Last time in Phys 157...
REFRIGERATORS: Can transfer heat from colder system to warmer system by doing work.

* Heat engine in reverse *

*Example diagram*
Crucial step:

Constant temperature expansion

(1 mole, $5L \rightarrow 20L$)

(adiabatic expansion would also work)
Constant volume heating

416 J
Constant temperature compression
Constant volume cooling
Net result of cycle:

\[ |Q| = 2729 \text{ J} \quad |W| = 230 \text{ J} \quad |Q_H| = 2959 \text{ J} \]
(a) Typical home refrigerator:
It’s a hot day and your house doesn’t have air conditioning. Your friend Sam suggests leaving the refrigerator door open in order to cool down the kitchen. What is an appropriate response here?

A) That’s a great idea, let’s do it!

B) Yes it will cool down the kitchen, but it’s a total waste of energy.

C) That won’t have any effect at all on the temperature of the room, but the food will go bad.

D) Hey Sam, that’s great that you’re thinking creatively, but it will actually make the room warmer than leaving the fridge door closed.
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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
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A) True

B) False

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.
Discussion Question:

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

Let’s use an analogy:
As time passes, we move between possible configurations of frogs.

All specific configurations are equally likely.
But...

$10^{500}$ configurations like this

$10^{530}$ configurations like this

($10^5$ possible pixel locations for each frog)
All possible configurations of frogs:

configurations with most of the frogs on the right
10^{30} times smaller area
If we start here

After a while, we are $10^{30}$ times more likely to end up in a $(50,50)$ configuration than a $(0,100)$ configuration.
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?

- all configurations of frogs are possible*
- vastly more configurations with a more balanced number of frogs*
- almost certain end up with a more balanced number than a less balanced number*
In the analogy with a thermodynamic system, the individual frogs represent

A) Molecules

B) Units of energy

C) Temperature
Analogy:

Frogs = energy
Conserved + move randomly

density of frogs = temperature
proportional to energy per molecule
* Energy is exchanged between nearby molecules via random processes (like hopping frogs).

* Vastly more configurations where energy is distributed more evenly between 2 sides.

* Heat will almost certainly flow from higher temp. side to lower temp. side.
Quantitatively:

frog distribution: \((0, 100)\)

\(\sim 10^{500}\) such configurations

\((10^5\text{ possible pixel locations for each frog})\)

frog distribution: \((50, 50)\)

\(\sim 10^{530}\) configurations

after a long time, a \((50, 50)\) distribution is

1,000,100,000,100,000,000,000,000,000,000,000,000,000 times more likely
**Entropy** is a measure of how many possible microscopic configurations there are for a specified set of macroscopic variables.

\[ e.g.: \quad 0 \quad 100 \quad \sim 10^{500} \text{ such configurations} \]

\[ \text{entropy is } \log(N) \sim 500 \]

\[ 50 \quad 50 \quad \sim 10^{530} \text{ configurations} \]

\[ \text{entropy is } \log(N) \sim 530 \]
2nd Law of Thermodynamics:

Total entropy never decreases.

→ probability of decrease is too small to comprehend

10 times more likely