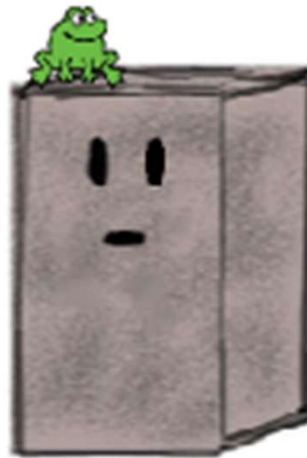
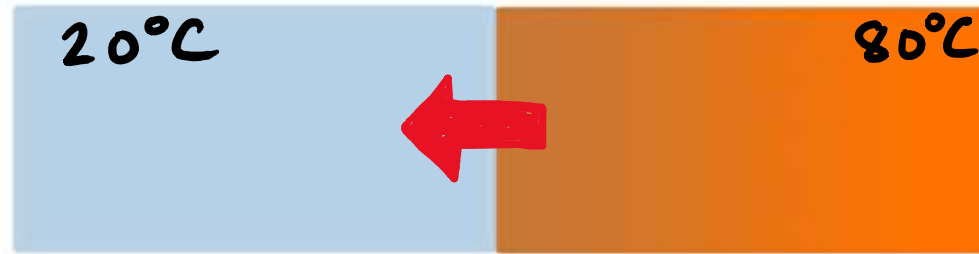




Last time
in Phys 157...



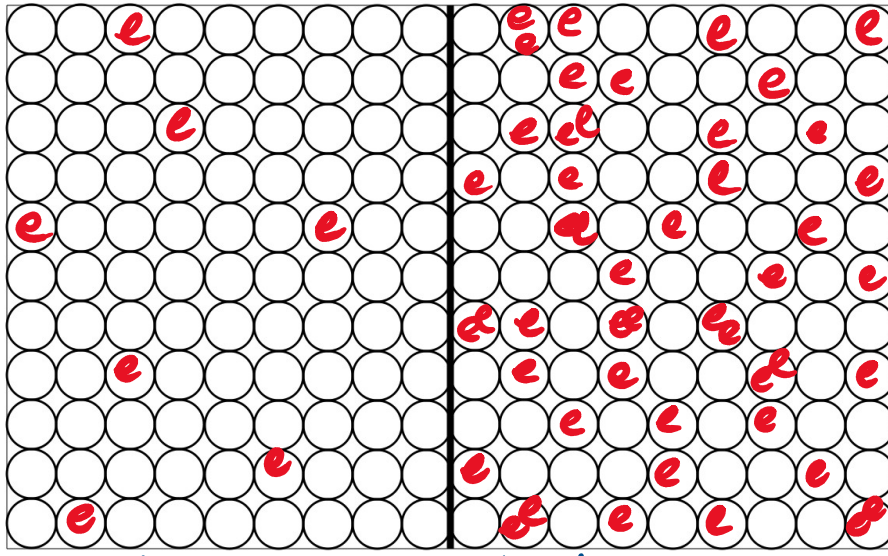
Last time
in Phys 157...



Why does heat always flow from hot objects to colder objects?

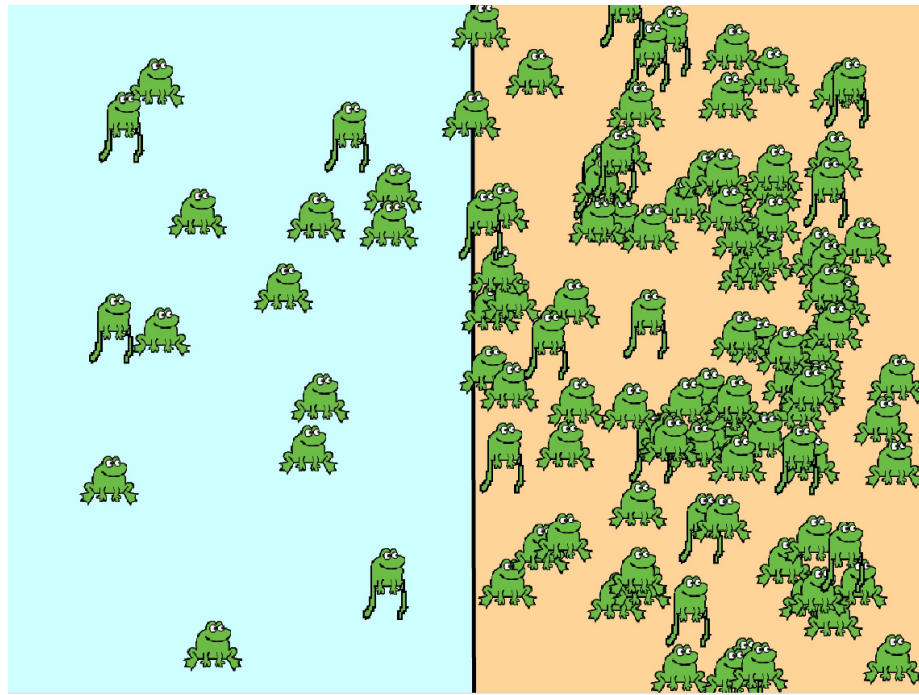
Why can't we make a refrigerator that requires no work done?

Why can't we make an engine that converts heat completely into work?



low T

high T



Analogy:

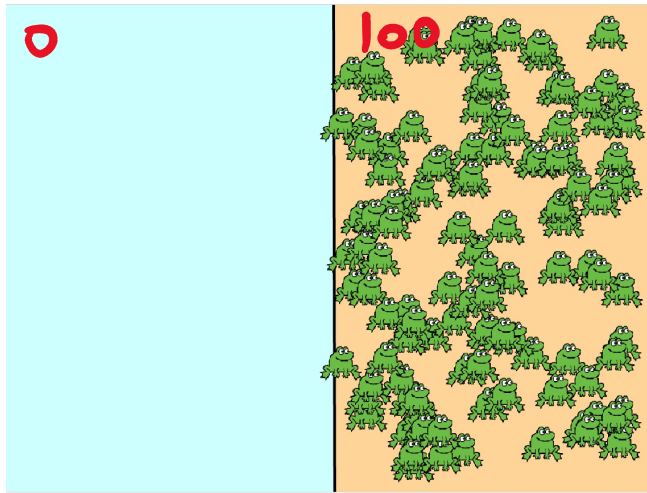
Frogs = energy

Conserved + move randomly

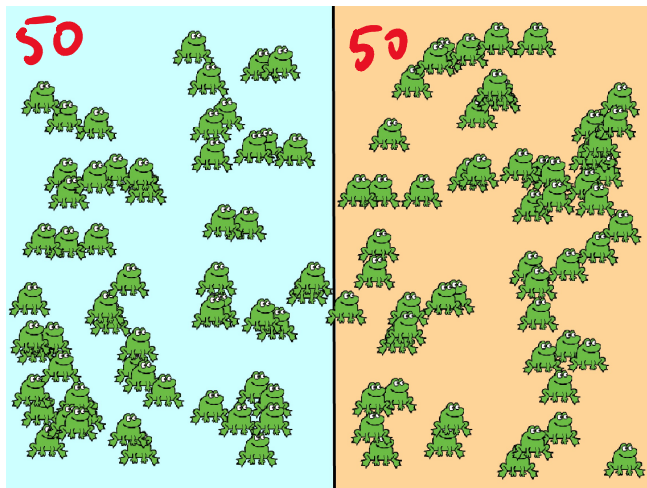
density of frogs = temperature

↑
proportional to energy per molecule

BUT...



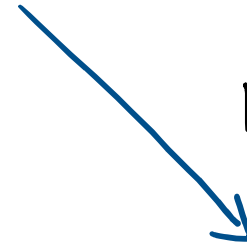
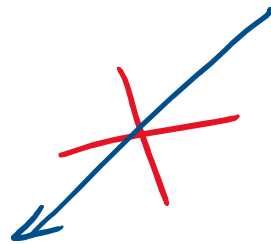
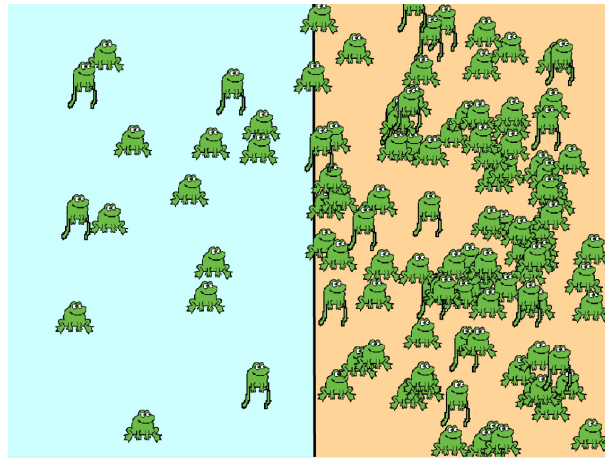
10^{500} configurations
like this



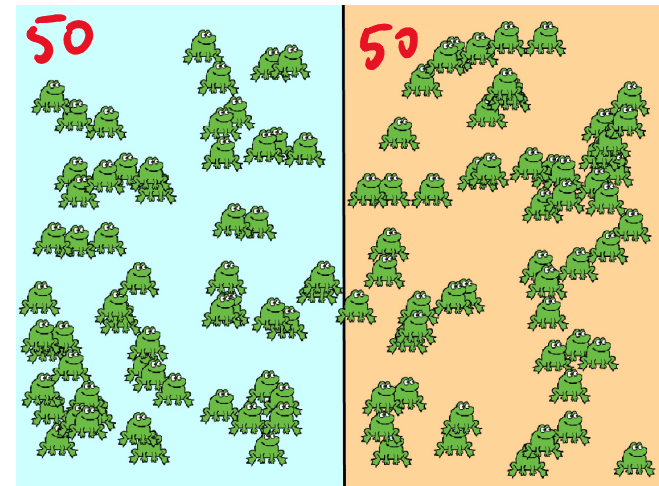
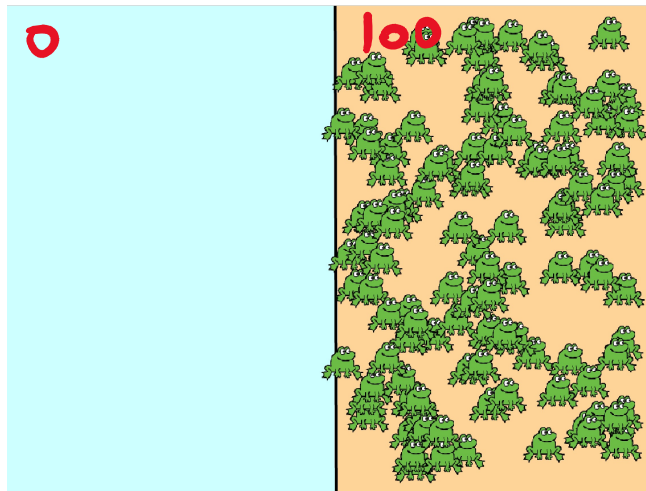
10^{530} configurations
like this

(10^5 possible pixel locations for each frog)

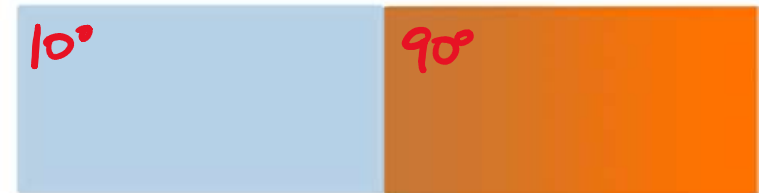
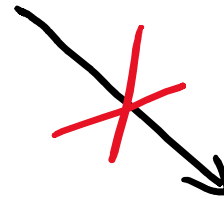
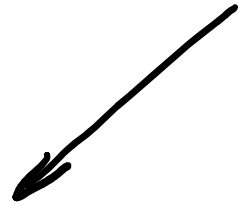
If we start here
and wait



10^{30} times more
likely to end up in
a configuration
similar to this:



If we start here:



10 | 000 000 000 000 000 000 000 000

times more likely to
end up here.

Define ENTROPY of a macroscopic configuration

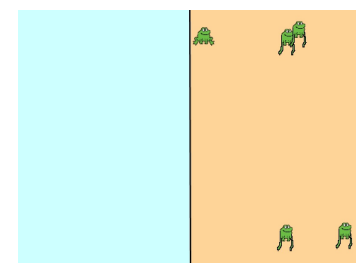
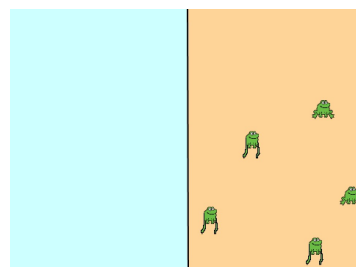
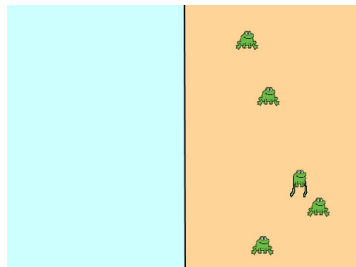
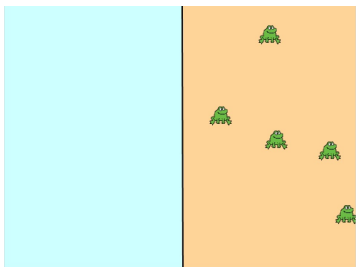
e.g.
(30,70) distribution
of frogs

e.g.2: gas with
pressure P, volume V,
temperature T

$$S = \text{const} \times \log[N]$$

number of microscopic
configurations of this
type

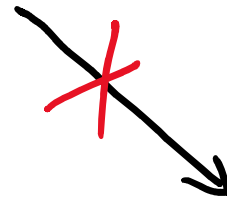
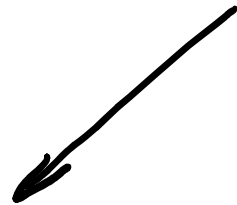
some microscopic configurations of frogs with ^{macroscopic} configuration (0,5)



2ND LAW OF THERMODYNAMICS:

Total entropy never decreases.

↳ probability of decrease
is unimaginably small



higher entropy
= far more states with these T_s



lower entropy
= far less states w. these T_s .

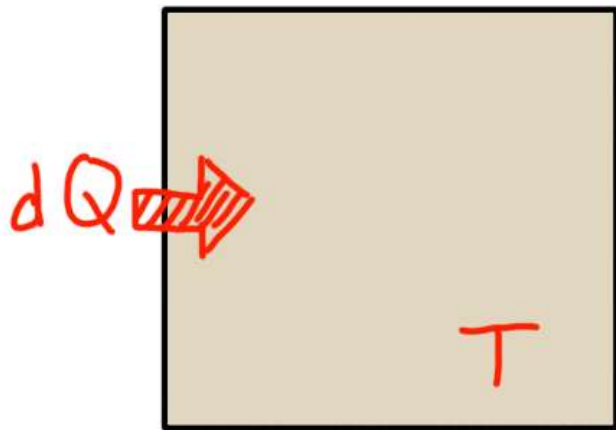
Entropy is additive (= "extensive")

$$S_{\text{TOTAL}} = S_1 + S_2$$



(because
 $\log(N_1 \times N_2)$
 $= \log(N_1) + \log(N_2)$)

ENTROPY: macroscopic definition



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

change in entropy

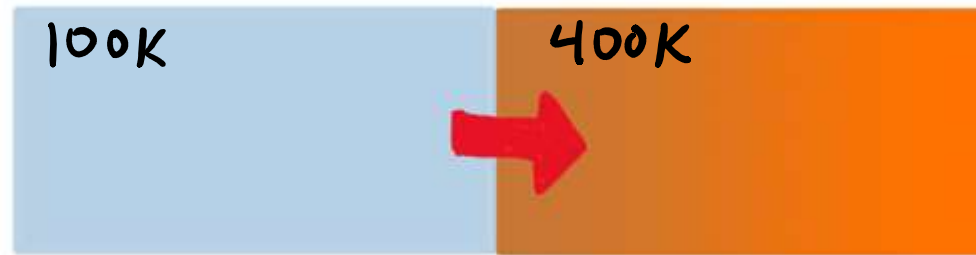
heat added

Amazing result:

we can prove this from the microscopic definition of S .

★ see bonus video ★

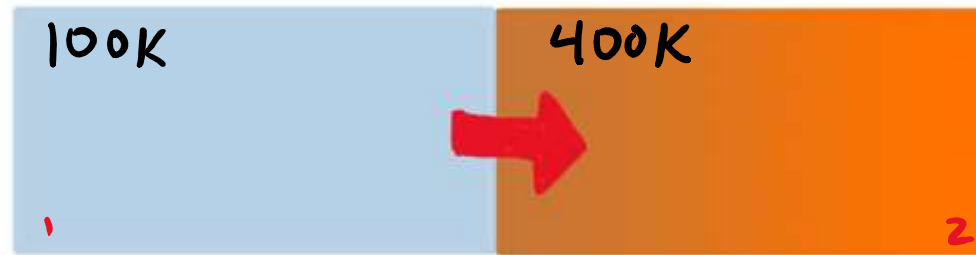
<https://www.youtube.com/watch?v=t7gyi8NhgYg>



Suppose that we had 1J of energy flow from the cold object to the hotter object. What would be the change in entropy of the whole system?

- A) -0.0125 J/K
- B) -0.0075 J/K
- C) 0
- D) 0.0075 J/K
- E) 0.0125 J/K

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



Suppose that we had 1J of energy flow from the cold object to the hotter object. What would be the change in entropy of the whole system?

- A) -0.0125 J/K
- B) -0.0075 J/K
- C) 0
- D) 0.0075 J/K
- E) 0.0125 J/K

$$\begin{aligned}
 \text{Have } dS &= dS_1 + dS_2 \\
 &= \frac{dQ_1}{T_1} + \frac{dQ_2}{T_2} \\
 &= \frac{-1\text{J}}{100\text{K}} + \frac{1\text{J}}{400\text{K}}
 \end{aligned}$$

$$= -0.0075 \text{ J/K}$$

BAD \rightarrow

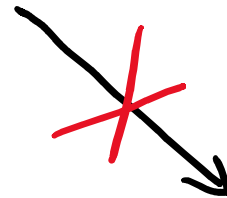
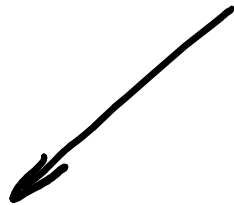
violates 2nd Law so won't happen

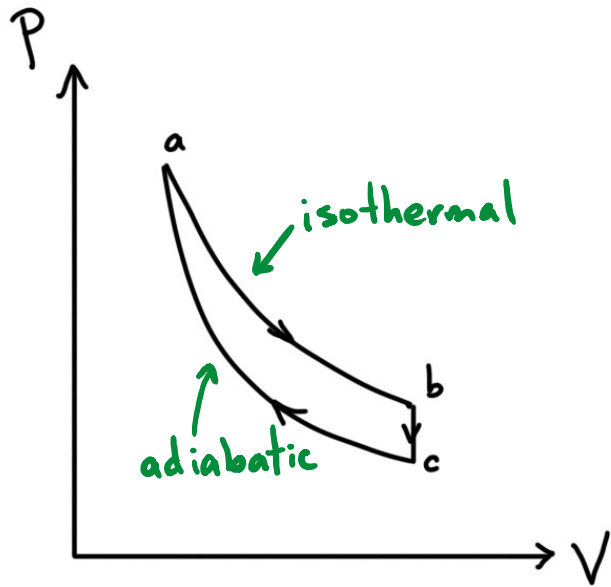
$$dS = \frac{dQ}{T}$$

2ND LAW OF THERMODYNAMICS:

Total entropy never decreases.

→ probability of decrease is too small to comprehend

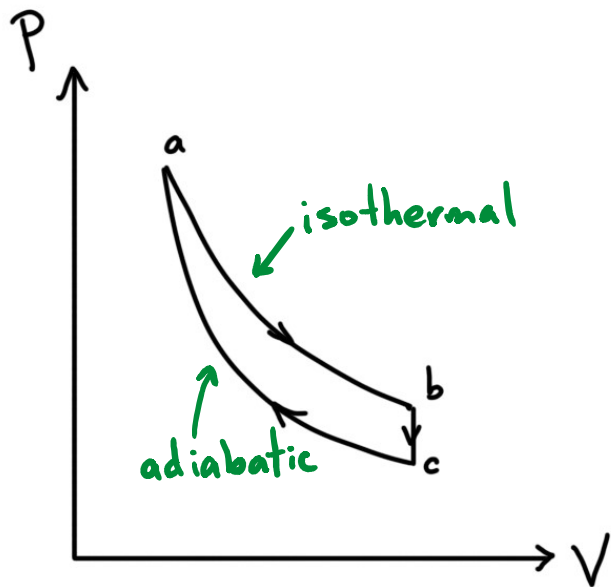




In the cycle shown, we can say that from $c \rightarrow a$,

- A) The entropy increases
- B) The entropy is constant
- C) The entropy decreases

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



In the cycle shown, we can say that from $c \rightarrow a$,

A) The entropy increases

B) The entropy is constant

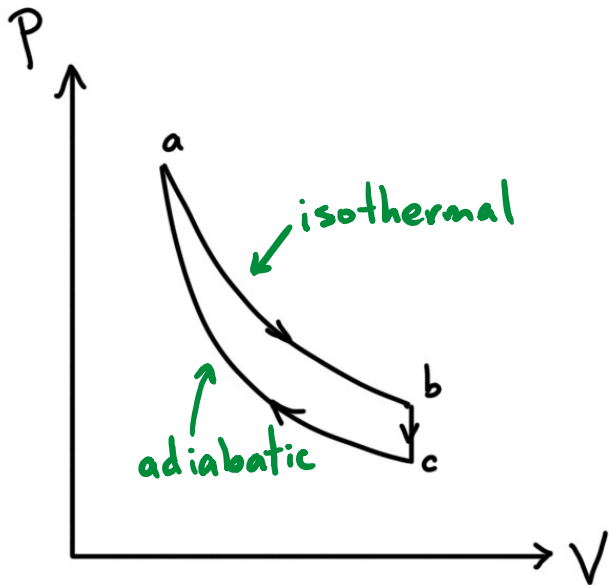
C) The entropy decreases

$c \rightarrow a$ adiabatic so $Q = 0$

$dQ = 0$ for each part so

$dS = 0$

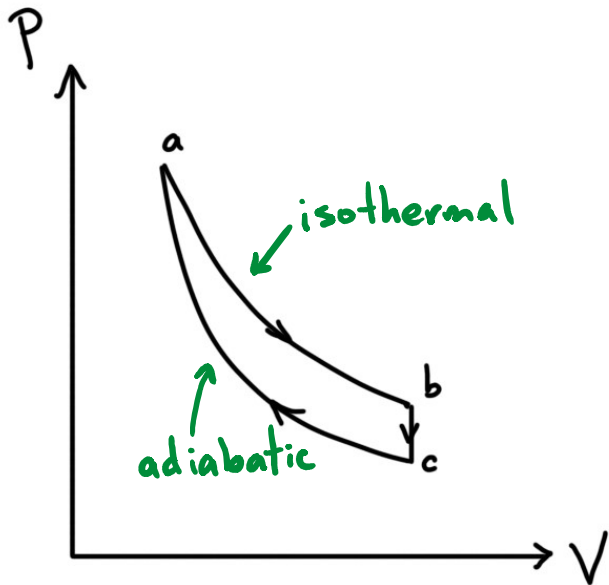
$$dS = \frac{dQ}{T}$$



In the cycle shown, heat Q enters the gas in the isothermal step $a \rightarrow b$ at temperature T . The entropy change during this step

- A) is equal to Q/T .
- B) is equal to $Q^2/(2T)$.
- C) Is equal to 0.
- D) is equal to $-Q/T$.
- E) cannot be determined from the information provided.

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



In the cycle shown, heat Q enters the gas in the isothermal step $a \rightarrow b$ at temperature T . The entropy change during this step

A) is equal to Q/T .

B) Is equal to 0.

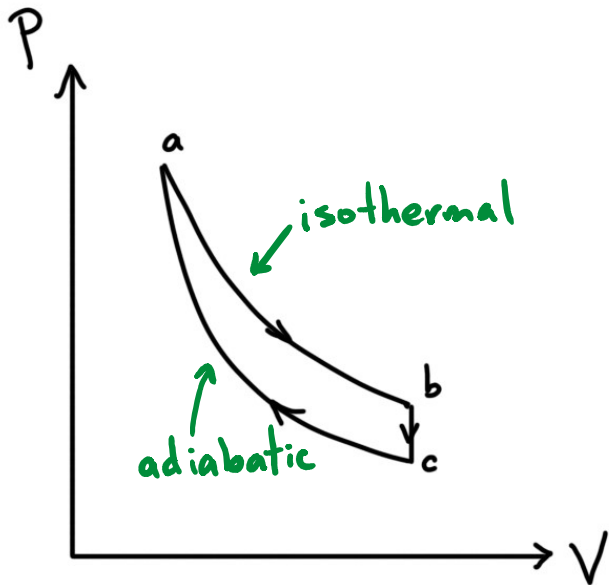
C) is equal to $-Q/T$.

D) cannot be determined from the information provided.

T const. so

$$\Delta S = \frac{Q}{T}$$

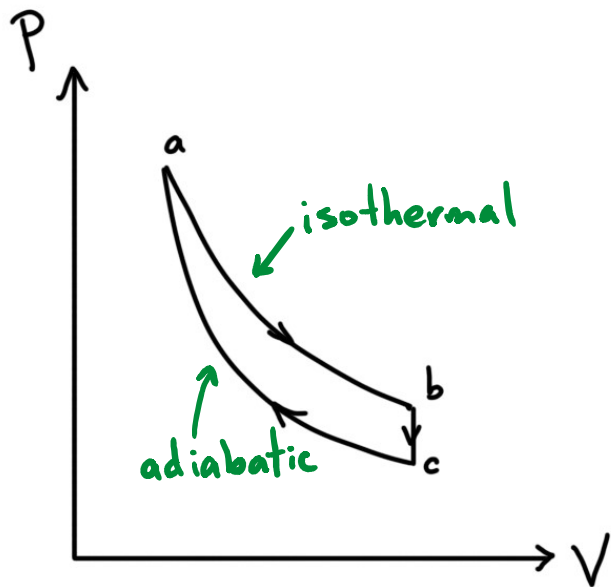
$$dS = \frac{dQ}{T}$$



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

- A) Positive
- B) Zero
- C) Negative

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



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

- A) Positive
- B) Zero**
- C) Negative

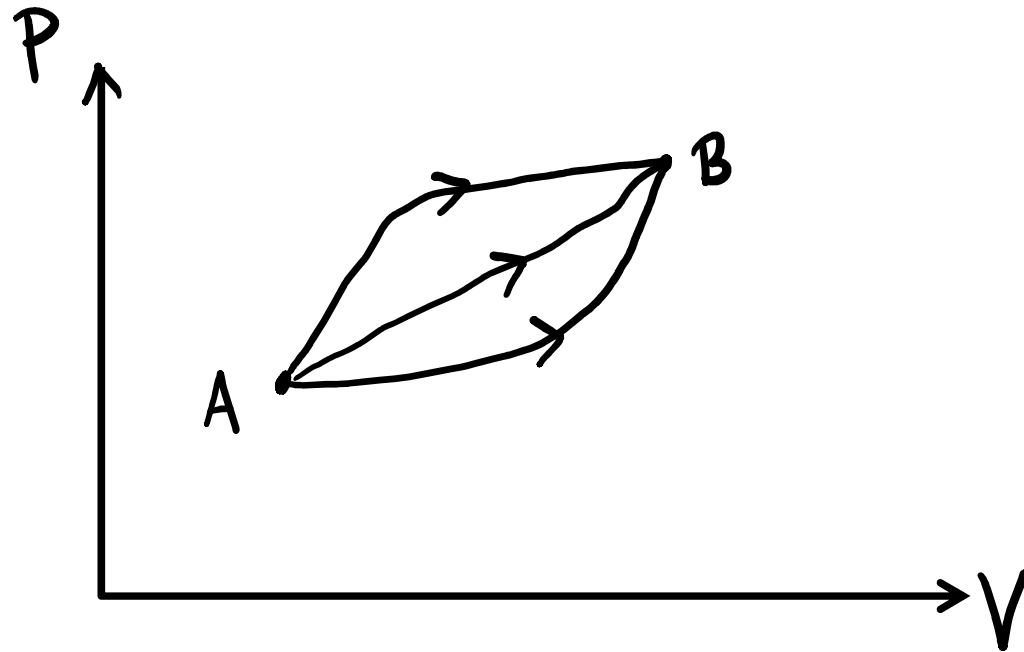
S is a state variable.

Around a whole cycle, we come back to the same state.

So $\Delta S = 0$.

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

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



ΔS same for all paths, zero for cycle.

But: S for environment usually increases!

EXTRA PROBLEM: 1 moles of ideal monatomic gas is cooled at constant volume from 300K to 200K. What is the change in entropy?

Hint: this is something like calculating work when pressure is changing.

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

1 moles of ideal monatomic gas is cooled at constant volume from 300K to 200K. What is the change in entropy?

Hint: this is something like calculating work when pressure is changing.

Have: constant volume $\Rightarrow W = 0$

$$\Rightarrow dQ = dU = n C_v dT$$

$$\Rightarrow dS = n C_v \frac{dT}{T} \quad \text{for each infinitesimal part.}$$

Now we add the parts:

$$\begin{aligned} \Delta S &= n C_v \int_{T_i}^{T_f} \frac{dT}{T} \\ &= n C_v \ln \left(\frac{T_f}{T_i} \right) \\ &= \frac{3}{2} n R \ln \left(\frac{T_f}{T_i} \right) \end{aligned}$$