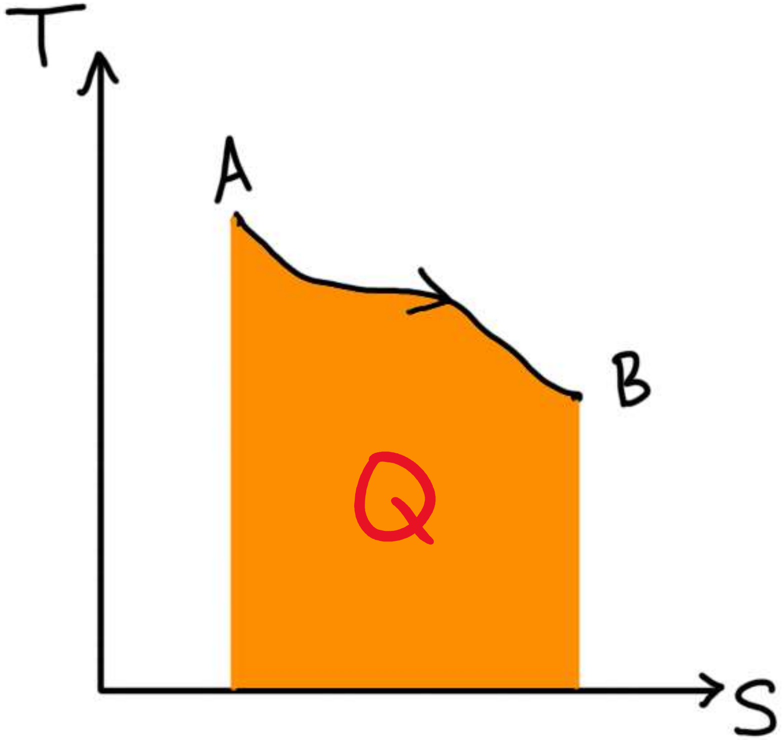
[✓ D) 12000 J]

E) 16000 J

Heat = area under curve on a T-S diagram

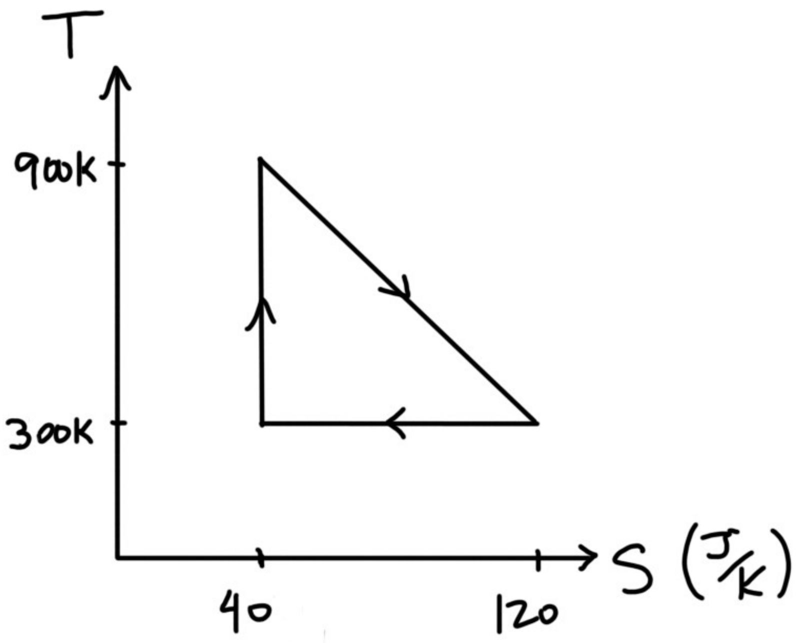
$$dQ = T\,dS$$

↖ area of small rectangle



S increasing ⇒ $Q > 0$

S decreasing ⇒ $Q < 0$



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

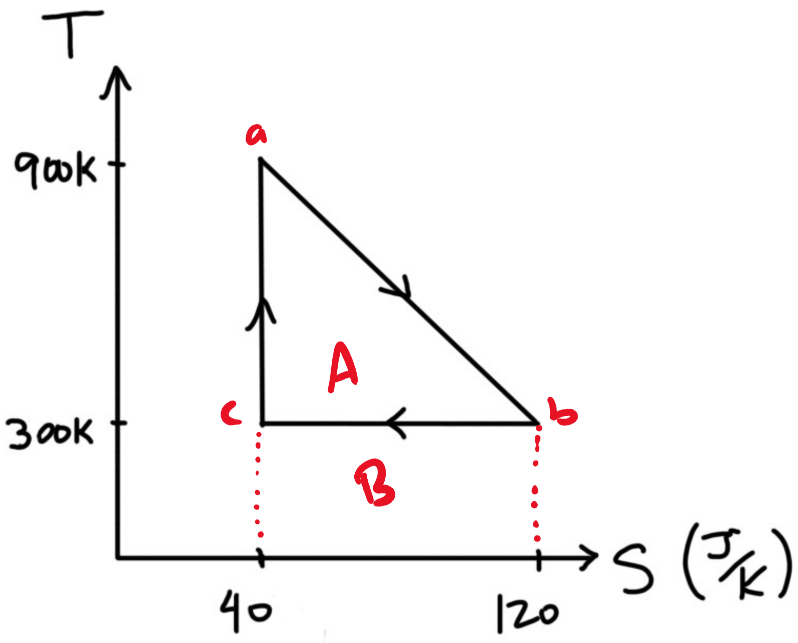
A) 4kJ

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]

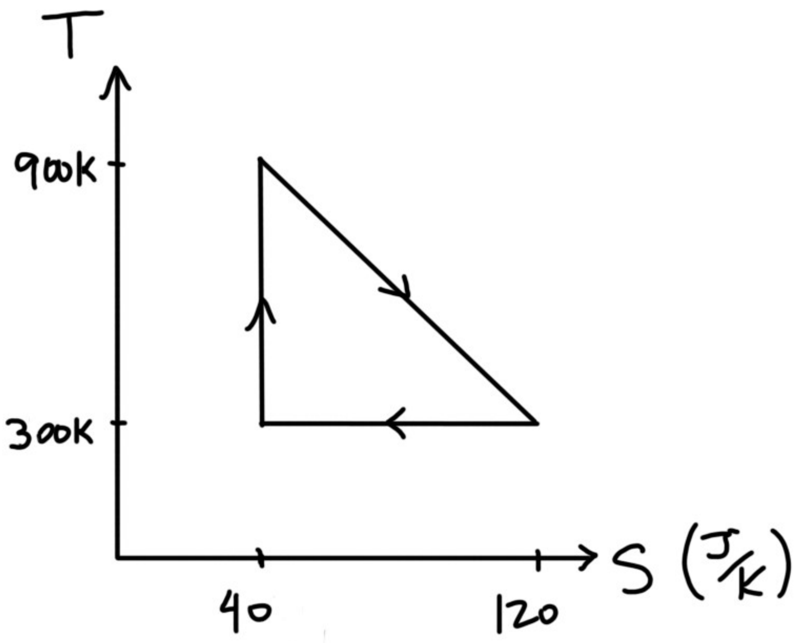
E) 32kJ

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

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

$Q_{c\to a} = 0$

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



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

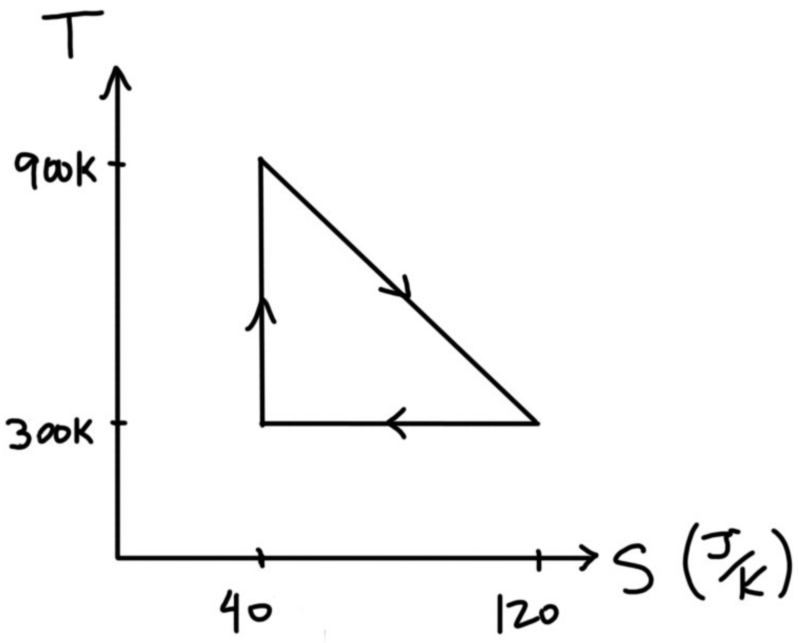
A) 4kJ

B) 8kJ

C) 12kJ

D) 24kJ

E) 32kJ



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

A) 4kJ

B) 8kJ

C) 12kJ

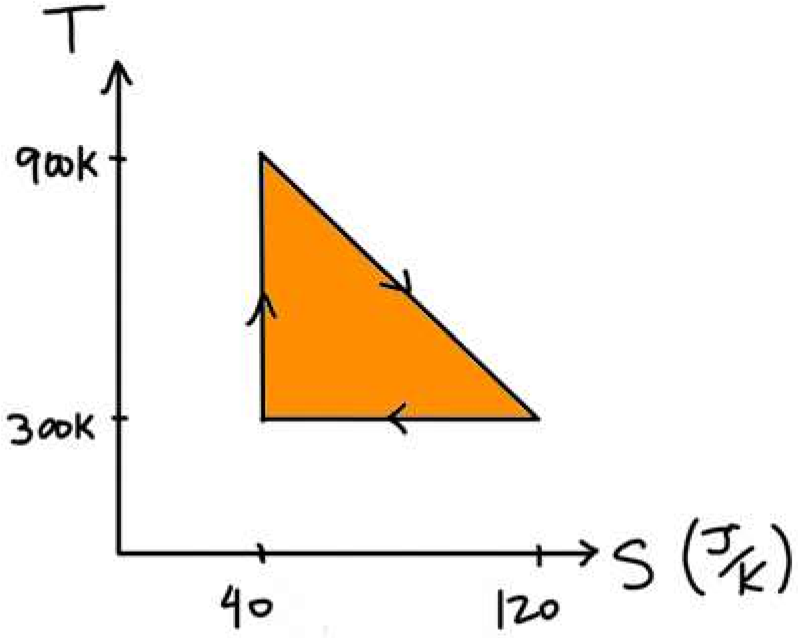
[✓ D) 24kJ]

E) 32kJ

$\Delta U = 0$ for full cycle

so $W = Q = 24\text{kJ}$

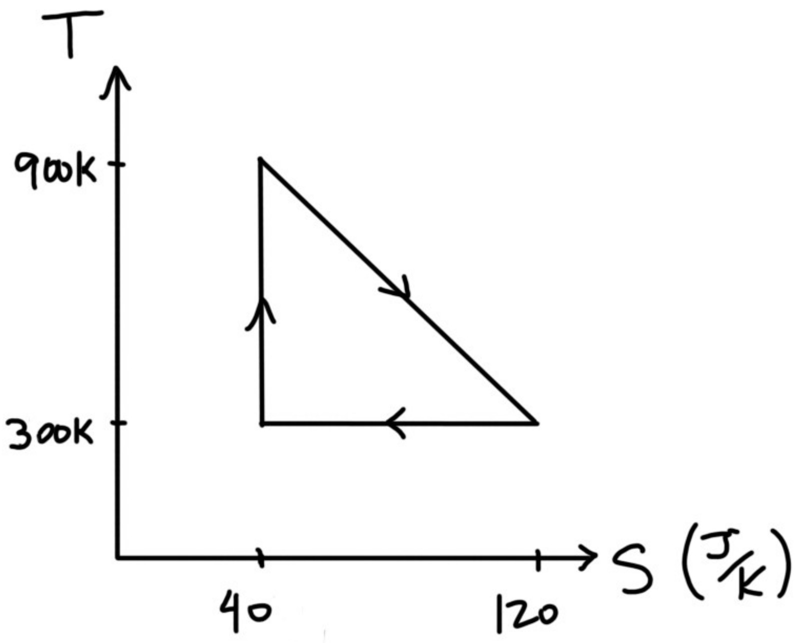
Net heat/work for a cycle from T-S diagram



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

clockwise : $Q > 0$

counterclockwise : $Q < 0$



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

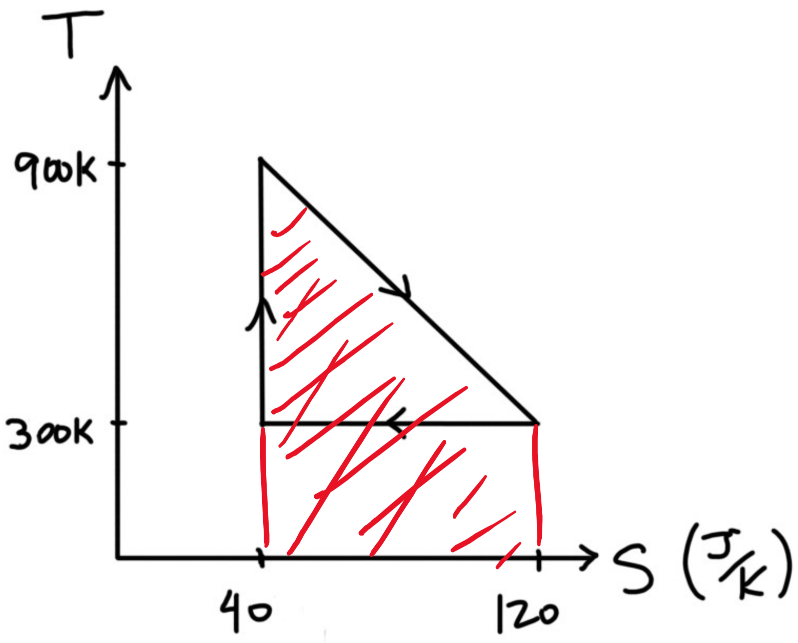
A) 0.333

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

$W_{net} = Q_{net}$

= area inside

= 24kJ

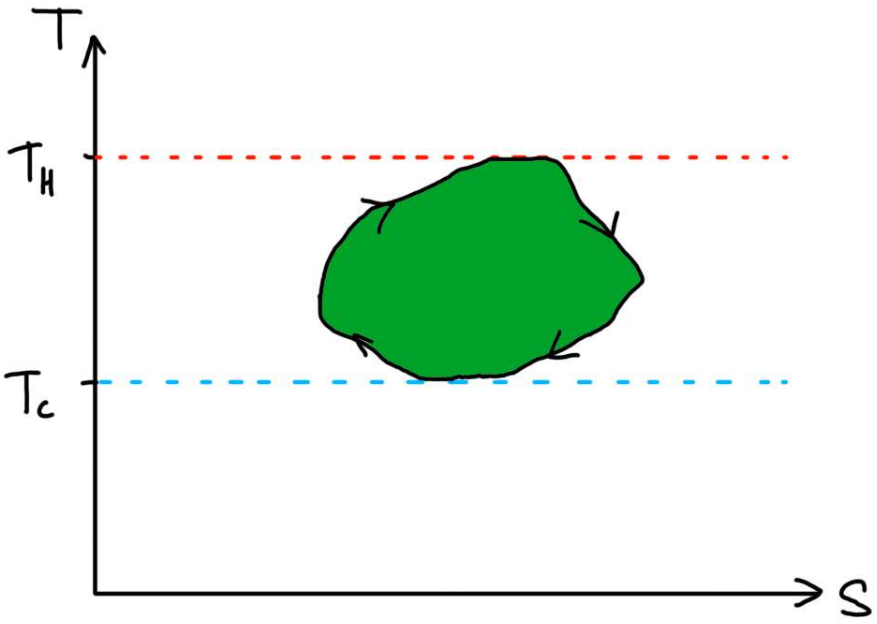
Q_{in} = area under part going to right.

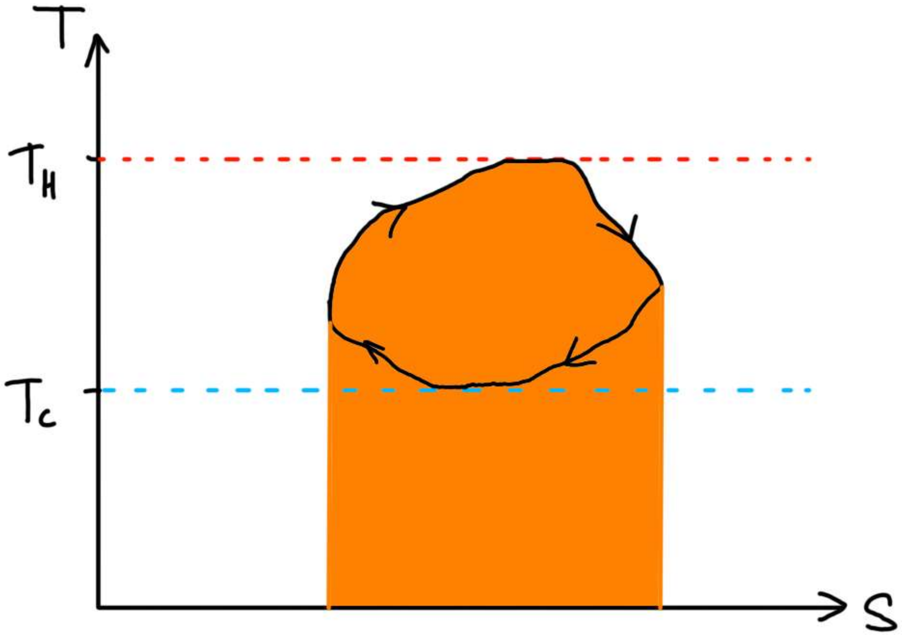
= shaded area

= 48kJ

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

Efficiency from a T-S diagram

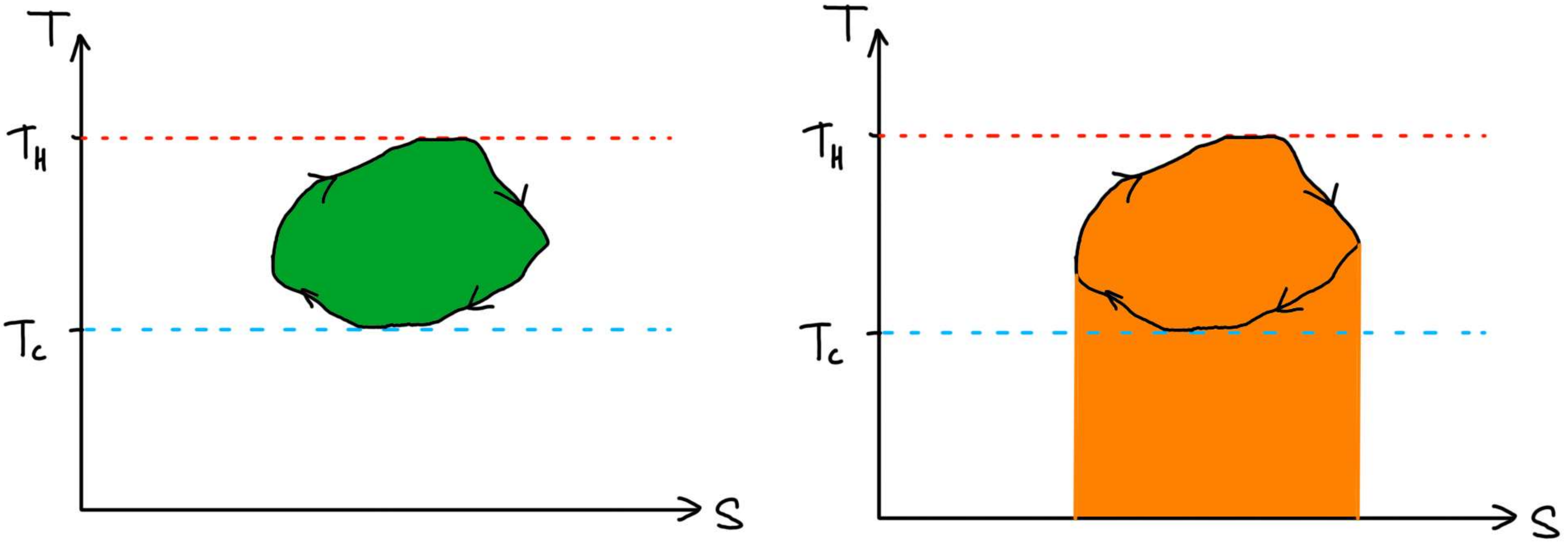




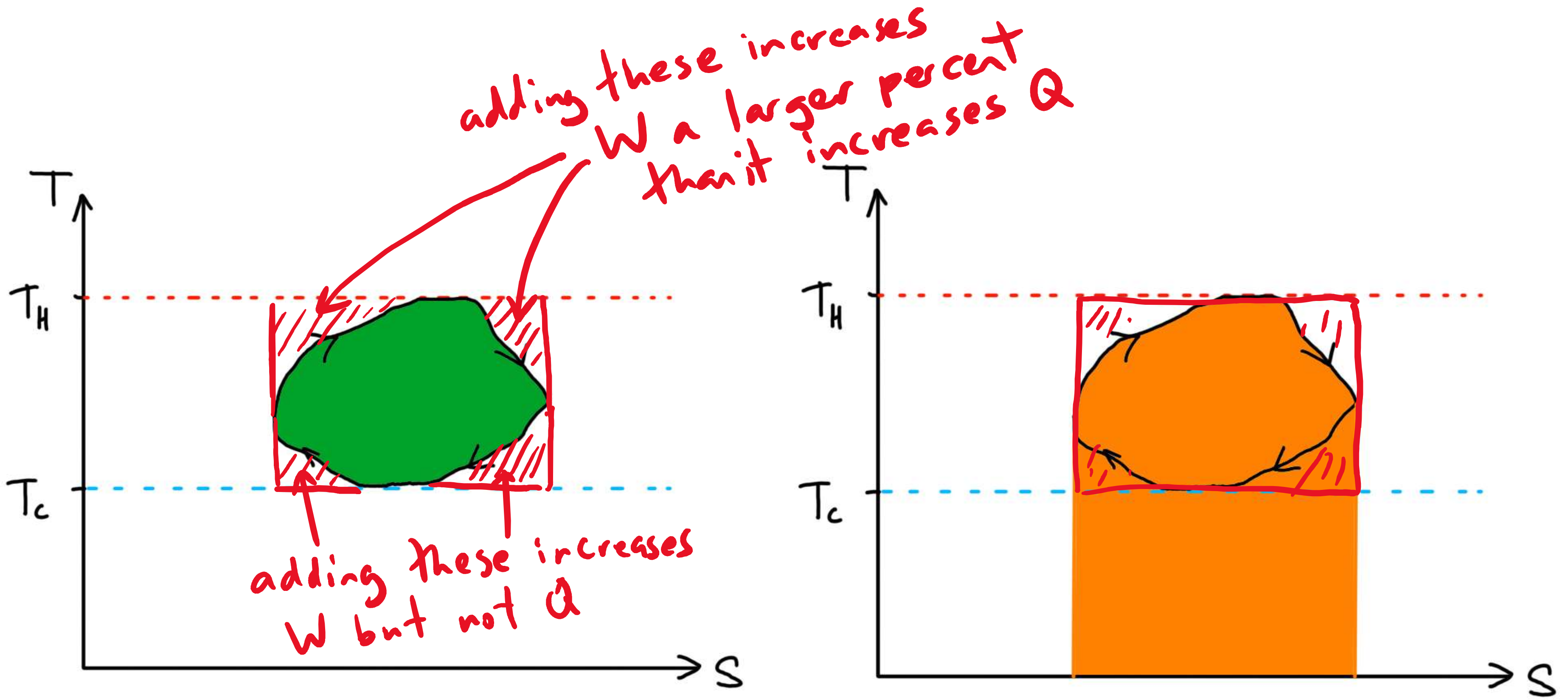
W_{net} = area enclosed

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

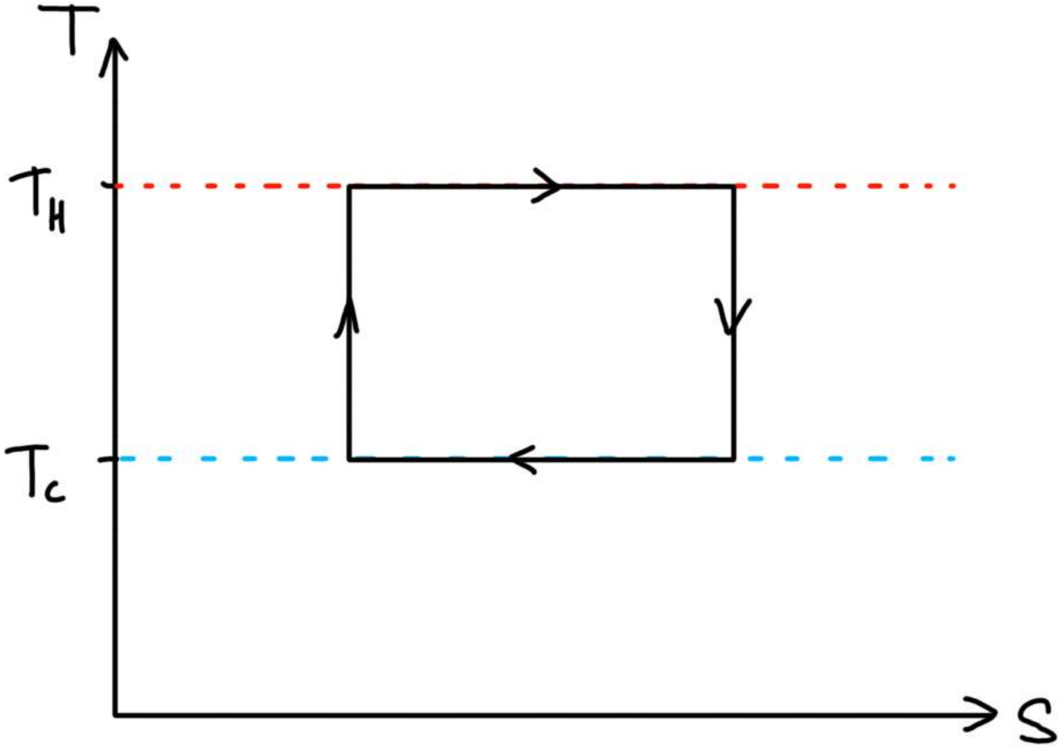


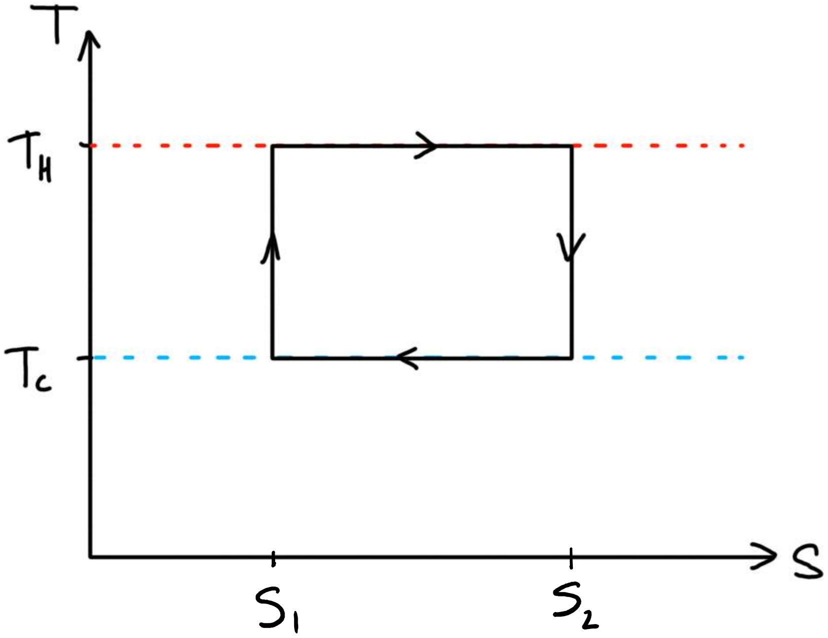
adding these increases W a larger percent than it increases Q

adding these increases W but not Q

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?

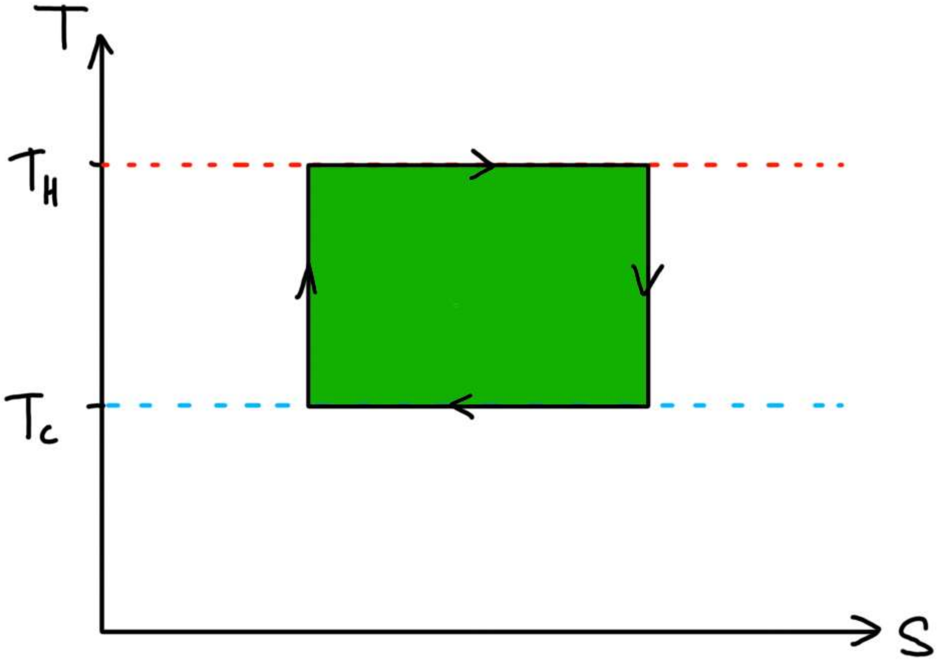
A) T_C / T_H

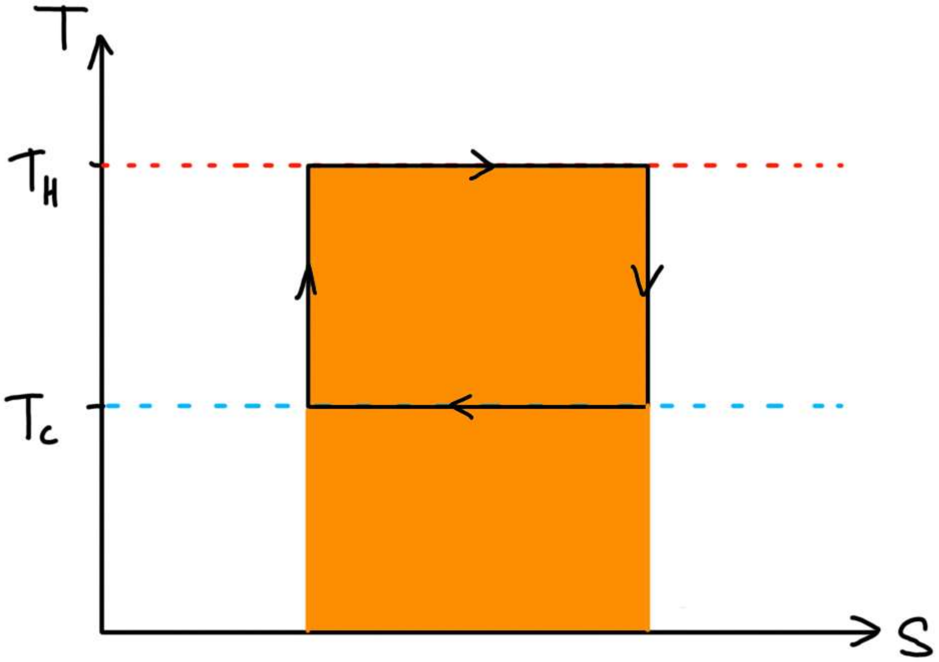
B) $(T_H - T_C) / T_H$

C) $T_H / (T_C + T_H)$

D) $T_C / (T_C + T_H)$

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



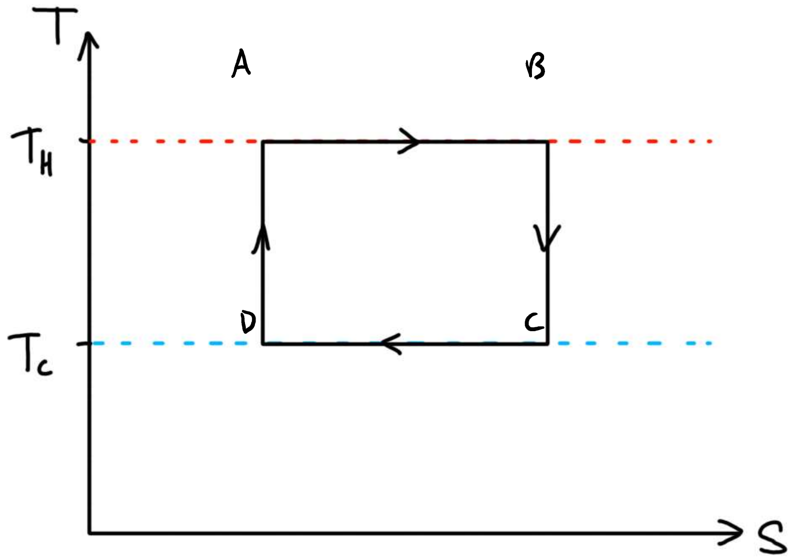


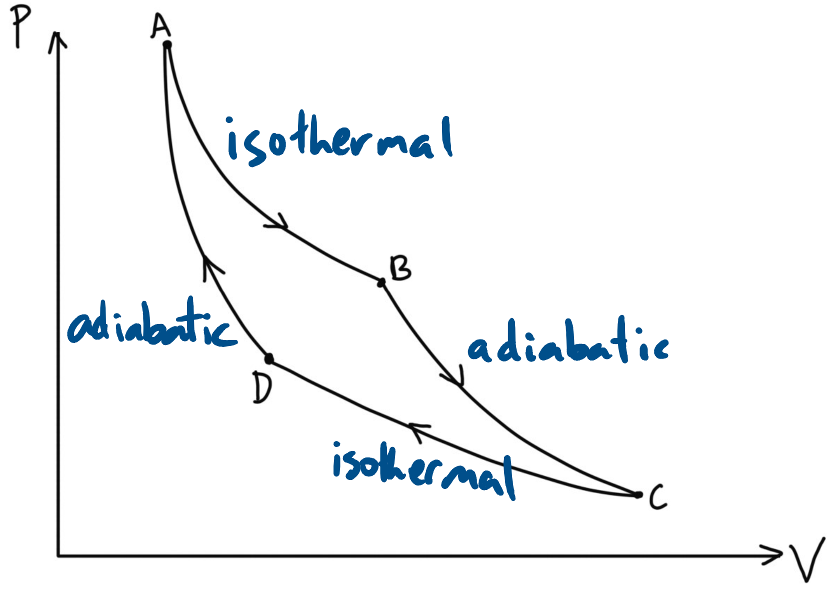
$$W = (T_H - T_c) \cdot \Delta S$$

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

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

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