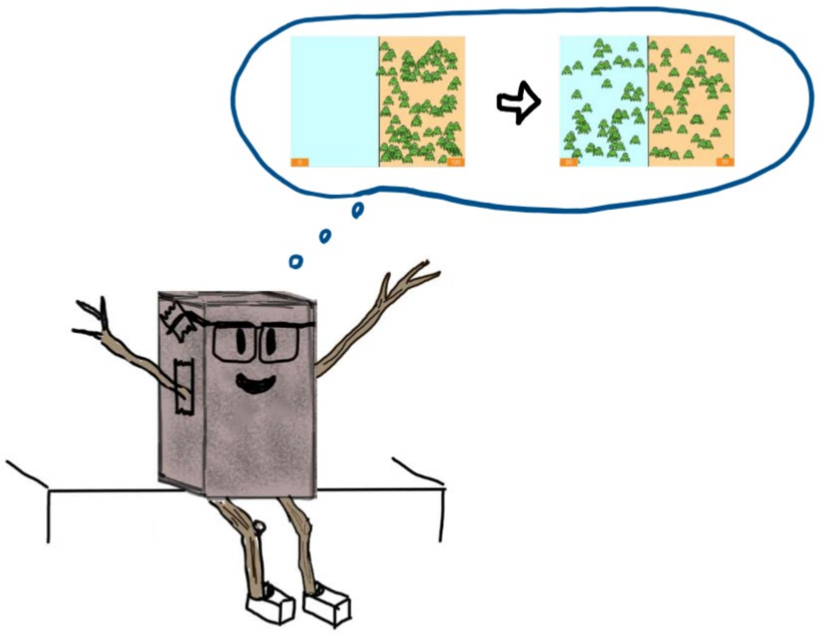
Lecture 24.

T,S-diagrams. Carnot cycle.

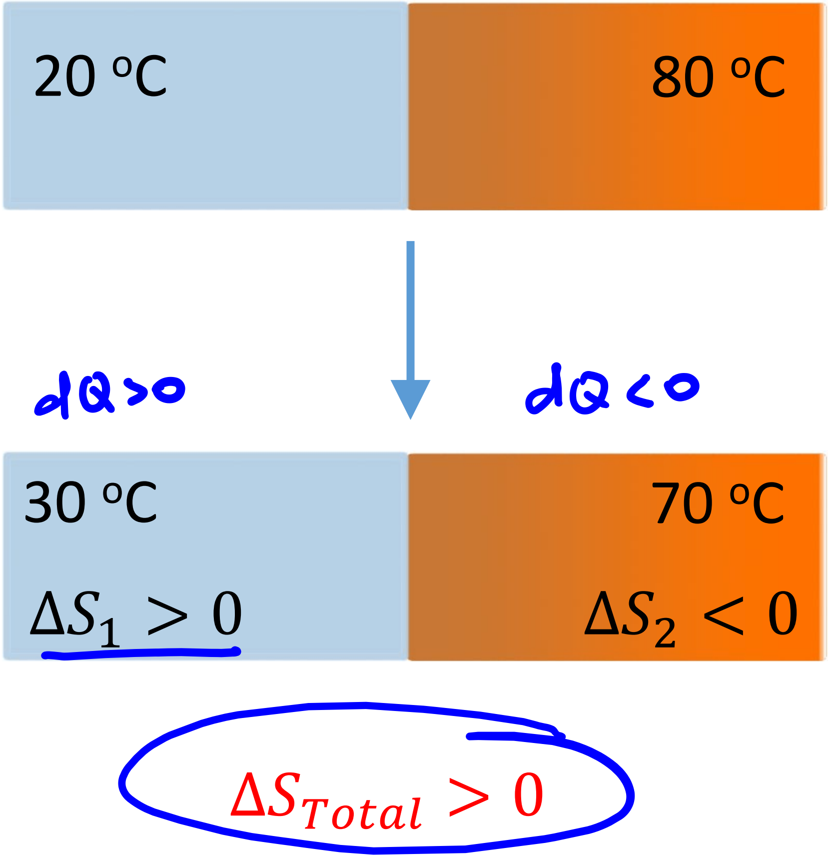


2nd Law of Thermodynamics

Last Time

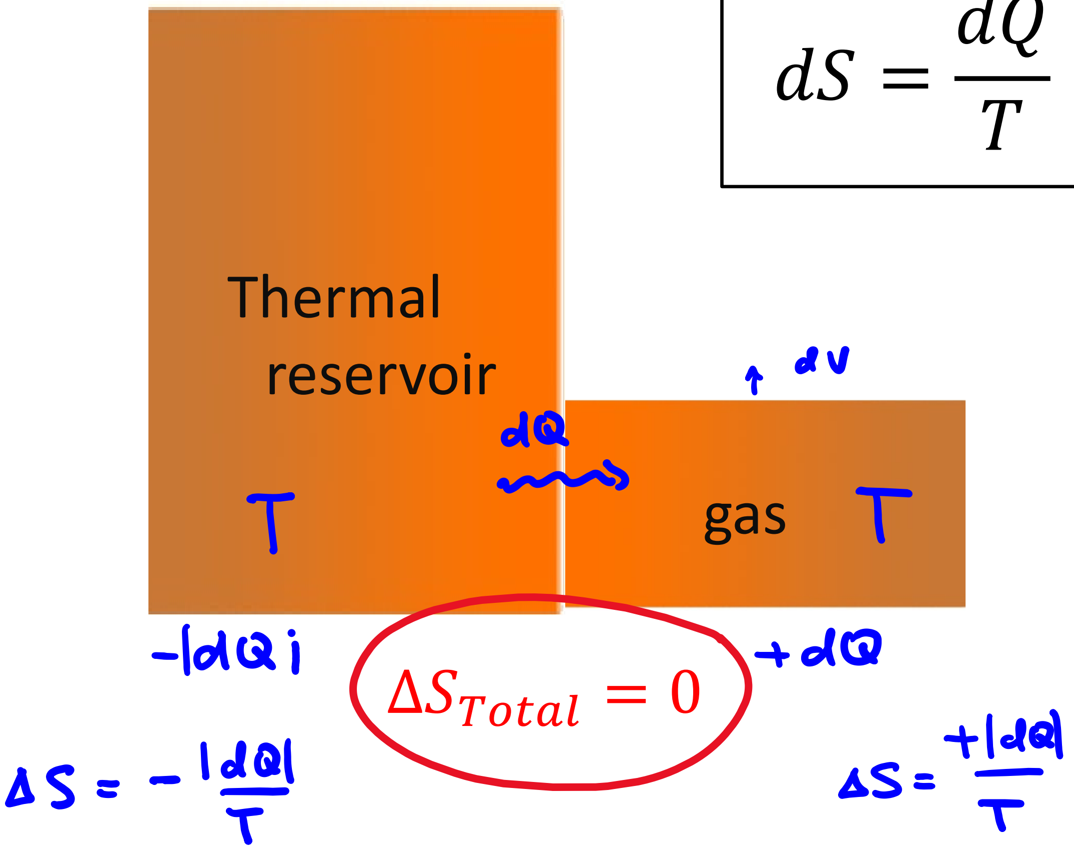
Total entropy never decreases

(of whole system – a probability of a part can decrease!)



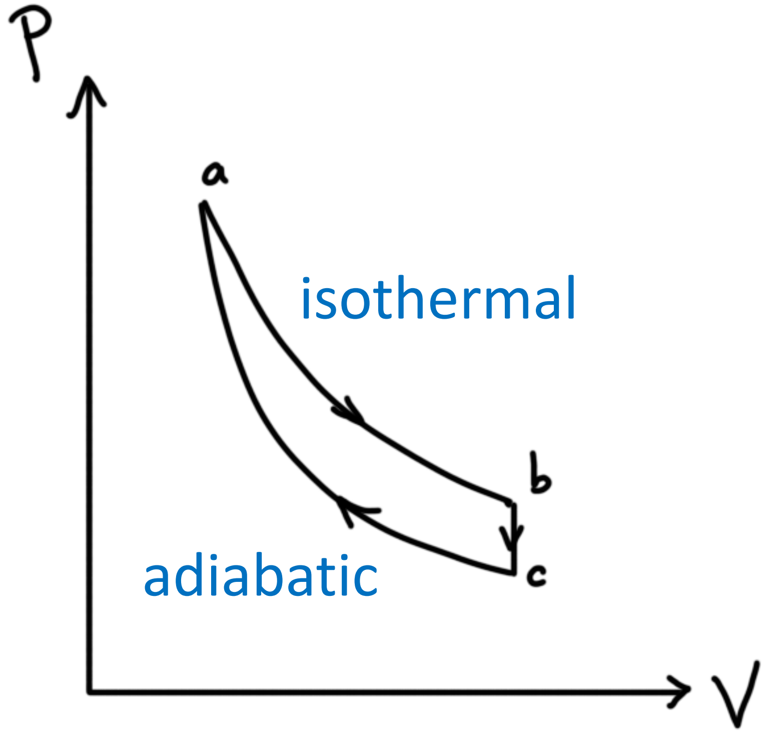
irreversible

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



reversible

Q: In the cycle shown, the change in entropy for the system around a complete cycle is

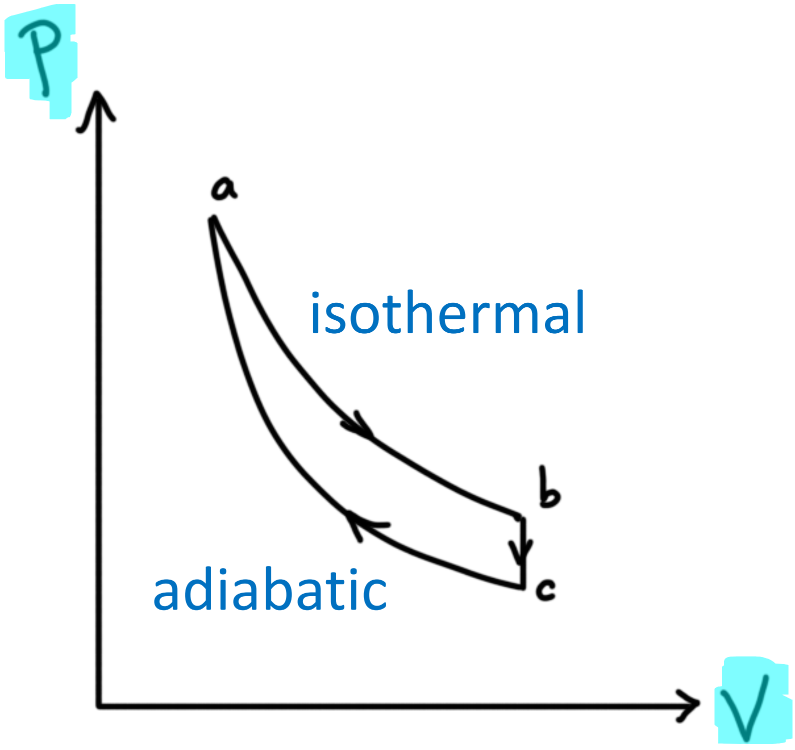


A. Positive

B. Zero

C. Negative

Q: In the cycle shown, the change in entropy for the system around a complete cycle is

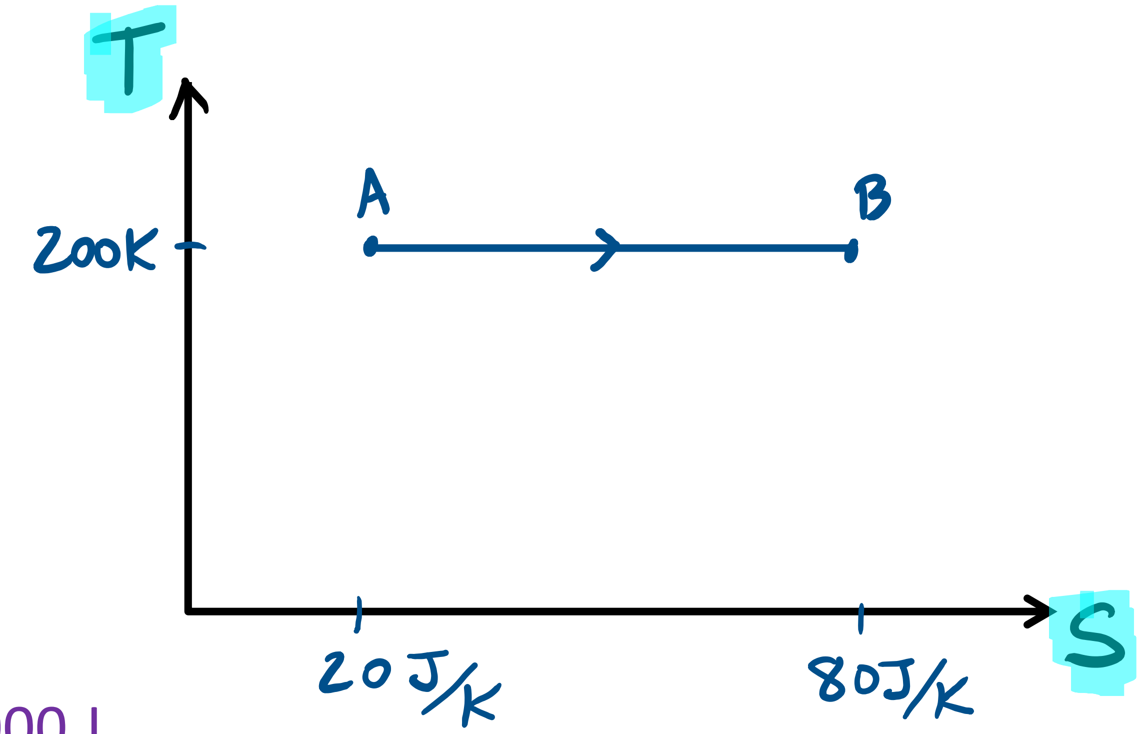


$$\boxed{dS = \frac{dQ}{T}}$$

- S is a state variable
- Around a whole cycle, we come back to the same state, so $\Delta S = 0$

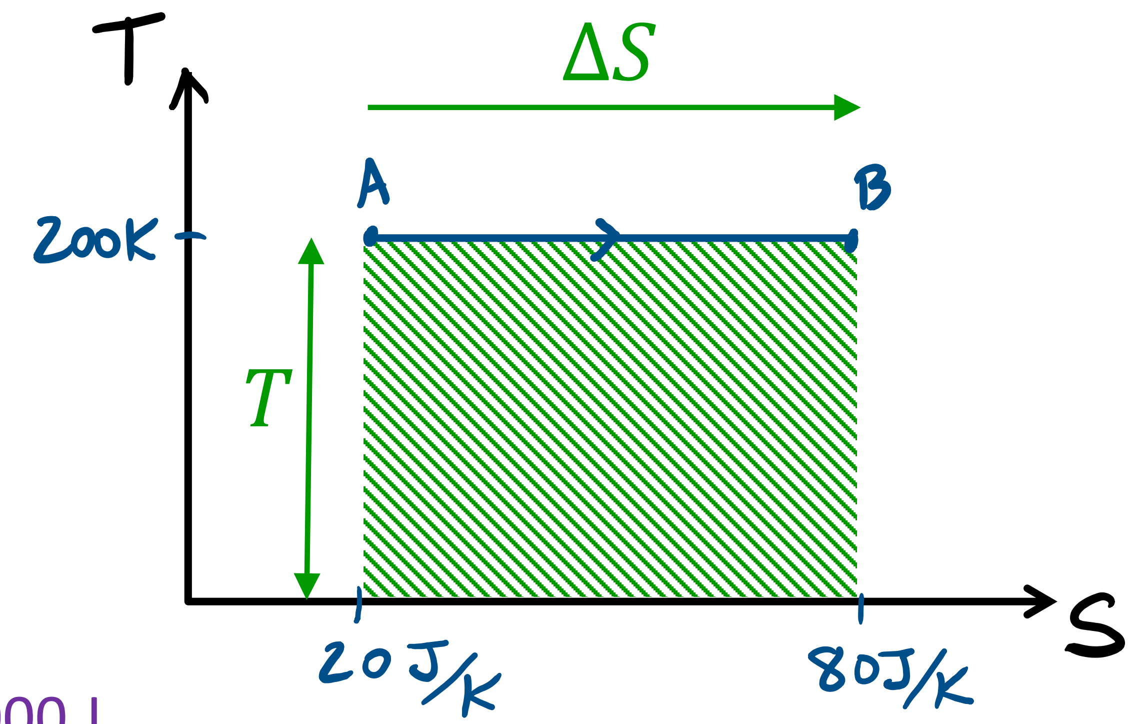
A. Positive
B. Zero ✓
C. Negative

Q: 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

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



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

- $dS = \frac{dQ}{T} \Longrightarrow dQ = TdS$
- T constant so $Q = T\Delta S$
  $= 200K \cdot 60\,J/K = 12{,}000\,J$

A. 4000 J

B. 8000 J

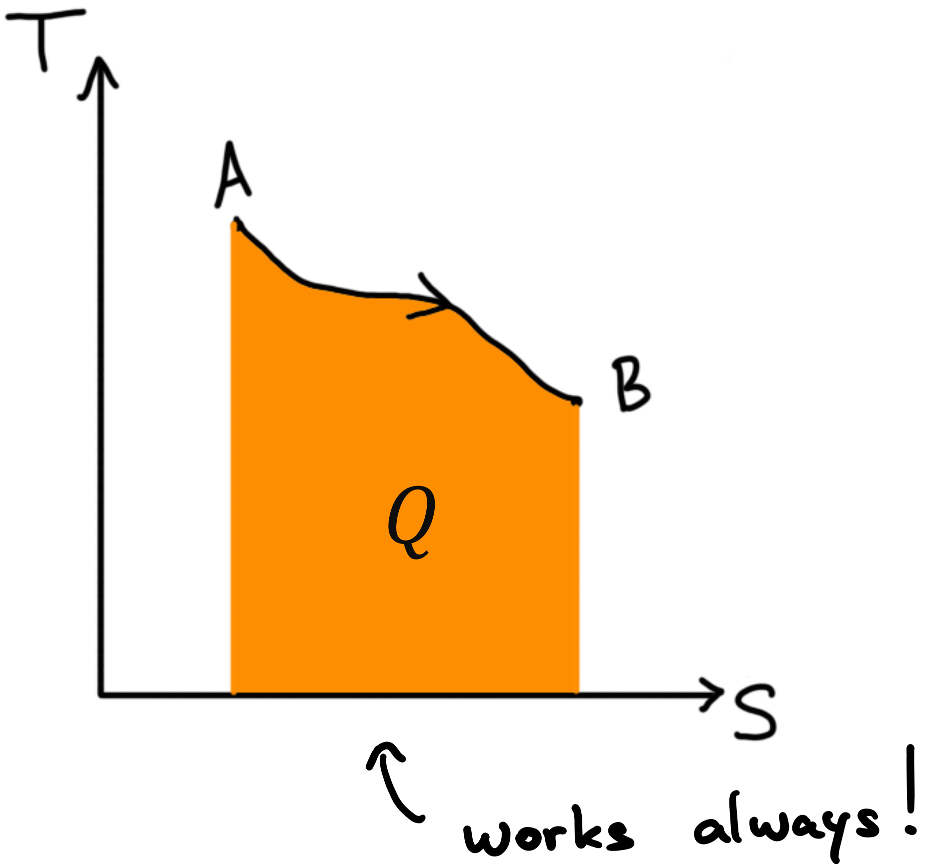
C. 10000 J

D. 12000 J ✓

E. 16000 J

- Heat = area under curve on a T-S diagram

$Q = T\Delta S$: only if $T =$ const



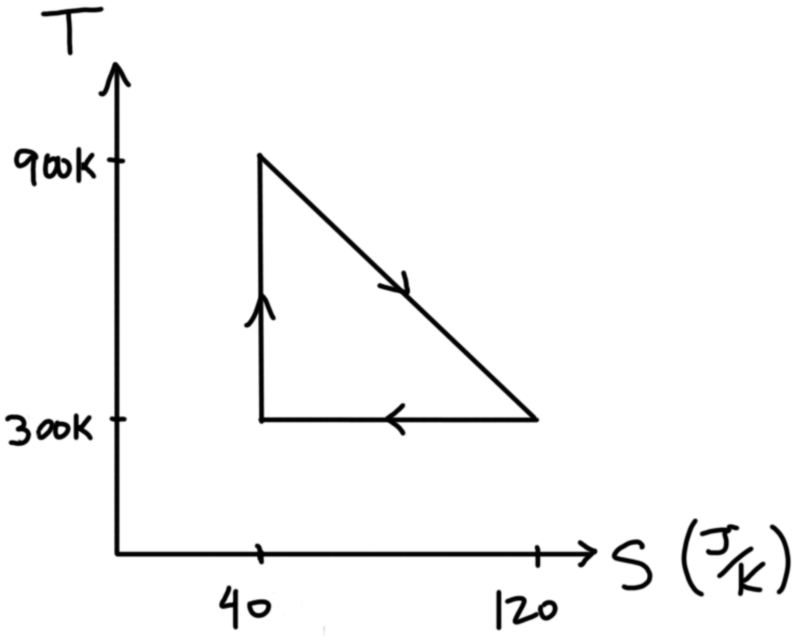
$$\boxed{dQ = TdS}$$

$$dQ = T\,dS$$

$$Q = \int dQ = \int_{T_1}^{T_2} T\,dS$$

- S increasing $\Longrightarrow Q > 0$
- S decreasing $\Longrightarrow Q < 0$

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



A. 4 kJ

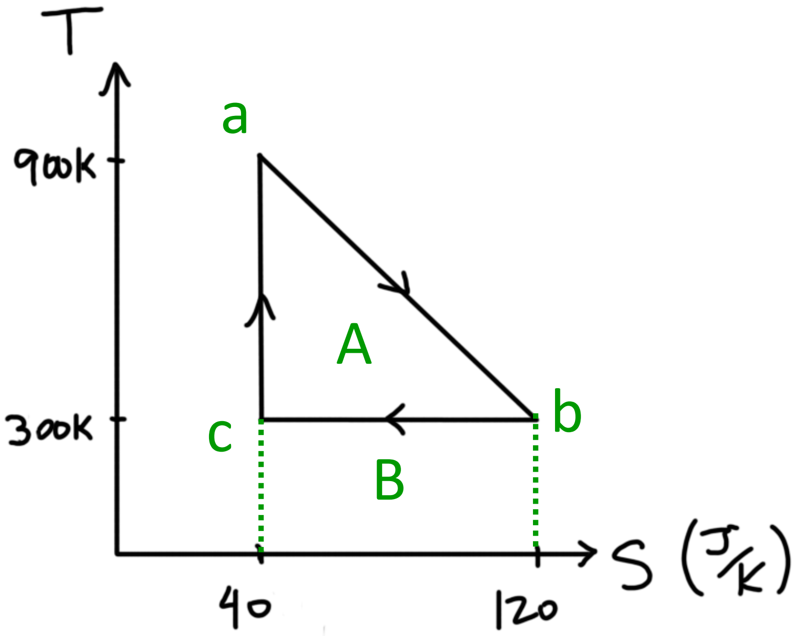
B. 8 kJ

C. 12 kJ

D. 24 kJ

E. 32 kJ

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



A. 4 kJ

B. 8 kJ

C. 12 kJ

D. 24 kJ

E. 32 kJ

$$Q_{net} = Q_{a\to b} + Q_{b\to c} + Q_{c\to a}$$

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

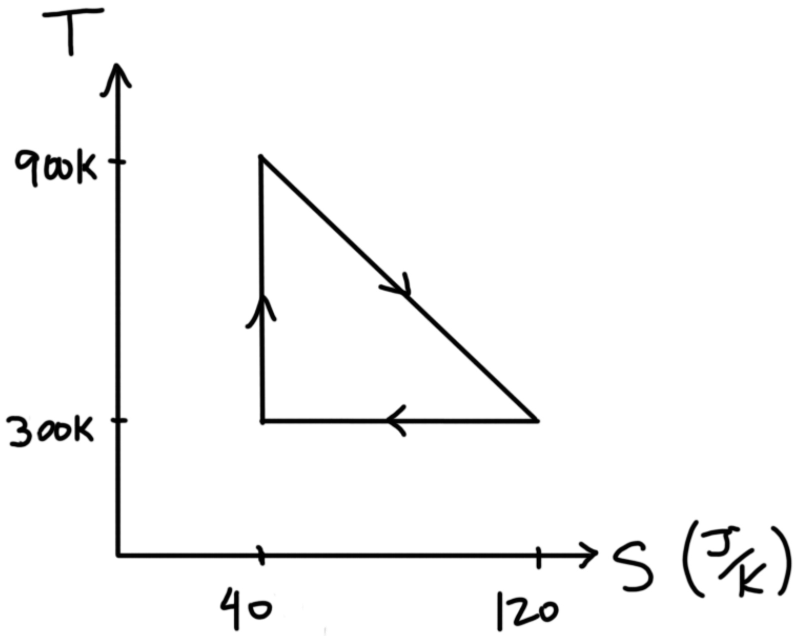
$$Q_{b\to c} = -\ area\ B$$

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

So:

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

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



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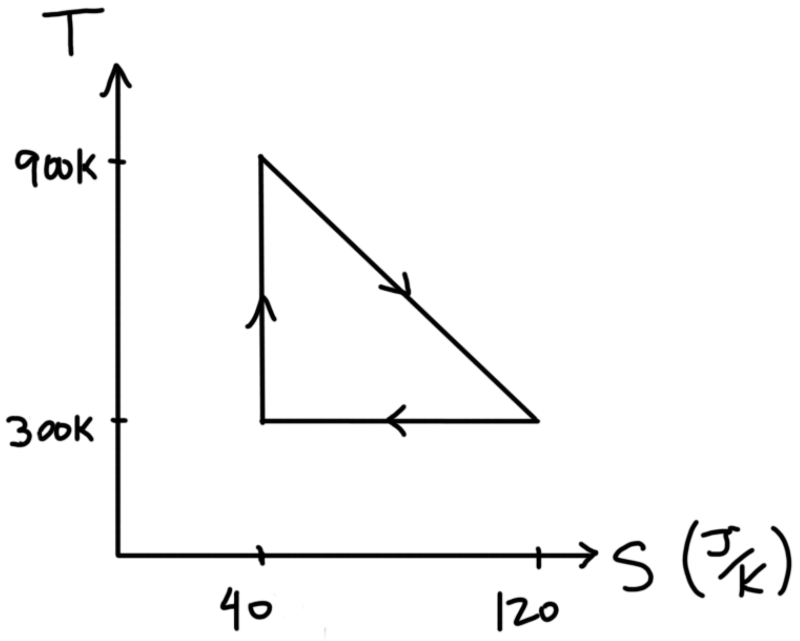


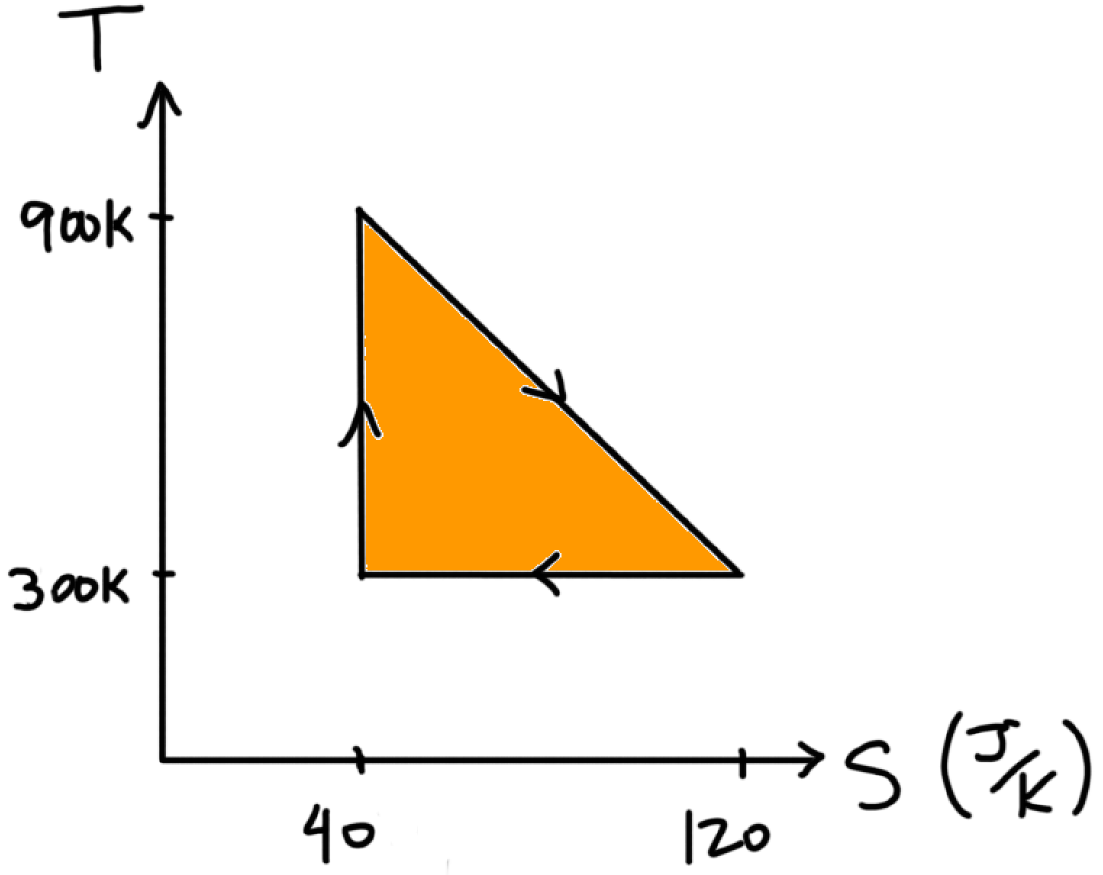
A. 4 kJ
B. 8 kJ
C. 12 kJ
D. 24 kJ ✓
E. 32 kJ

$\Delta U = 0$ for full cycle

So $W_{net} = Q_{net} = 24\ kJ$

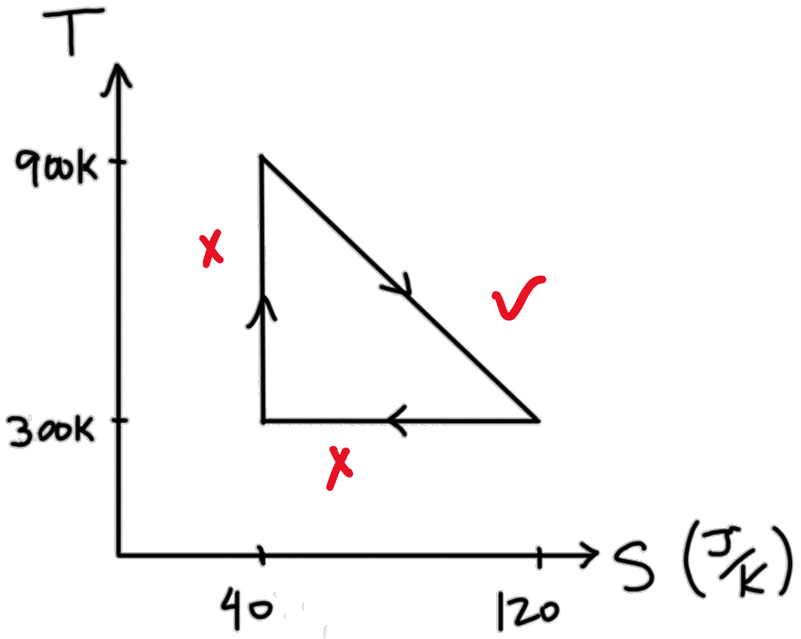
$\Delta U = Q - W$ 1st law

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



- $Q_{net} = W_{net} =$ area inside
- Clockwise: $Q > 0$
- Counterclockwise: $Q < 0$

Q: What is the efficiency described by the cycle shown?



$$e = \frac{W_{net}}{Q_{in}}$$

$$\Delta U = 0 : W_{net} = Q_{net}$$

A. 0.333

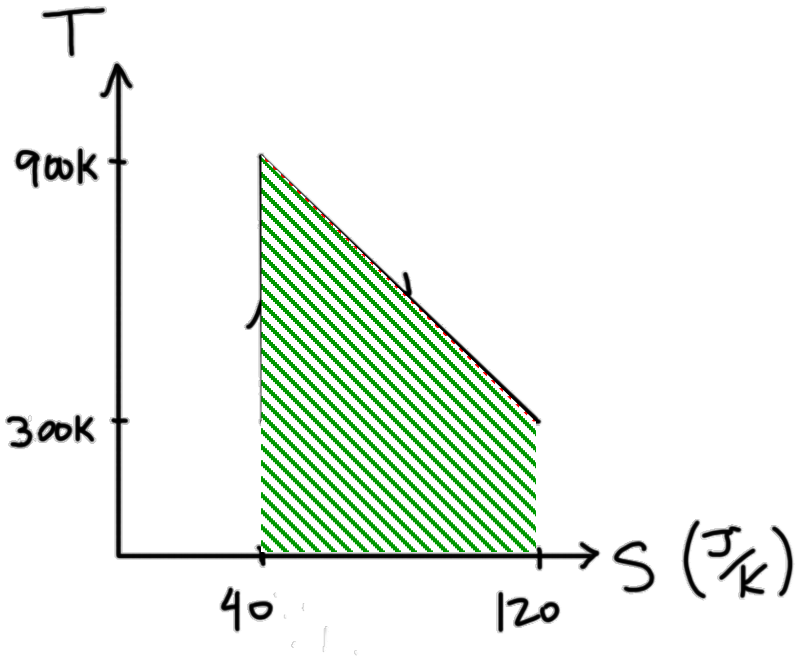
B. 0.400

C. 0.500

D. 0.666

E. 1.000

Q: What is the efficiency described by the cycle shown?



A. 0.333

B. 0.400

C. 0.500

D. 0.666

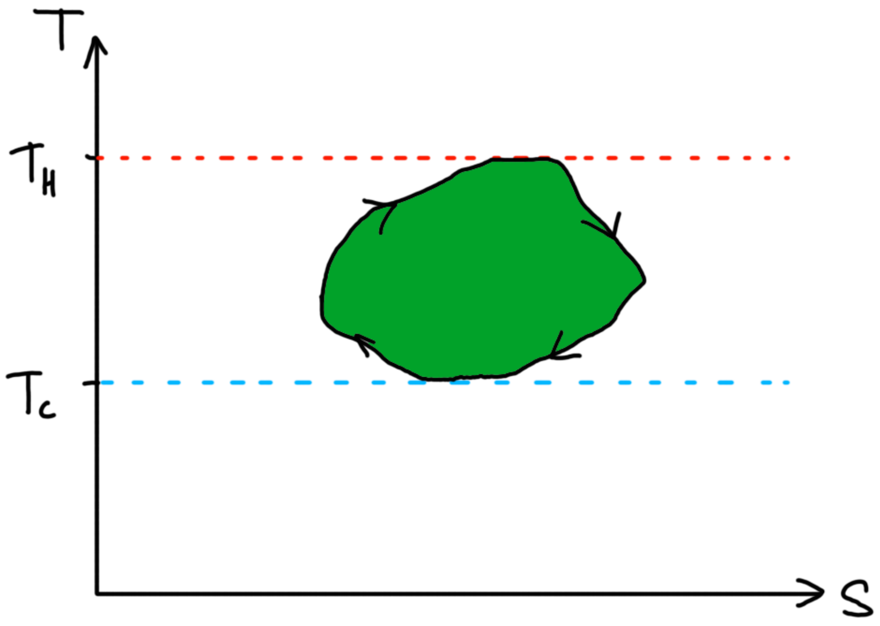
E. 1.000

- $W_{net} = Q_{net} =$ area inside = 24 kJ
- Q_{in} = area under part going to right

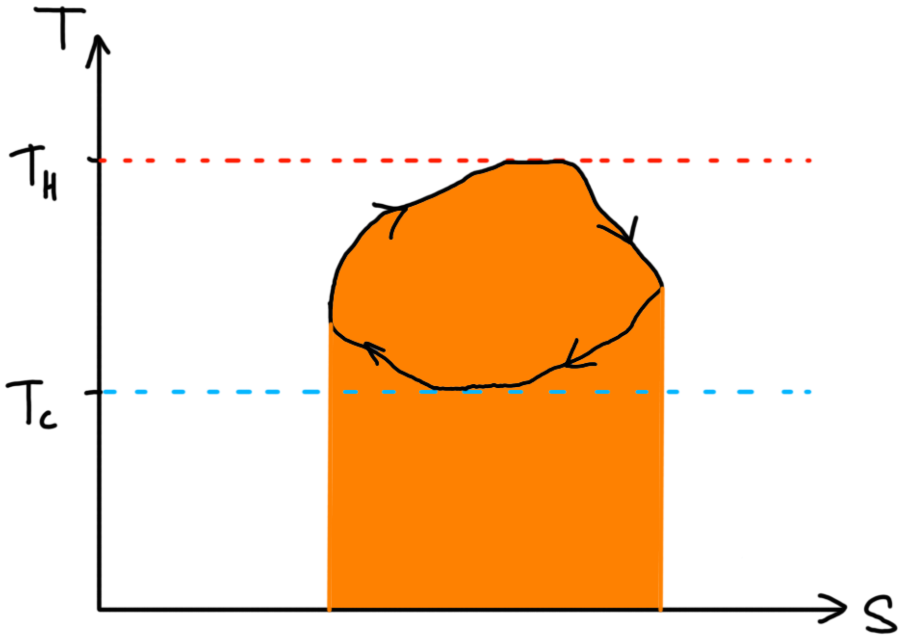
  = green shaded area = 48 kJ

$$e = \frac{W_{net}}{Q_{in}} = \frac{1}{2}$$

- Efficiency for a cycle from T-S diagram



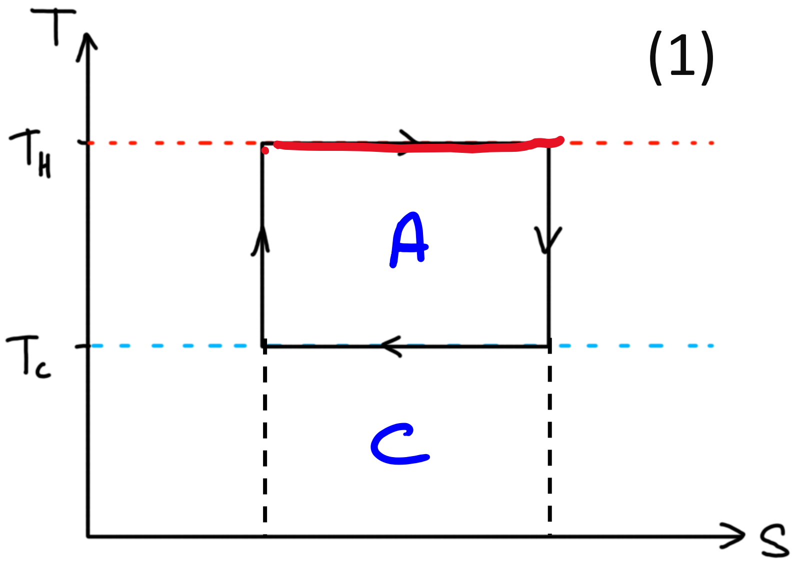
W_{net} = area enclosed

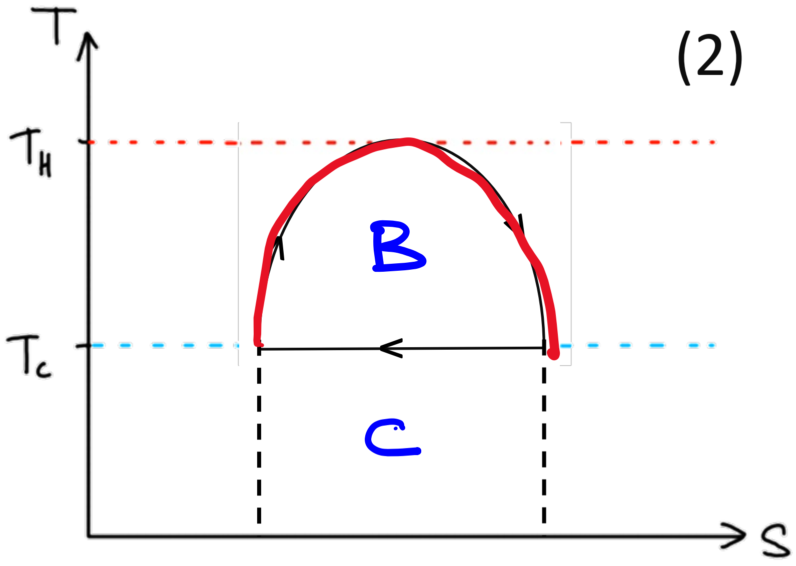


Q_{in} = area under $\Delta S > 0$ parts

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

Q: Which of these two cycles has a higher efficiency?





$$e_1 = \frac{A}{(A+C)} \;\overset{>}{?}\; e_2 = \frac{B}{(B+C)}$$

$$A(\cancel{B}+C) \;?\; B(\cancel{A}+C)$$

$$A\cancel{C} > B\cancel{C}$$

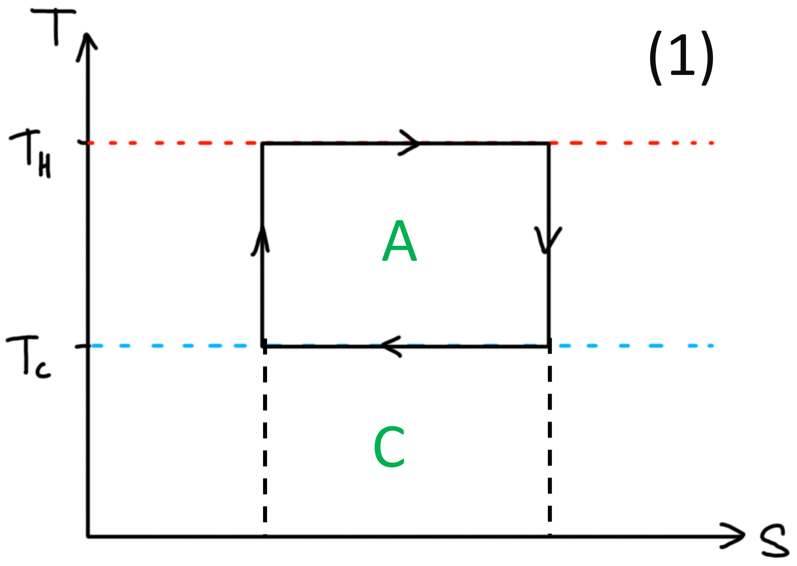
D. It depends

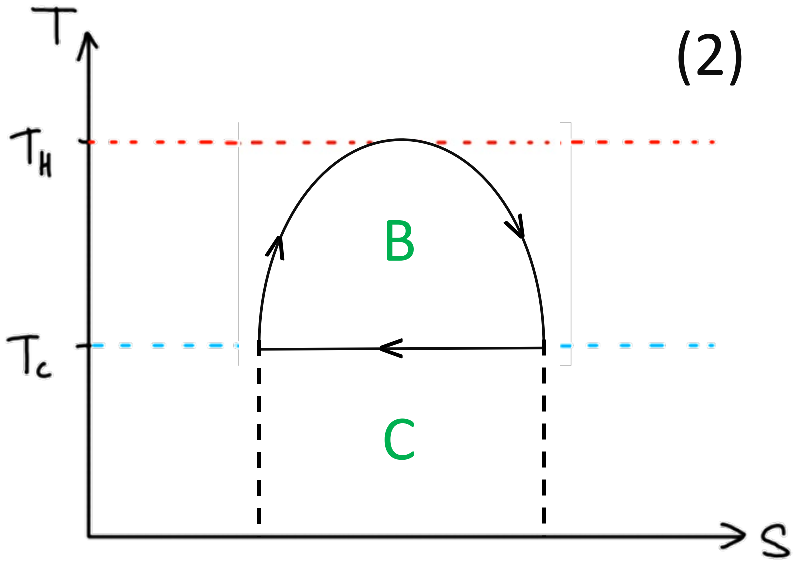
A. (1)

B. (2)

C. Same efficency

Q: Which of these two cycles has a higher efficiency?



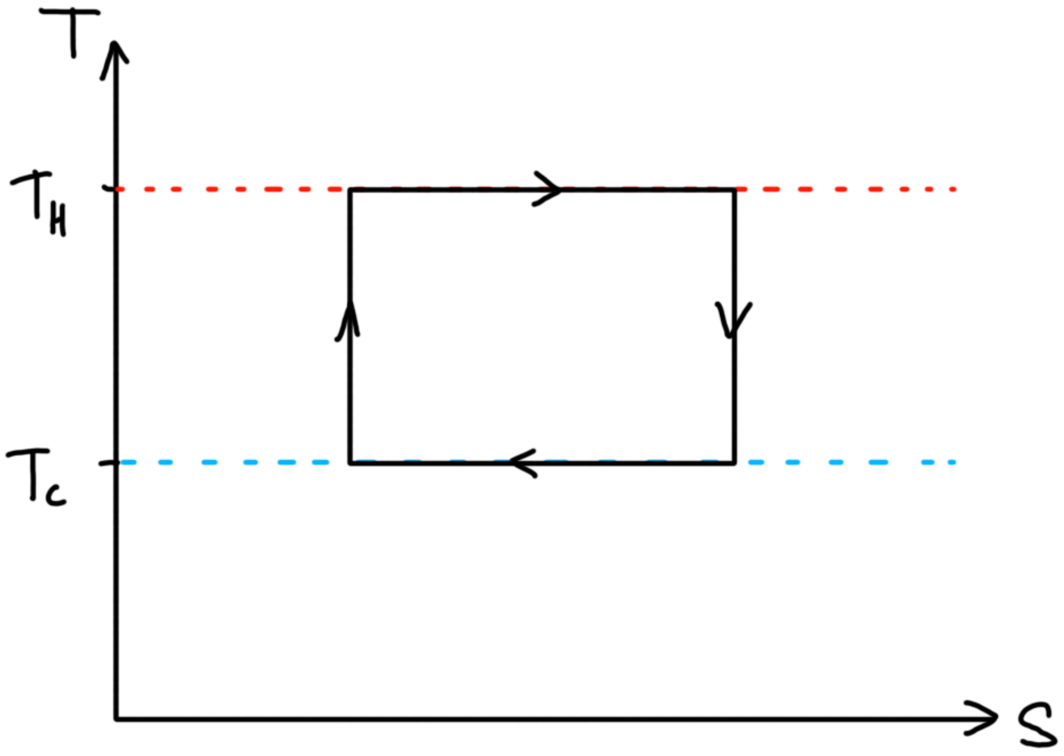


- $e_1 = \frac{A}{A+C}$? $e_2 = \frac{B}{B+C}$
- $A(B + C)$? $B(A + C)$
- AC ? BC
- A ? B
- Since $A > B$, we get that $e_1 > e_2$

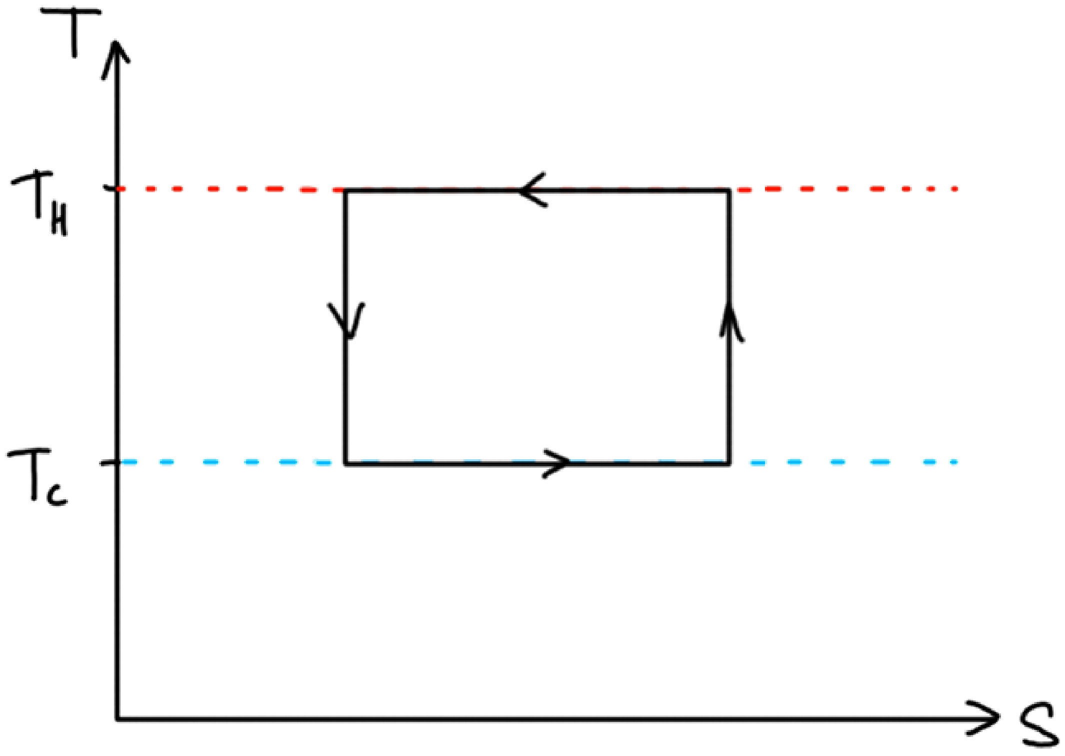
A. (1) ✓
B. (2)
C. Same efficency

Carnot Cycle

- Maximum possible efficiency for fixed maximum and minimum temperatures T_H, T_C
- Each step is reversible (either adiabatic or isothermal)

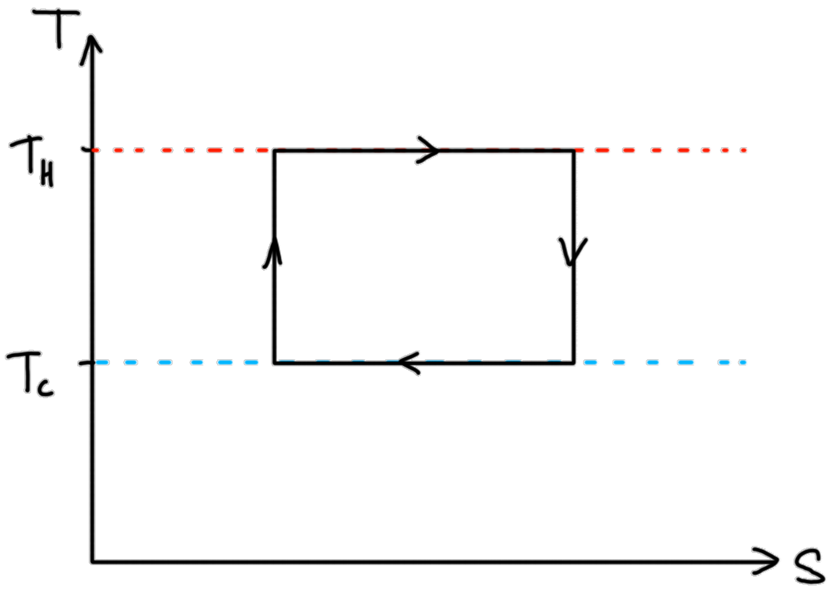


Carnot Engine



Carnot Refrigerator

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



$$e = \frac{W_{net}}{Q_{in}}$$

A_{encl}

$A_s \uparrow$

A. T_C/T_H

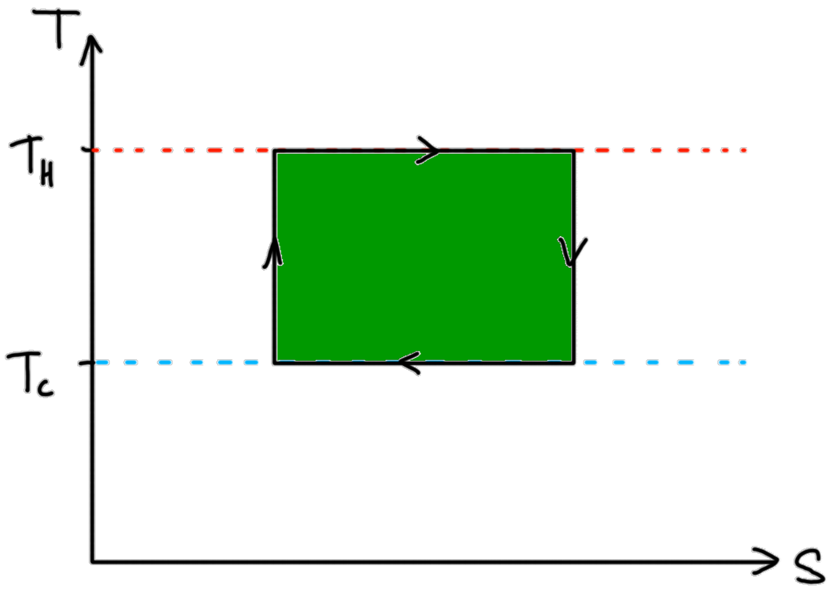
B. $(T_H - T_C)/T_H$

C. $T_H/(T_C + T_H)$

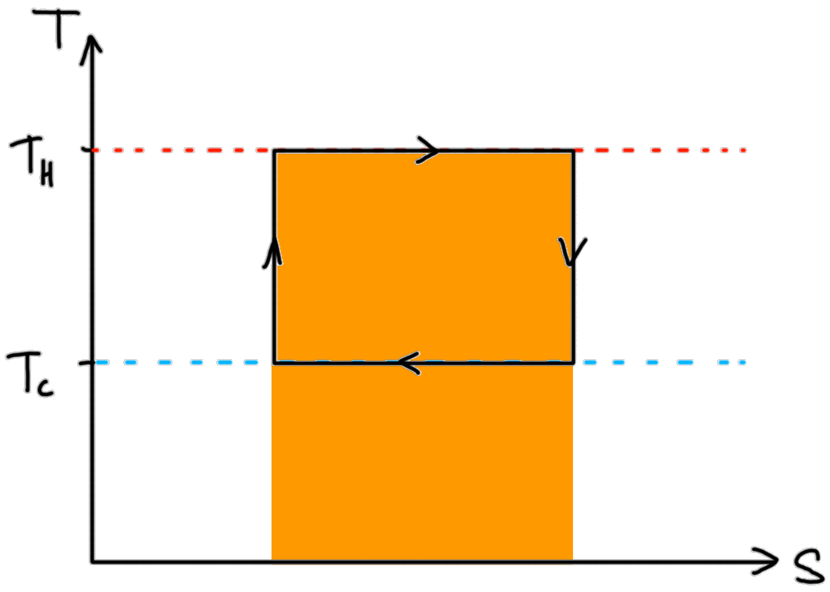
D. $T_C/(T_C + T_H)$

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

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



$$W_{net} = (T_H - T_C) \cdot \Delta S$$



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

A. T_C/T_H

B. $(T_H - T_C)/T_H$ ✓

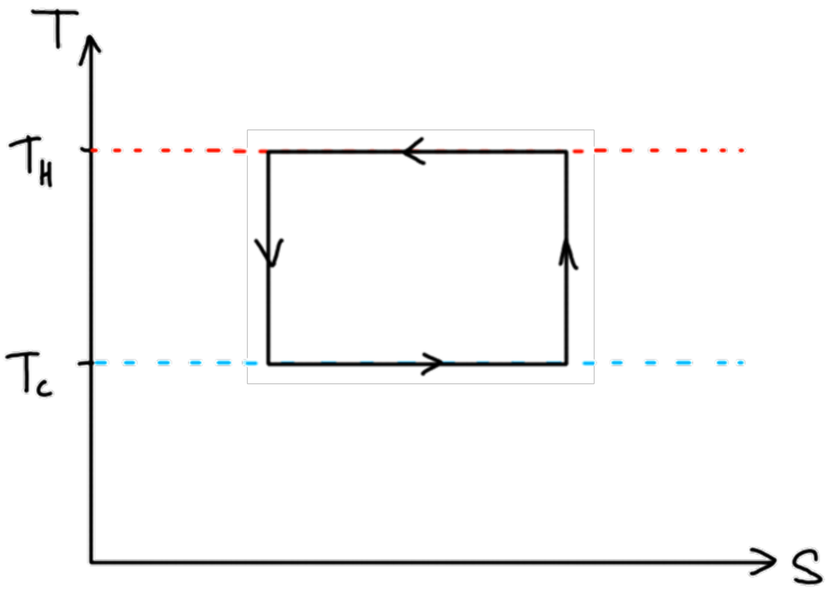
C. $T_H/(T_C + T_H)$

D. $T_C/(T_C + T_H)$

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

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

Q: What is the coefficient of performance of the refrigerator described by the Carnot cycle shown?



$$K = \frac{|Q_c|}{W_{net}}$$

A. T_C/TH

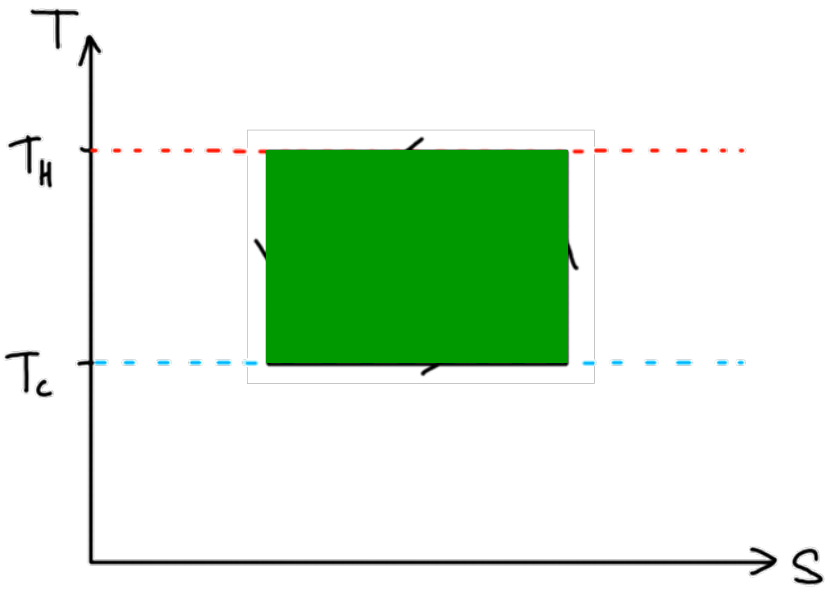
B. $(T_H - T_C)/T_H$

C. $T_H/(T_H - T_C)$

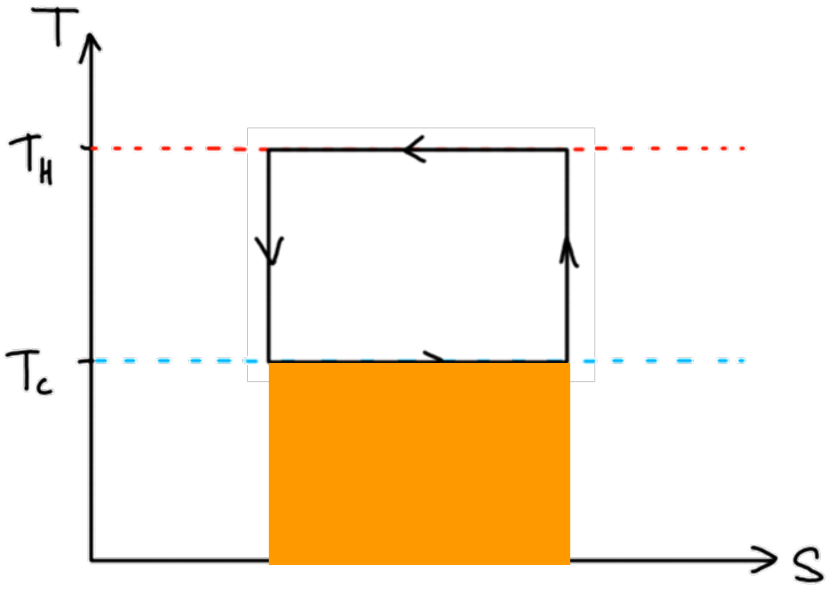
D. $T_C/(T_H - T_C)$

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

Q: What is the coefficient of performance of the refrigerator described by the Carnot cycle shown?



$W_{net} = -(T_H - T_C) \cdot \Delta S$



$Q_C = T_C \cdot \Delta S$

A. T_C/TH

B. $(T_H - T_C)/T_H$

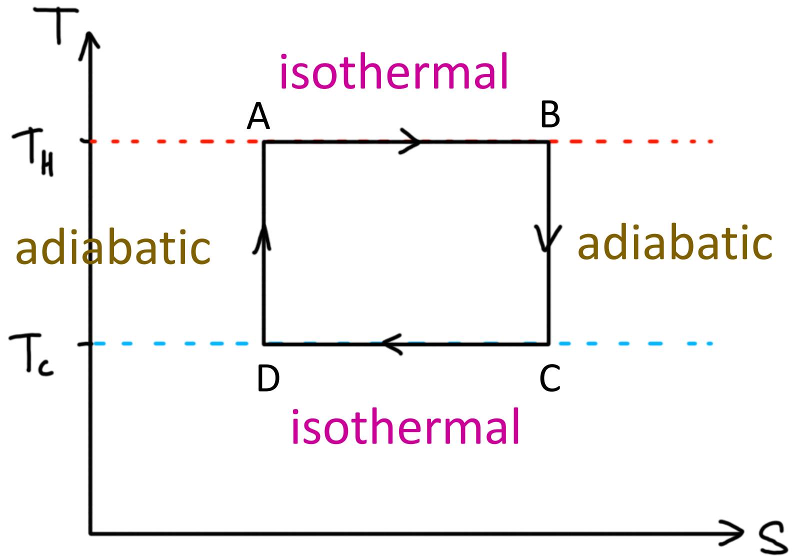
C. $T_H/(T_H - T_C)$

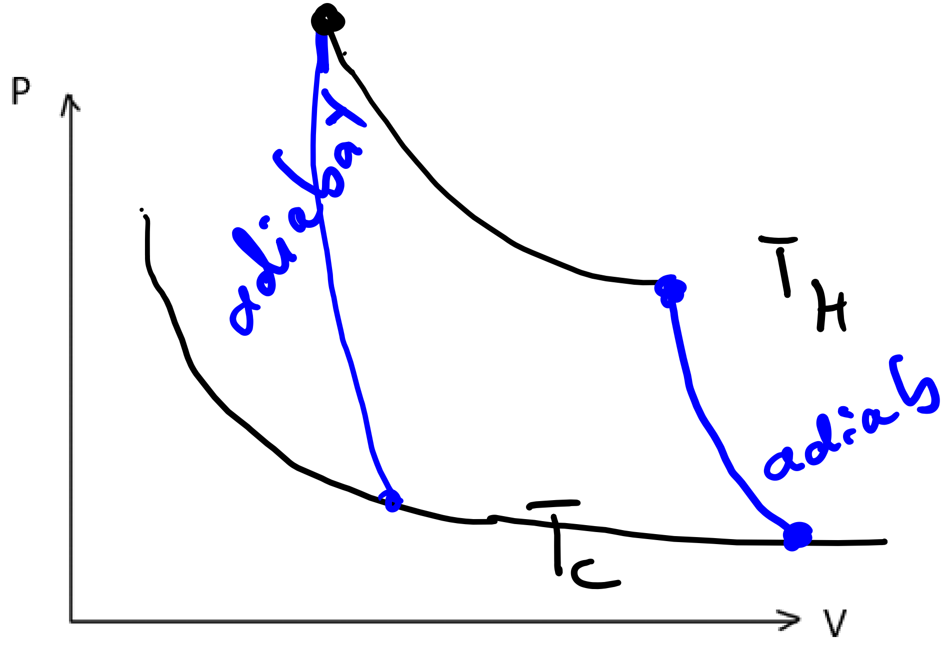
D. $T_C/(T_H - T_C)$ ✓

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

$$K = \frac{|Q_C|}{|W_{net}|} = \frac{T_C}{T_H - T_C}$$

- Carnot Cycle



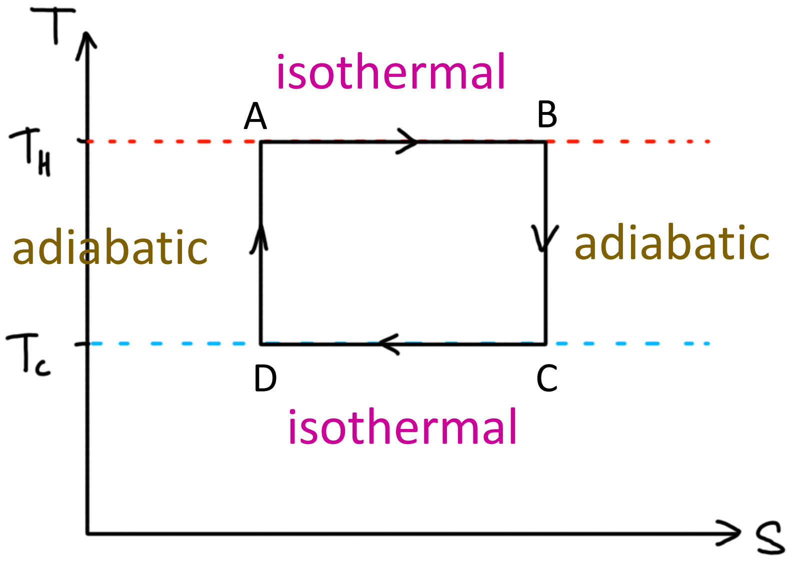


A. Done

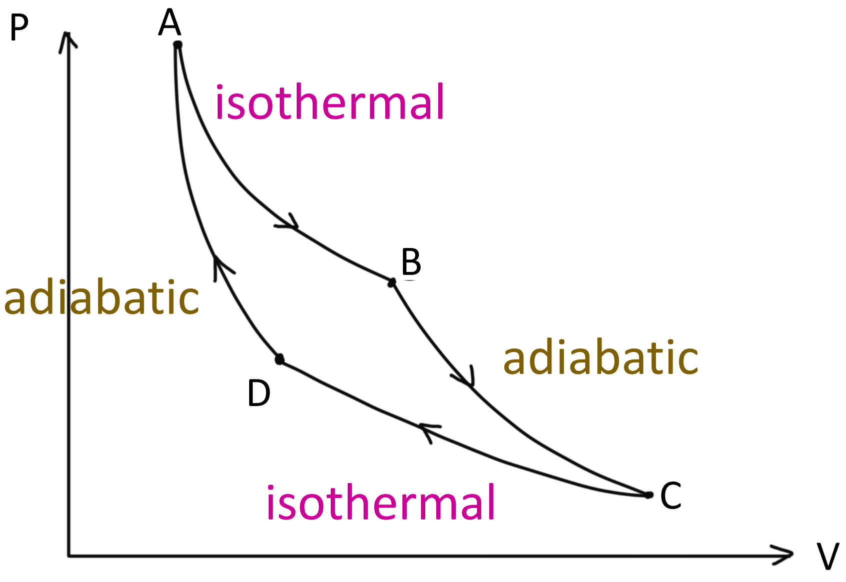
B: ☹

Q: Draw this cycle in P,V-coordinates

- Carnot Cycle: maximum possible efficiency for fixed maximum and minimum temperatures T_H, T_C



$\Leftrightarrow$



Efficiency$_{max}$: $e = 1 - \frac{T_C}{T_H}$

- Reversing to get a refrigerator:

Coef of Performance$_{max}$: $K = \frac{T_C}{T_H - T_C}$

- Larger efficiency or CoP would violate 2nd Law of Thermodynamics

- Not so useful in practice since isothermal processes must be very slow