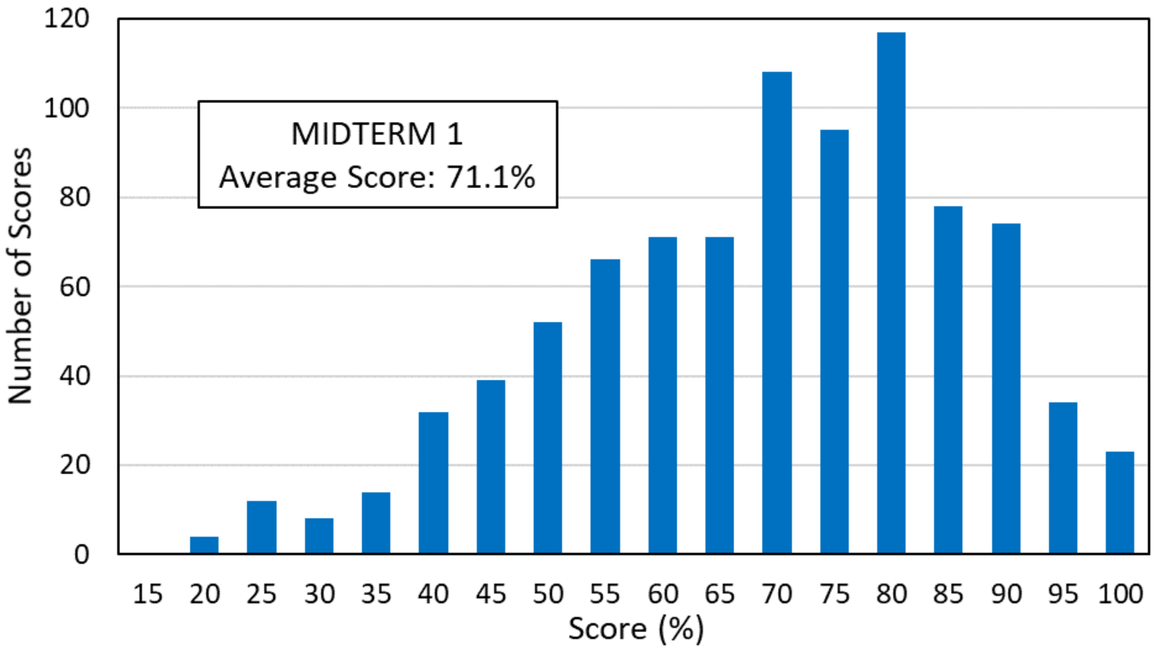
Midterm 1 (2023)



If you didn’t do well on the written part:

- Next time, demonstrate what you DO know for the written problems, so we can give you credit for it, even if you aren't sure, or are stuck, on some parts.

If you want to adjust your learning strategy:

- The best way to learn is deliberate practice
- Talk with other people about PHYS 157 stuff
- Try “teaching” mini-lectures/tutorials on PHYS 157 stuff

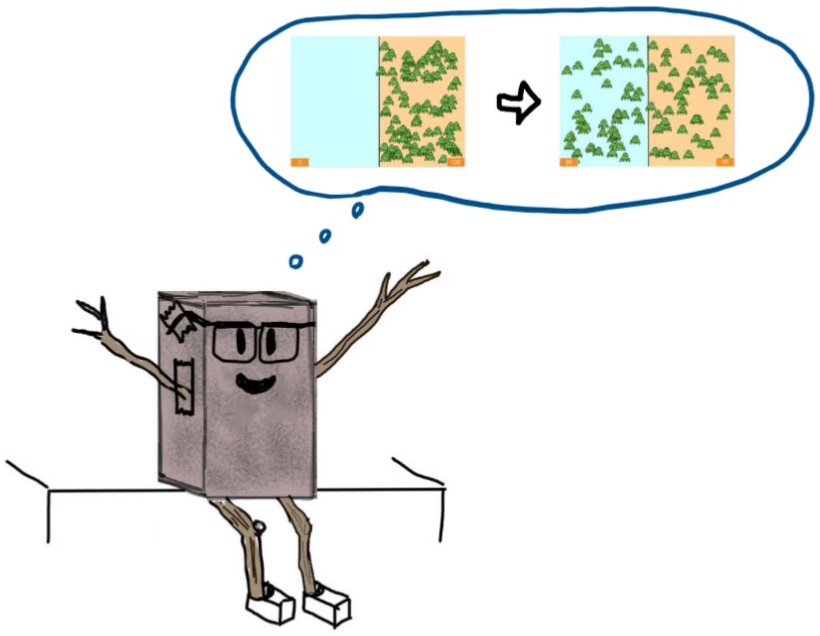
Reading Quizzes	3%
Tutorials	6%
MP Homework	6%
Written Homework	9%
Quizzes	18%
First midterm	13%
Second midterm	13%
Final exam	32%

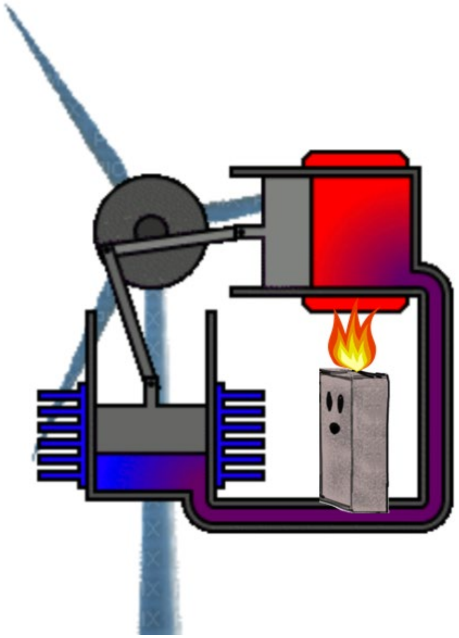
Interact with the teaching team and your peers:

- My time: Tuesdays 10:30 onwards
- Cannot attend? Check other instructors
- HW help session (Mon-Tue 5:00 pm)
- Hebb 112 is an undergrad drop-in center: Come to do your homework with your classmates, chat about difficult concepts, ask your questions, help your peers

Lecture 22.

Stirling engine. Frogs and entropy.

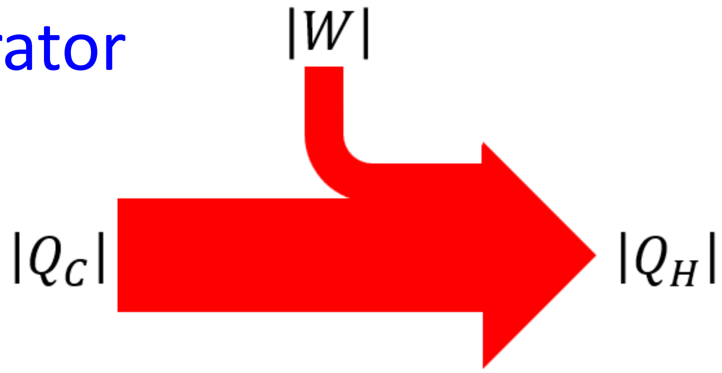


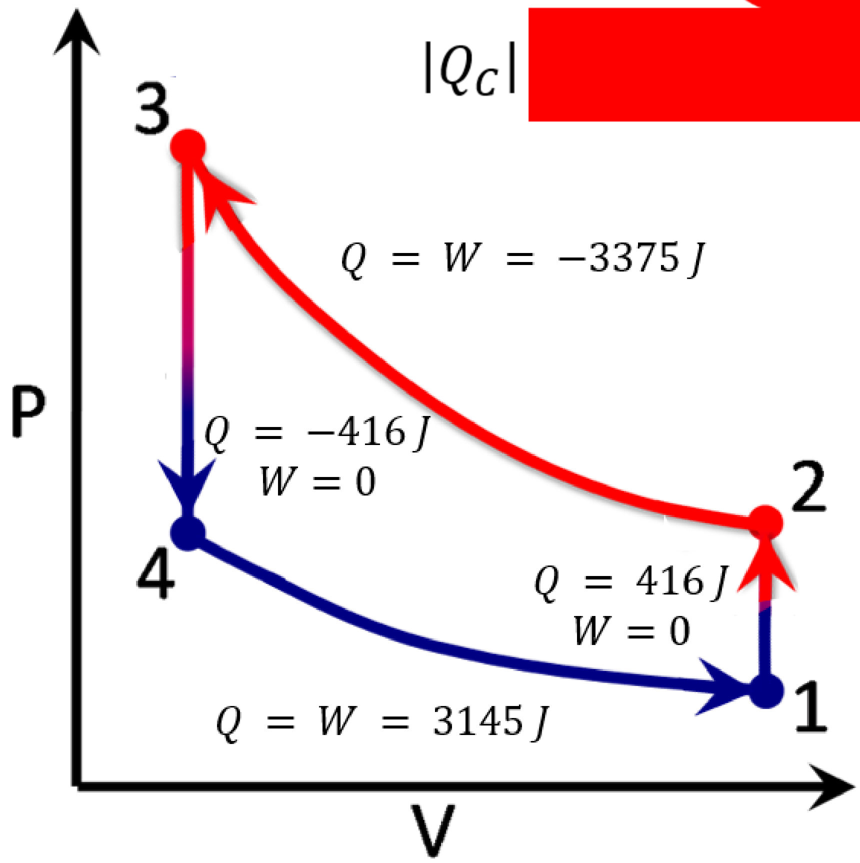


Last Time

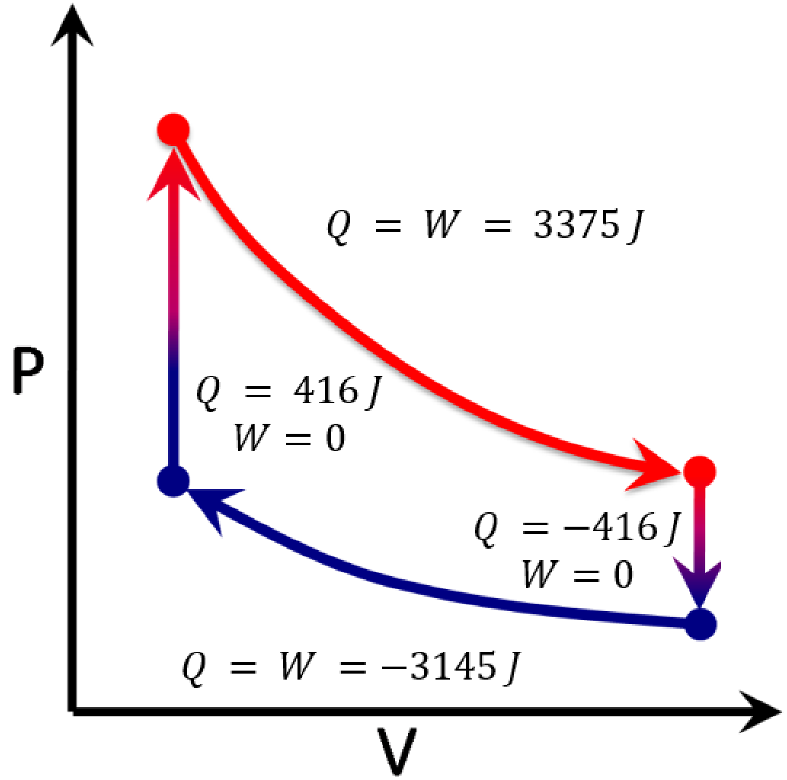
- Coefficient of performance:
  $\mathrm{COP} = Q_C / W_{net}$

Refrigerator

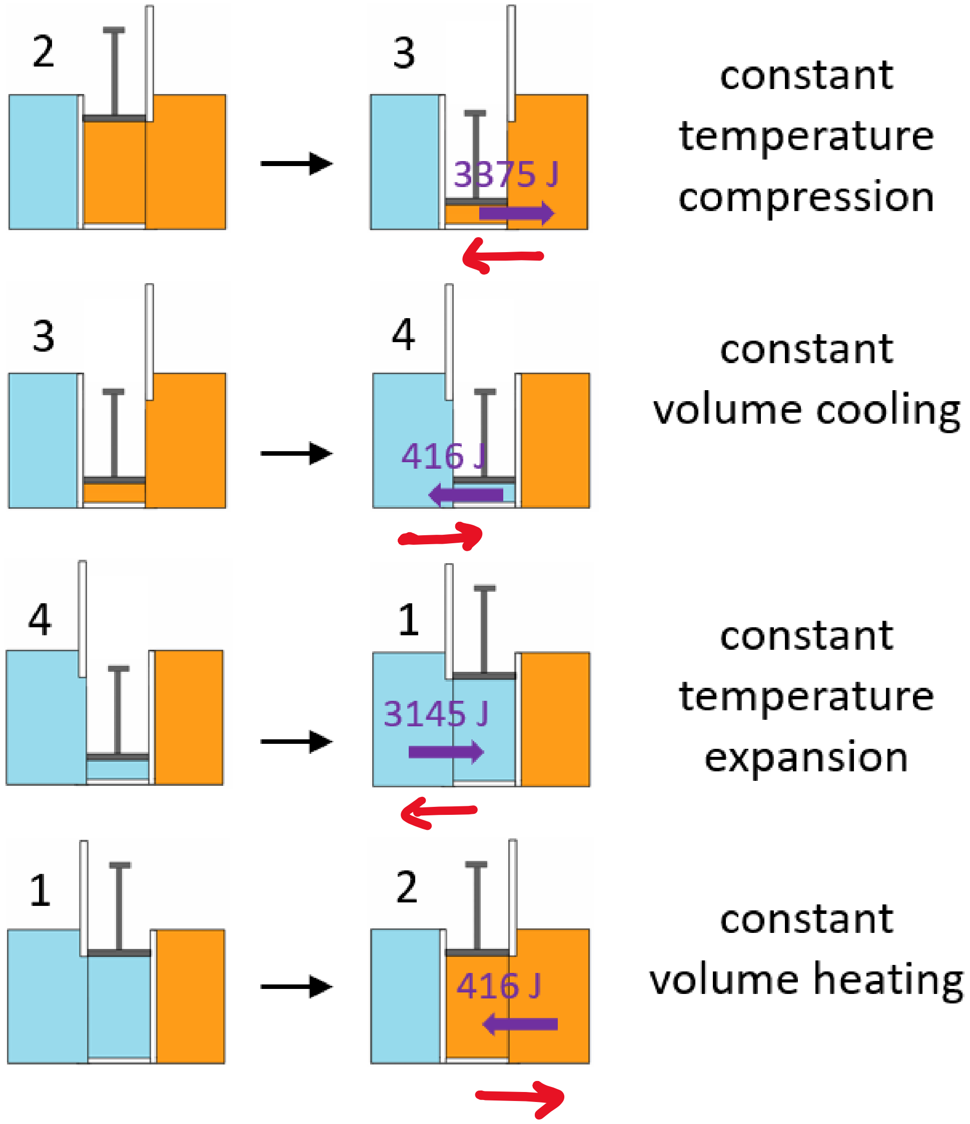




Can we get an engine by flipping the processes?

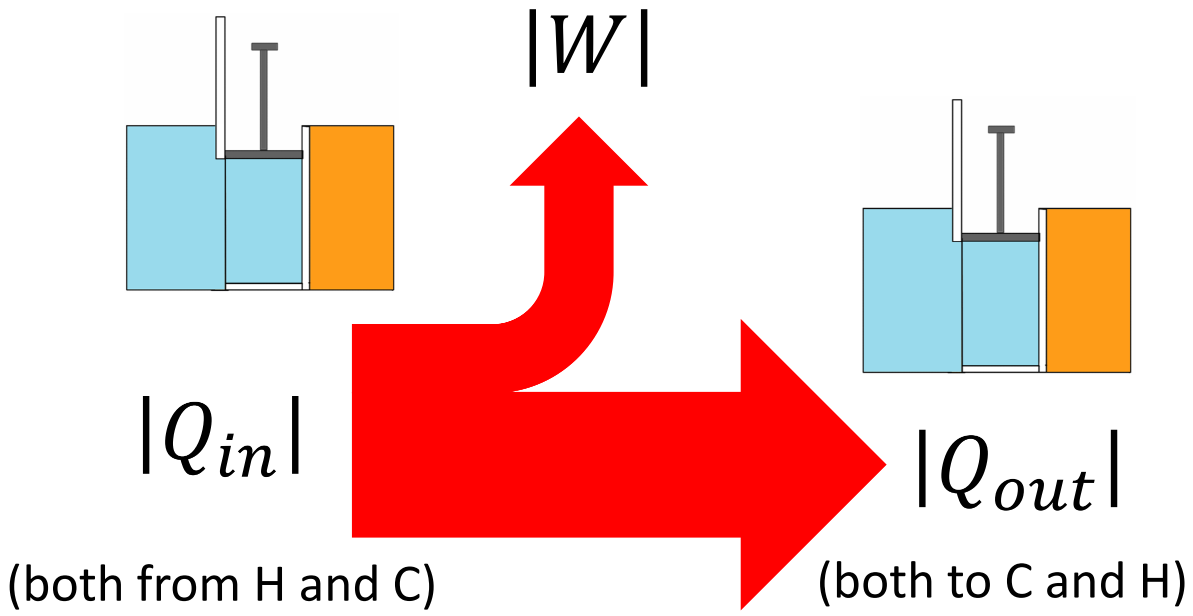


Our refrigerator:



- Reverse the processes!

- Efficiency: $e = W_{net}/Q_{in}$



- With parameters from our refrigerator:

$$|Q_{in}| = 3375 + 416 = 3791\,J$$

$$|Q_{out}| = 3145 - 416 = 3561\,J$$

$$|W_{net}| = 230\,J$$

Stirling Engine Efficiency

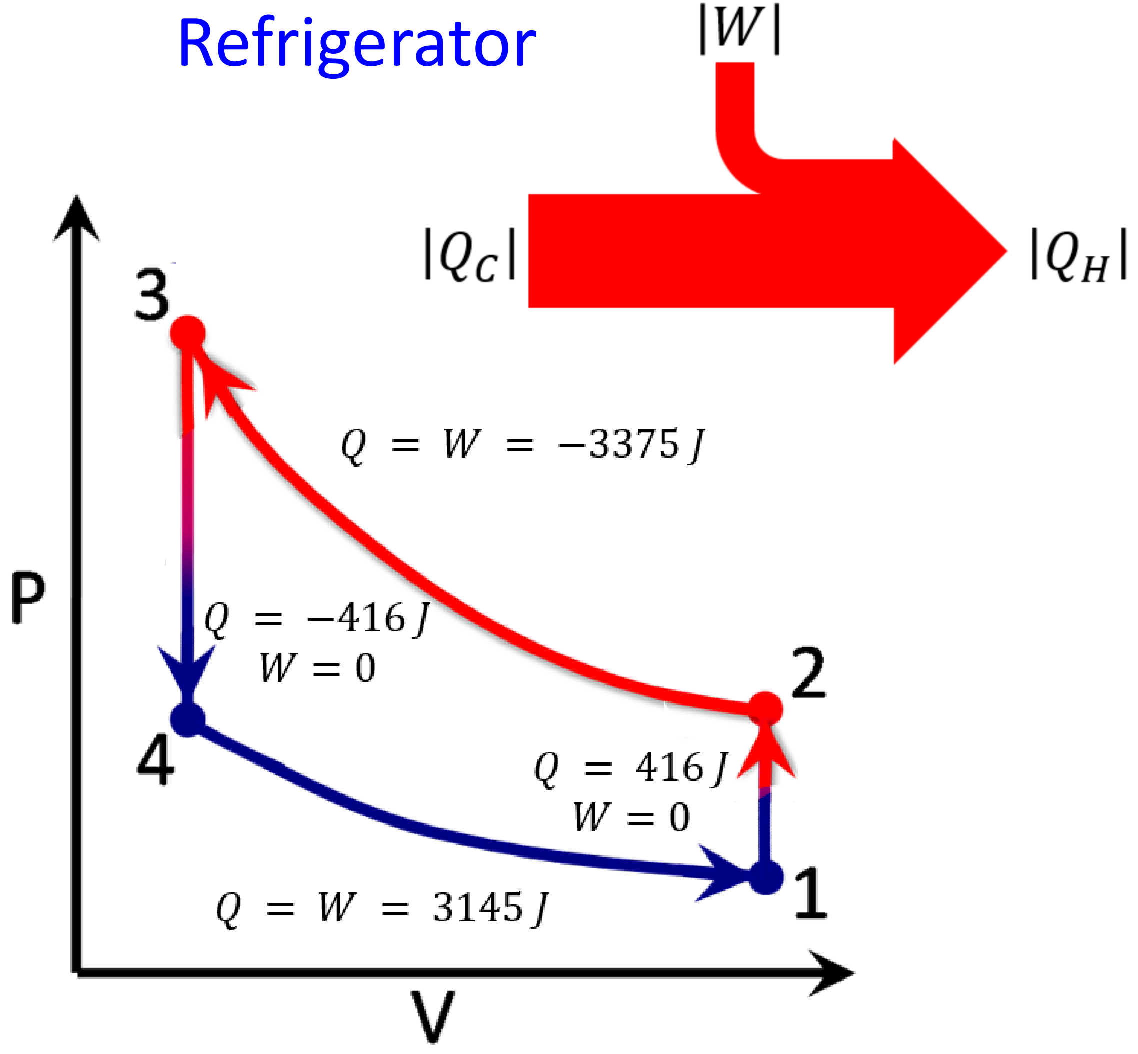
Q: Find its efficiency with parameters from previous example (refrigerator):

A. 6.1% ✓
B. 6.5%
C. 7.8%
D. Something else

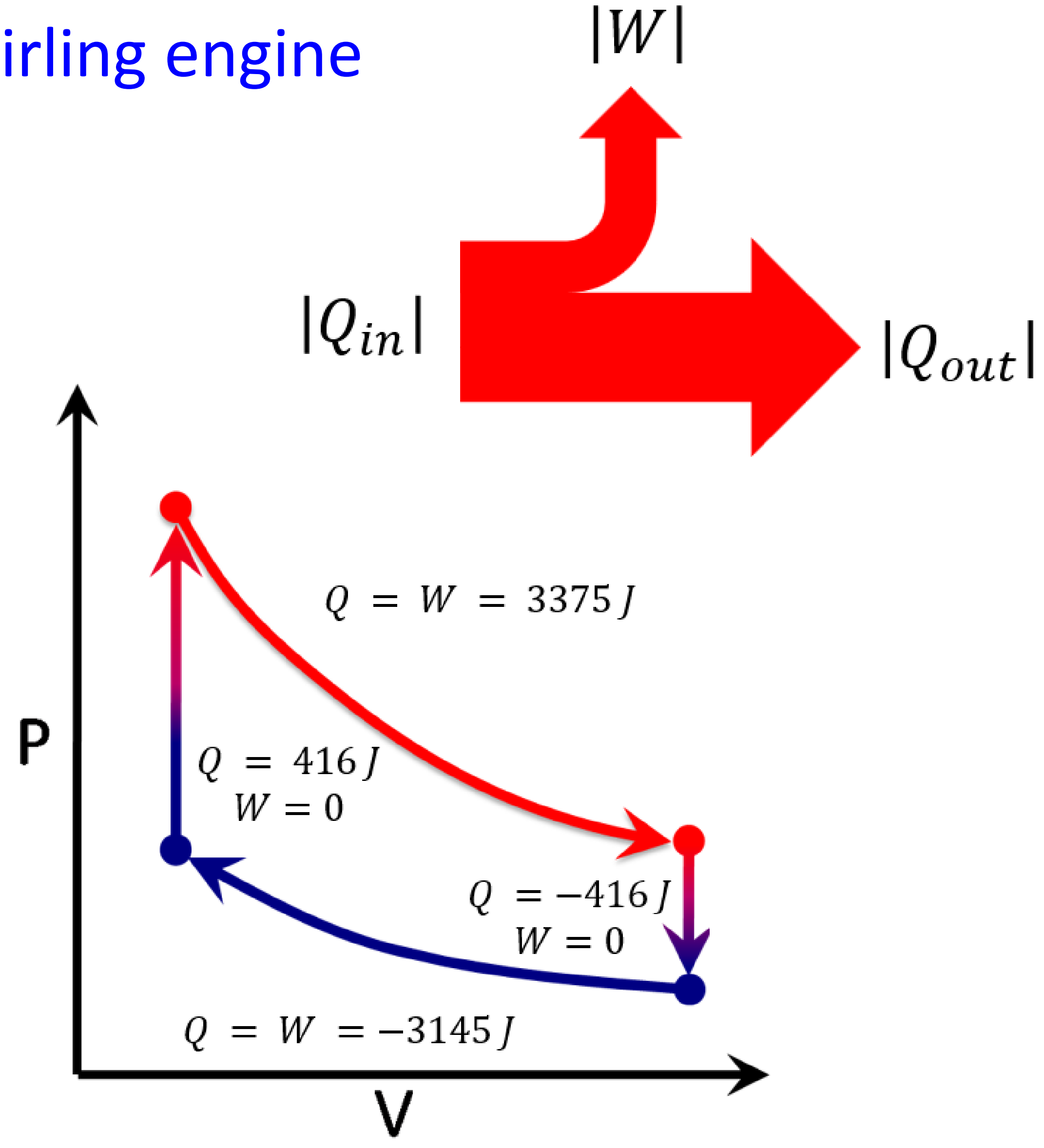
- $e = \frac{|W_{net}|}{|Q_{in}|}$
- $W_{net} = 230\ J$ as before (but now done by gas)
- $Q_{in} = 3375 + 416 = 3791$

Summary

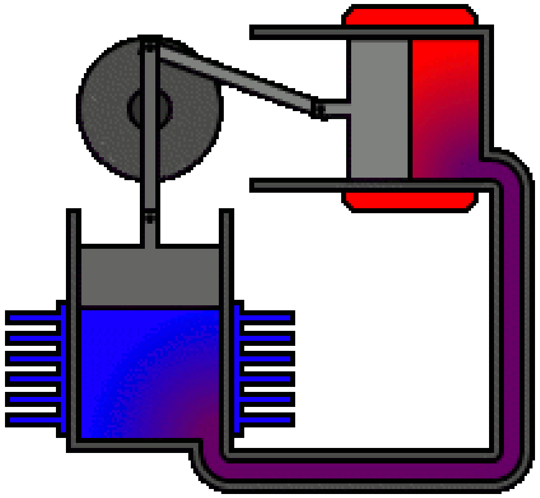
Refrigerator

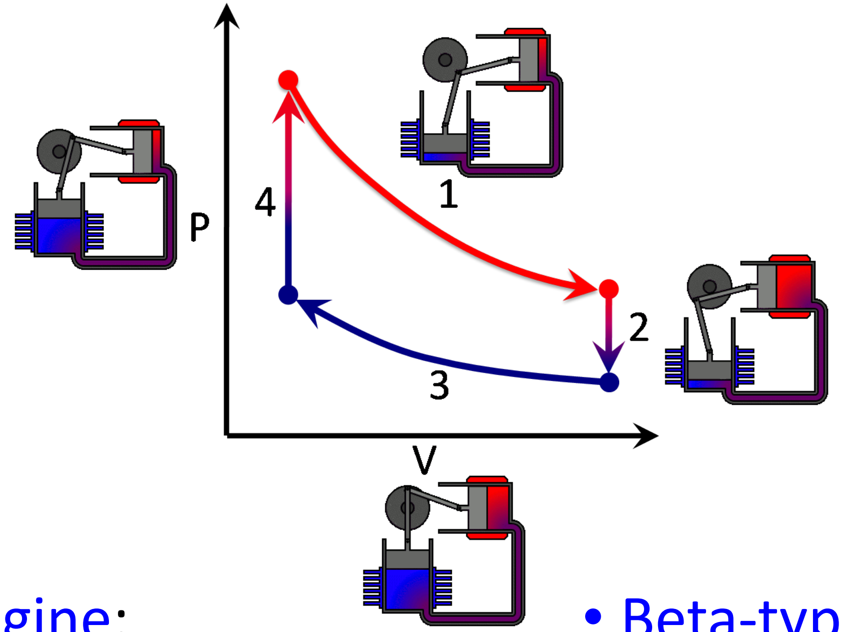


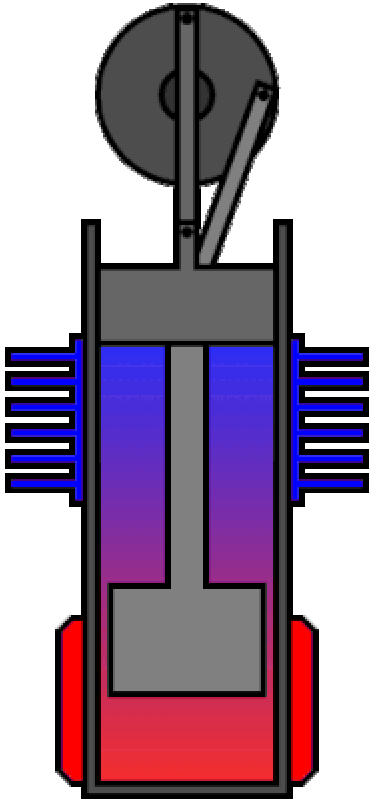
Stirling engine



Stirling Engine Mechanical Linkages



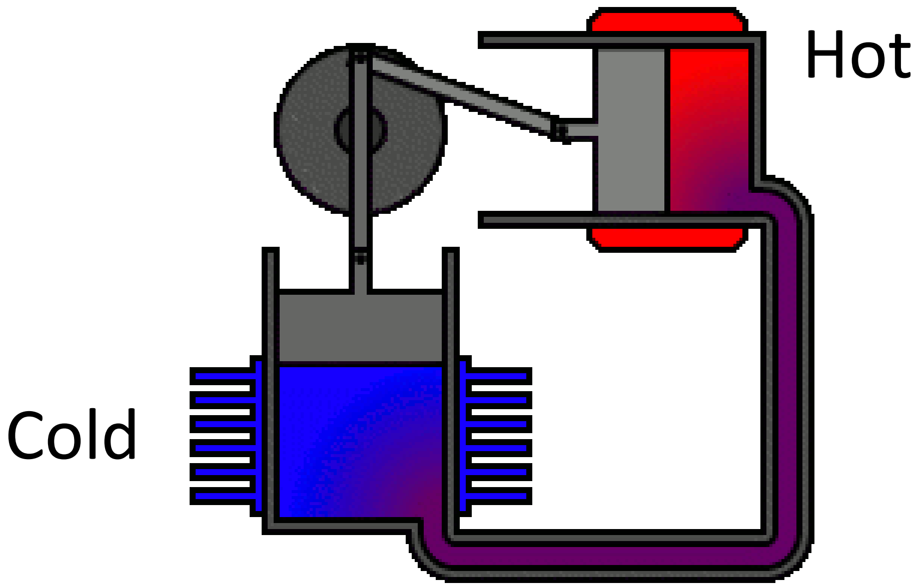


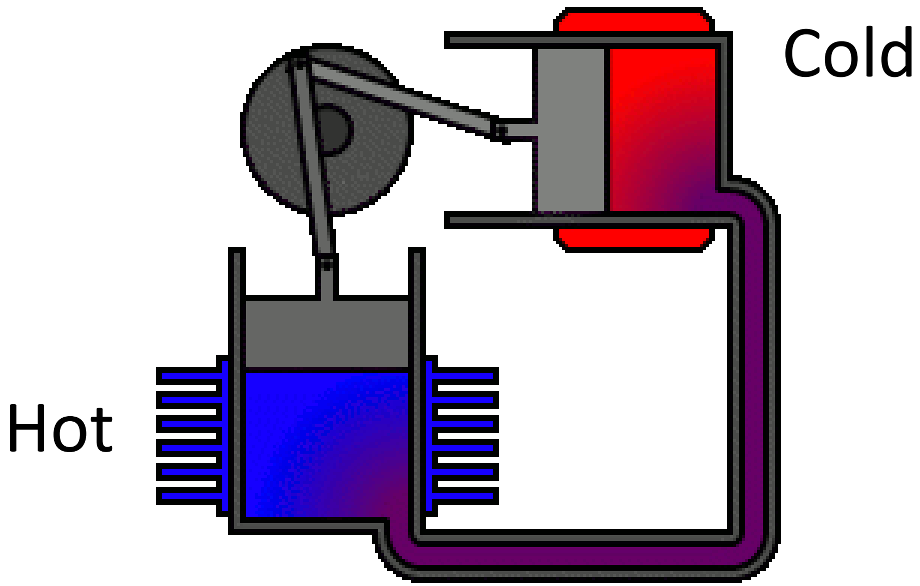


- **Alpha-type Stirling engine**:
  - ➢ Two cylinders
  - ➢ Expansion cylinder (red) is maintained at a high temperature
  - ➢ Compression cylinder (blue) is cooled
  - ➢ Passage between them contains the regenerator

- **Beta-type Stirling engine**:
  - ➢ One cylinder
  - ➢ Hot at one end, cold at the other
  - ➢ Loose-fitting displacer shunts the air between the hot and cold ends of the cylinder
  - ➢ power piston at open end of cylinder drives a flywheel

Q: What will happen if we replace the flame with liquid nitrogen in the Stirling engine?

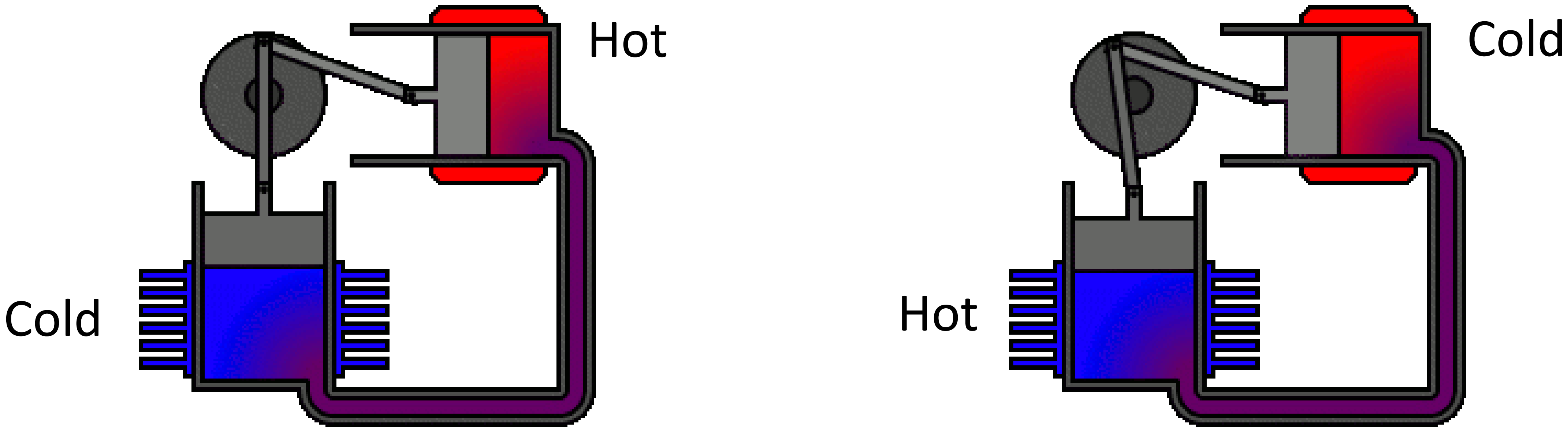




A. The Stirling engine will not run
B. The Stirling engine will run backwards
C. The Stirling engine will run in the same direction
D. It will become a refrigerator

Demo: Stirling Engine In Reverse

Q: What will happen if we replace the flame with liquid nitrogen in the Stirling engine?



Engine runs backward so that phase of two pistons is reversed!

A. The Stirling engine will not run
B. The Stirling engine will run backwards
C. The Stirling engine will run in the same direction
D. It will become a refrigerator

Advantages and disadvantages of Stirling Engines

- Advantages
  - Can run on any available heat source, including solar or nuclear, not just those produced by combustion
  - No explosive combustions, so much quieter
    - Used in submarines!
  - Efficiency can be high (~ 15-30% for real engines)
- Disadvantages
  - Cost of production higher than for internal combustion engine
  - Size and mass is larger than for comparable internal combustion engine
  - Start / stop very slowly (takes time for initial warm up / cool down)

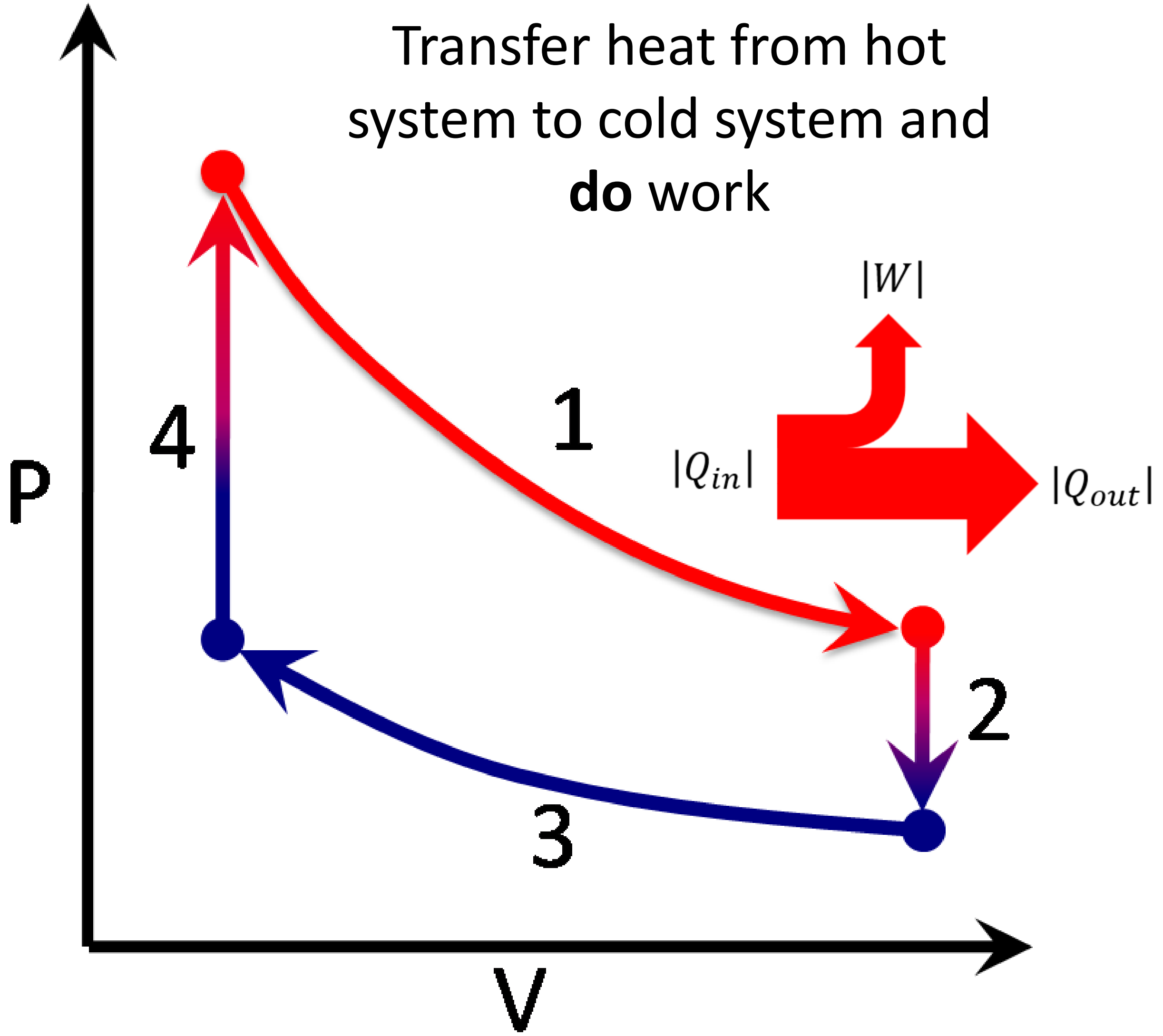
$$e = \frac{W_{net}}{Q_{in}}$$

Engines & Refrigerators

$$K = \frac{Q_C}{W_{net}}$$

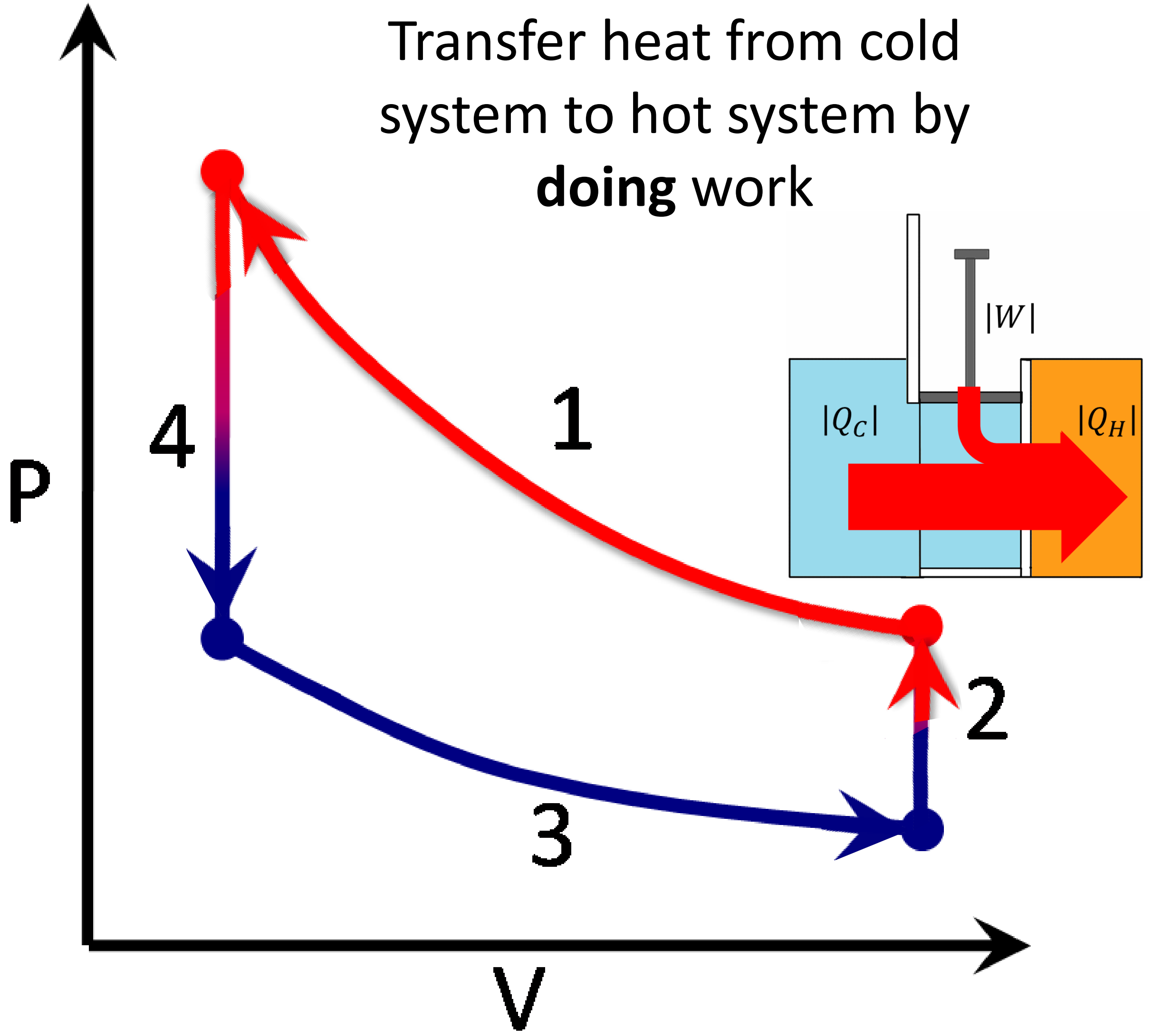
"heat engine"

Transfer heat from hot system to cold system and **do** work



"refrigerator"

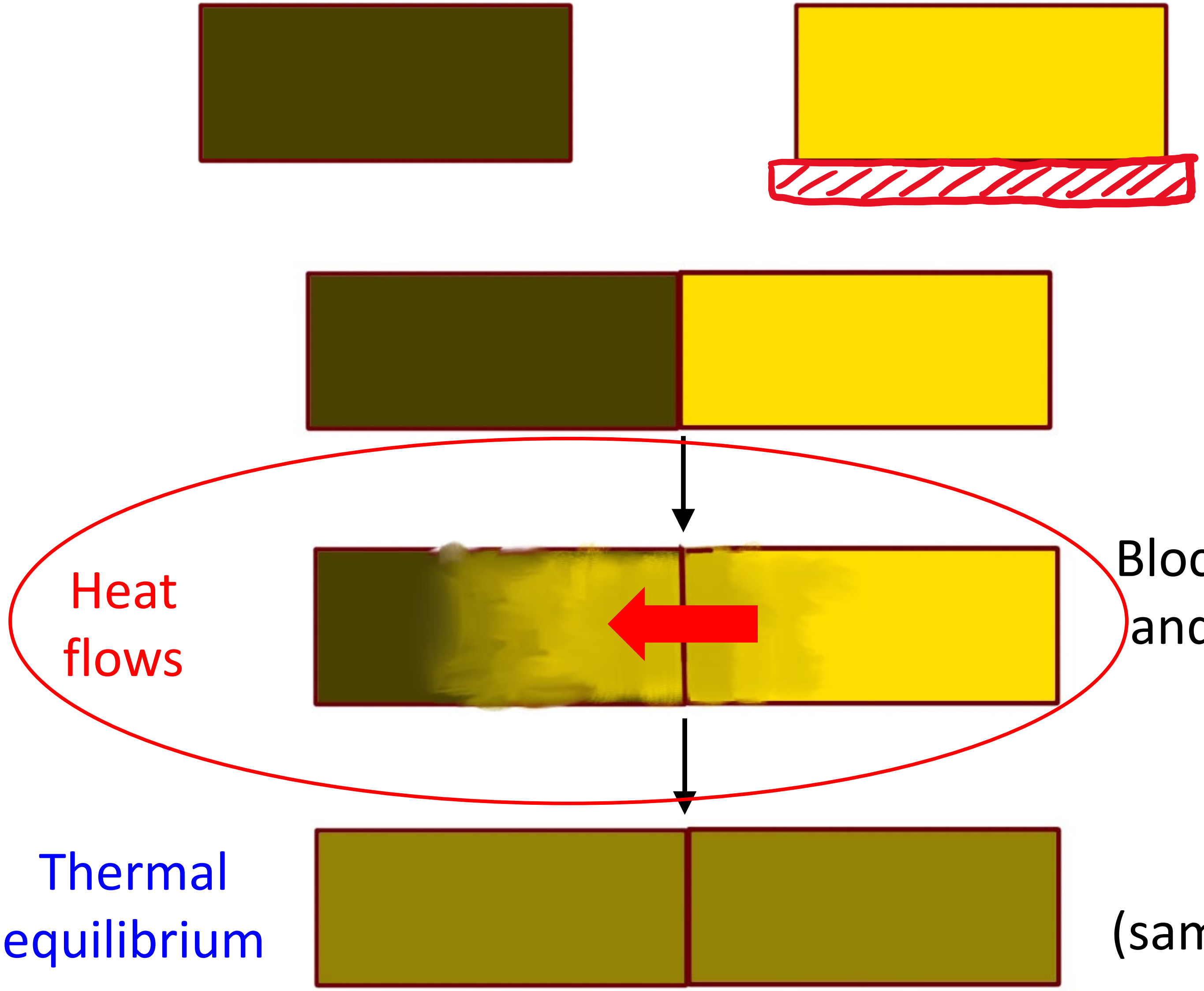
Transfer heat from cold system to hot system by **doing** work



Frogs and Arrow of time

In equilibrium with room — In equilibrium with hot plate

From lecture 2…

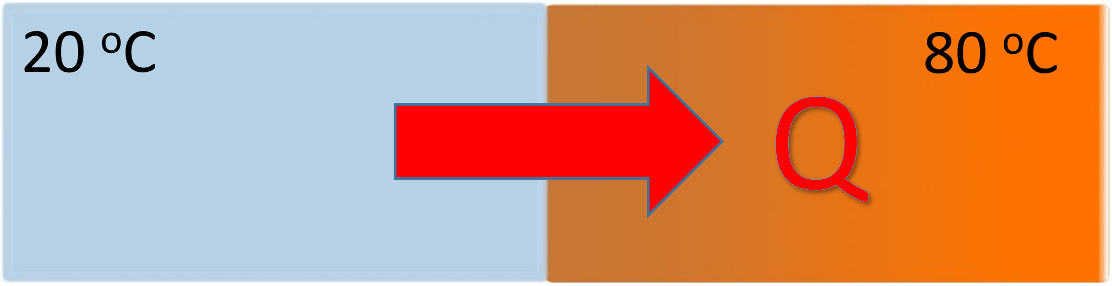


Place them in thermal contact

Blocks are not in equilibrium with each other, and each block is not in an equilibrium state (some parts are hotter)

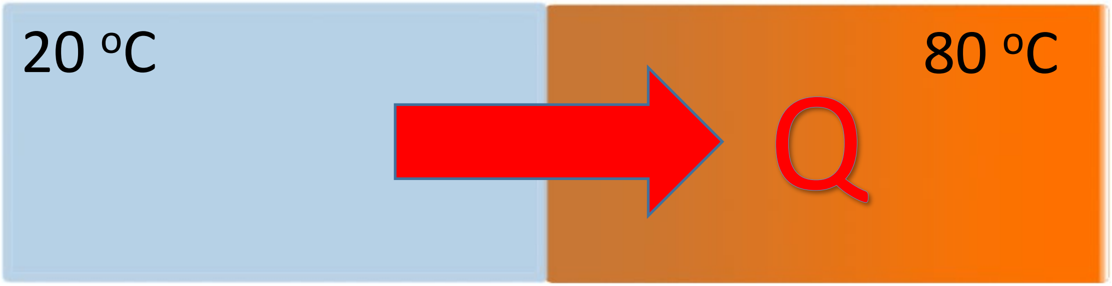
Blocks are in equilibrium (same temperature & temperature is uniform)

Q: A flow of heat from a cold object to a hot object (without any associated work) would violate conservation of energy.



A. True
B. False

Q: A flow of heat from a cold object to a hot object (without any associated work) would violate conservation of energy.



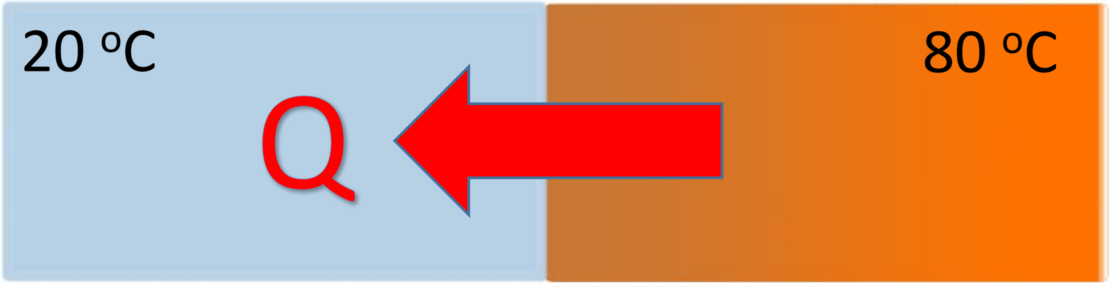
If we moved 100 J from the cold object to the hot object, total energy would be conserved. The cold object would get colder and the hot object would get hotter.

BUT, this never happens spontaneously! Why?

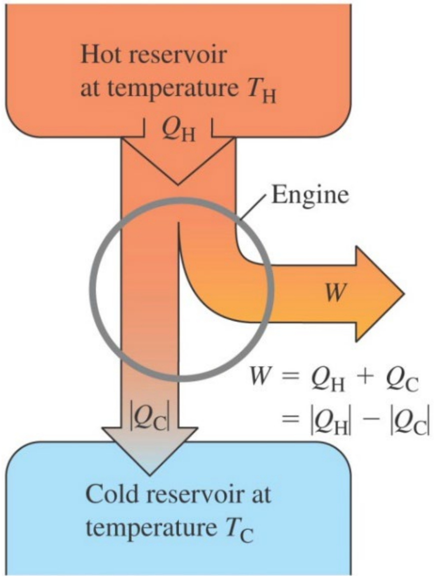
A. True
B. False ✓

Directions of thermodynamic processes

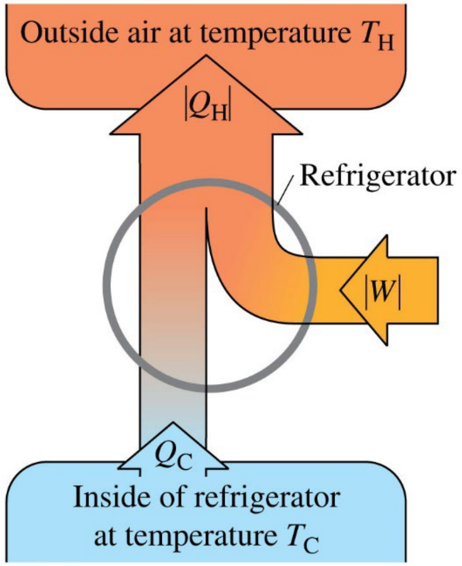
- Why does heat always flow from hot objects to colder objects?



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



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

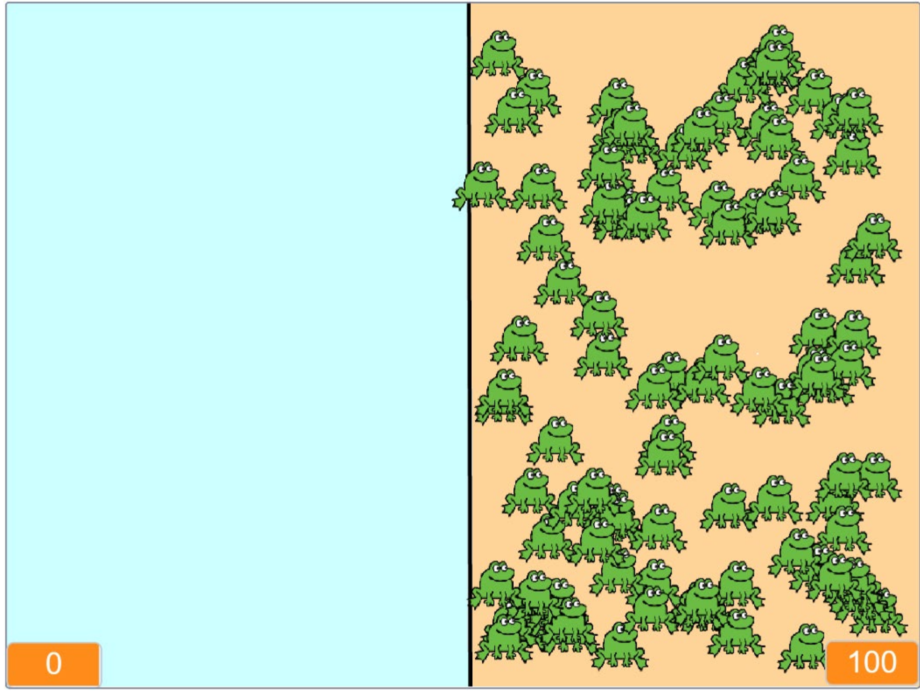


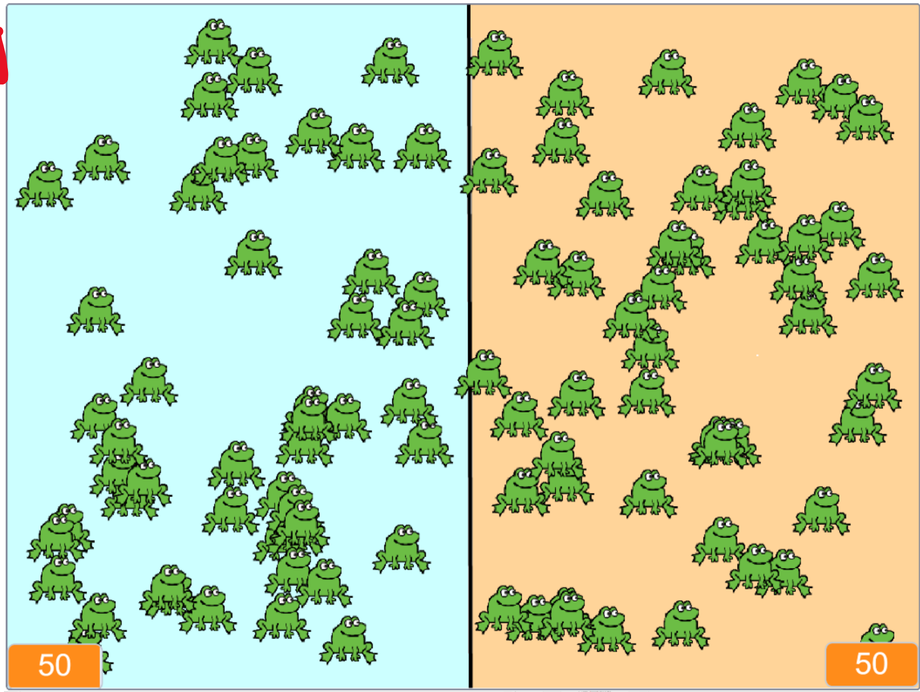
Let's use an analogy: frogs!

https://scratch.mit.edu/projects/588512804/

If the frogs move around randomly, why is there always a net movement of frogs from an area of high average frog density to an area of low average frog density?

- As time passes, we move between possible configurations of frogs
- all configurations of frogs are equally likely…
- …BUT:
  - ➢ Vastly more configurations with a more balanced number of frogs –
  - ➢ Hence, almost certain to end up with a more balanced number than a less balanced number





Q: In the analogy with a thermodynamic system, the individual frogs represent:

A. Molecules
B. Units of energy
C. Temperature

Q: In the analogy with a thermodynamic system, the individual frogs represent:

Frogs ⟷ Energy

(both are conserved and move around the system randomly)

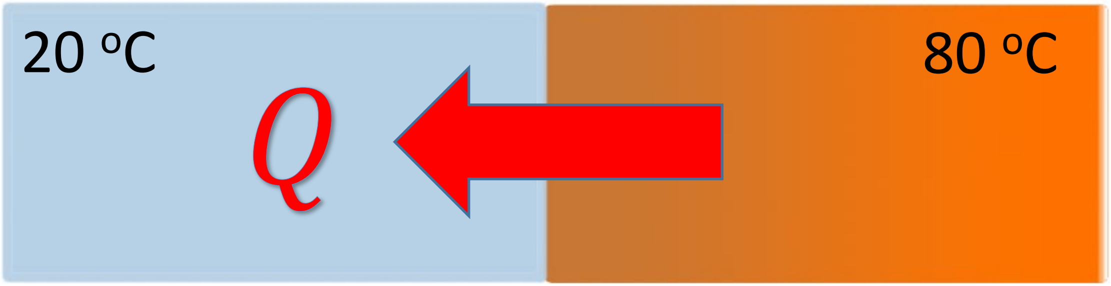
Density of frogs is analogous to temperature

A. Molecules
B. Units of energy ✓
C. Temperature

Flow of heat…

Energy

~ total # of frogs



Temperature

~ total density of frogs

- Energy is exchanged between nearby molecules via random processes (like hopping frogs)
- Vastly more configurations where energy is distributed more evenly between both sides
- Heat (energy) will almost certainly flow from higher temp (higher energy density) side to lower temp (lower energy density) side

Quantitatively:

Frog distribution: (0, 100)

~ 10^{500} such configurations

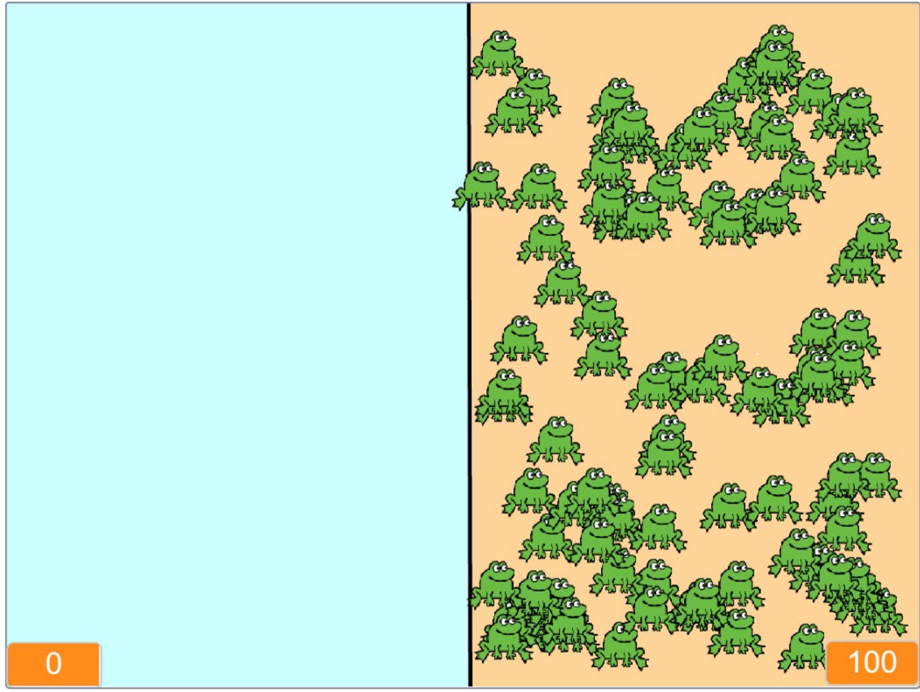
(10^5 possible pixel locations for each frog)

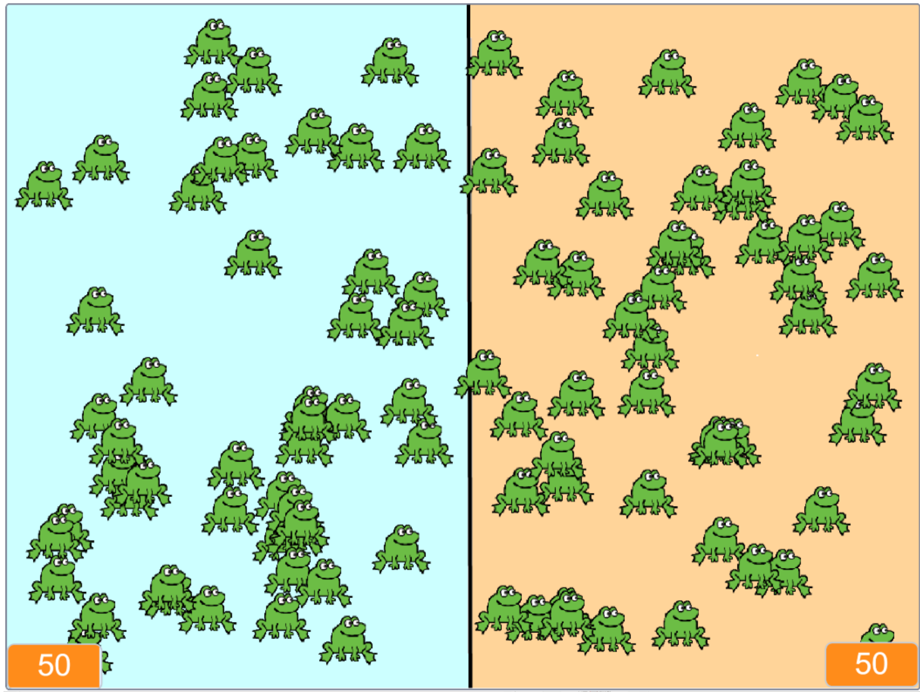
Frog distribution: (50, 50)

~ 10^{530} such configurations

(2×10^5 possible pixel locations for each frog)

Even if we start in a (0,100) configuration, if we wait a while, we are 1,000,000,000,000,000,000,000,000,000,000 times more likely to be in a (50,50) configuration than a (0,100) configuration





Extra: where do these numbers come from?

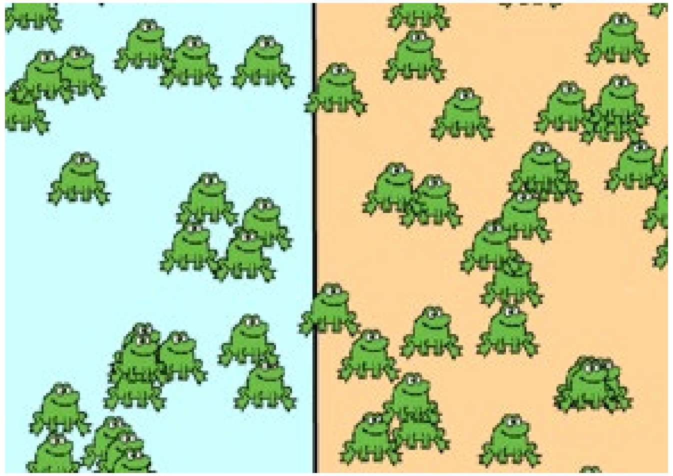
$3! = 1 \cdot 2 \cdot 3$

$5! = 1 \cdot 2 \cdot 3 \cdot 4 \cdot 5$

- n frogs to the left, $N - n$ frogs to the right:

$$\#\ \text{configurations} = \boxed{\frac{N!}{n!\,(N-n)!}} \times 10^{5N}$$

$N = 100$



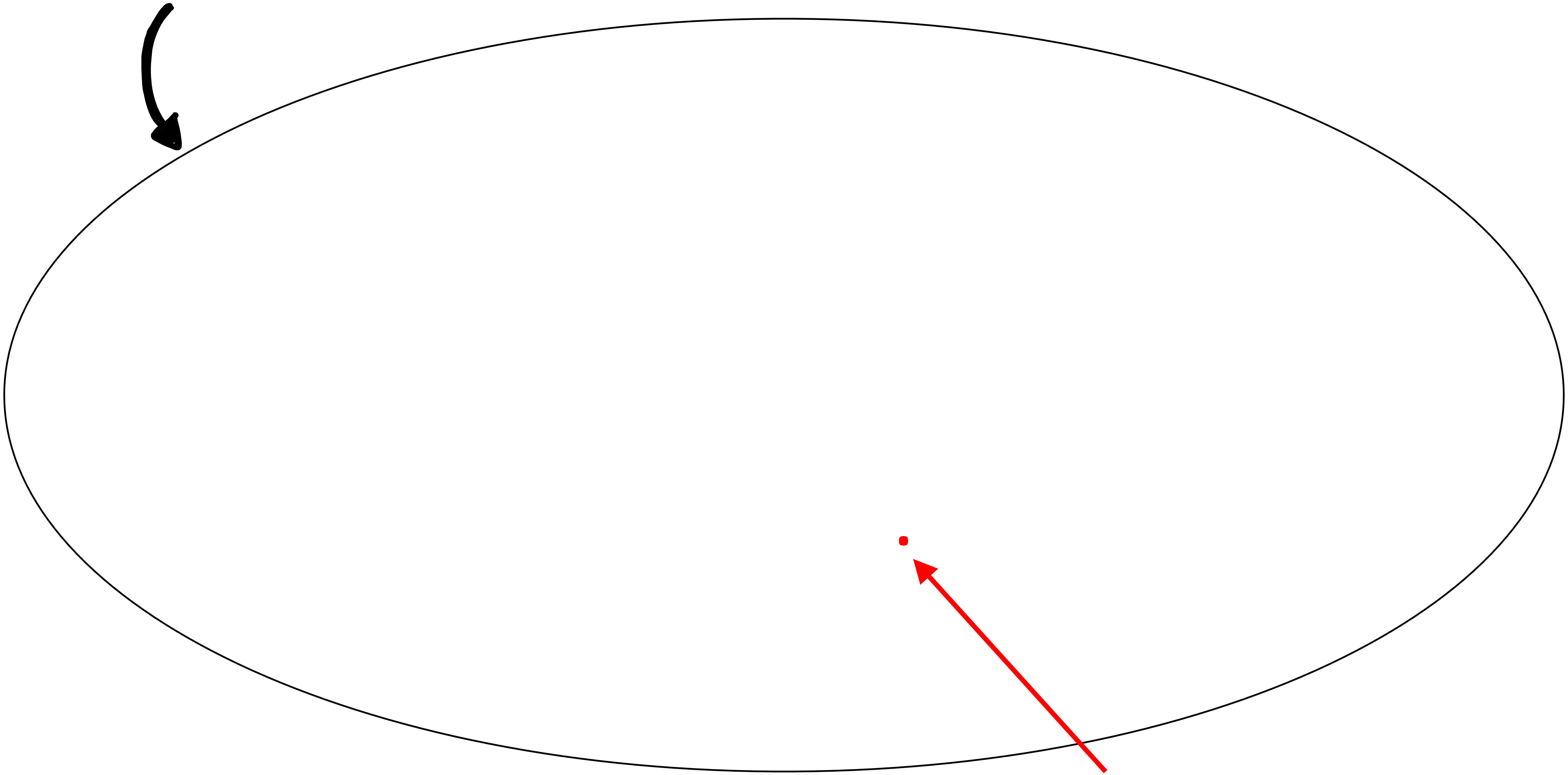
n $\quad N-n$

$n = 50$

- 10^{5N} comes from 10^5 pixels per frog

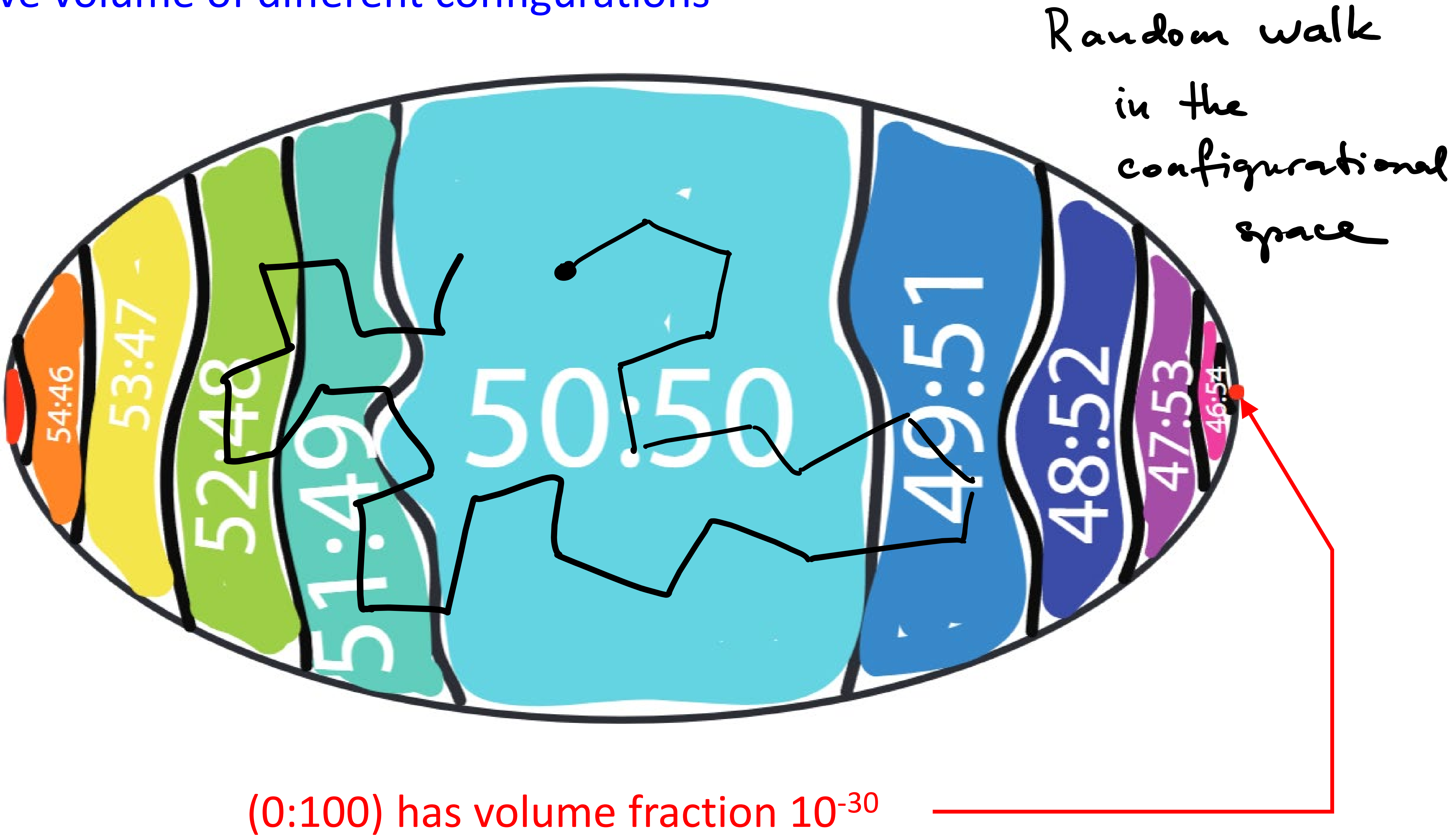
- It can be ignored since it is the same for all configurations

All possible configurations of frogs



configurations with most of the frogs on the right ~ 10^{30} times smaller area

Relative volume of different configurations



Entropy

a measure of how disordered a system is

ordered state

low entropy

disordered state

high entropy

Microscopic definition of entropy

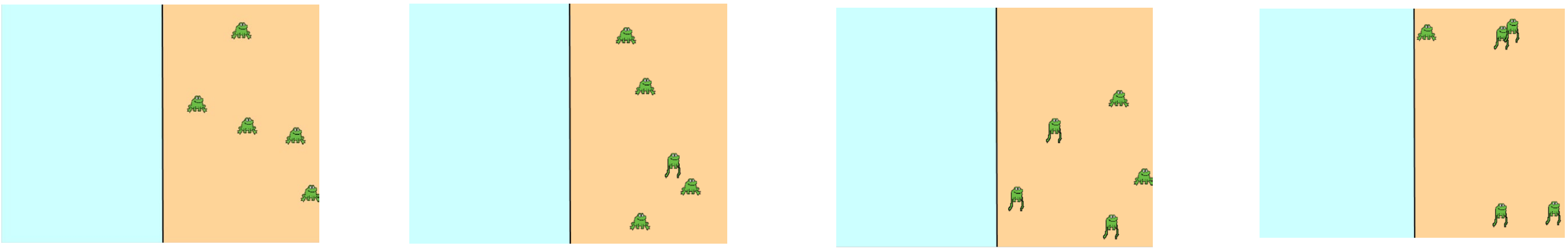
- Entropy is a measure of how many possible microscopic configurations there are for a specified set of macroscopic variables

- Macroscopic variables (or macroscopic configuration) means
  - e.g., (30,70) distribution of frogs, or
  - e.g., a gas with pressure P, volume V, temperature T

- Define ENTROPY of a macroscopic configuration as:

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

N is the number of microscopic configurations of this macroscopic configuration



(0,5)

Some microscopic configurations of frogs with macroscopic configuration (0,5)