Three materials properties

- Thermal expansion:

  Expansion or elongation as T is increased

- Thermal conductivity:

  Rate of transfer of heat through a material

- Specific heat:

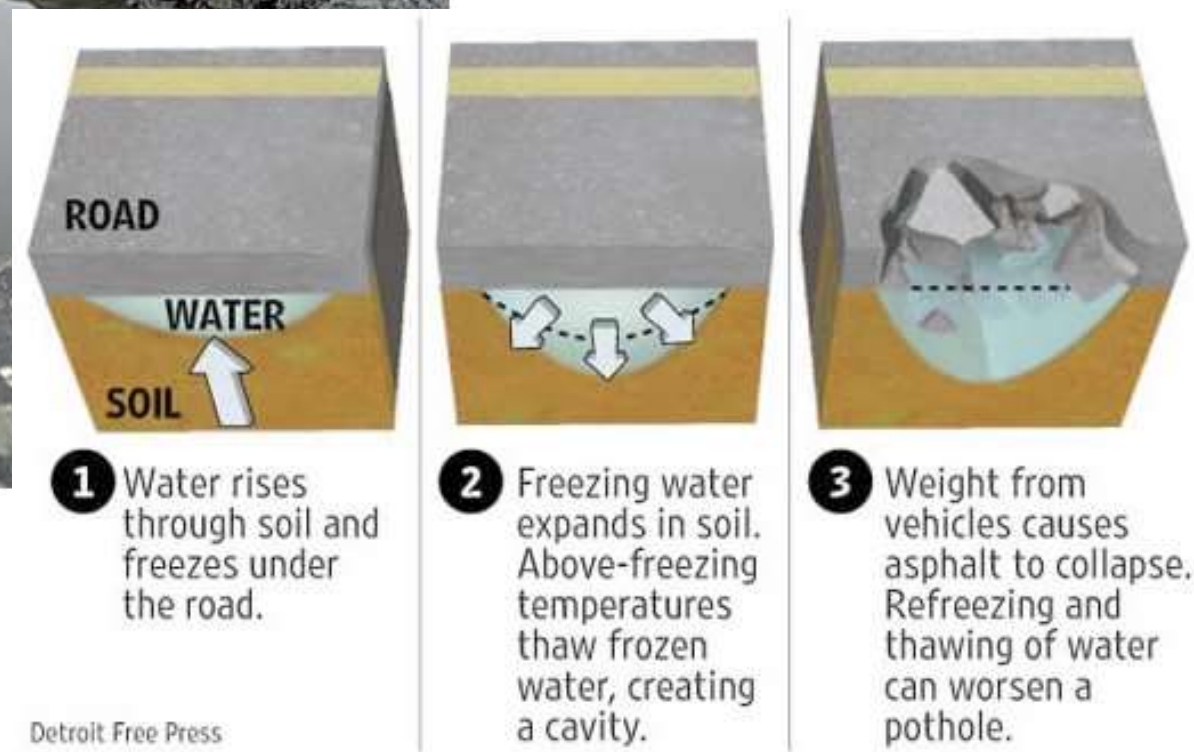
  Amount of energy needed to increase T

Thermal expansion

Expansion or elongation as T is increased

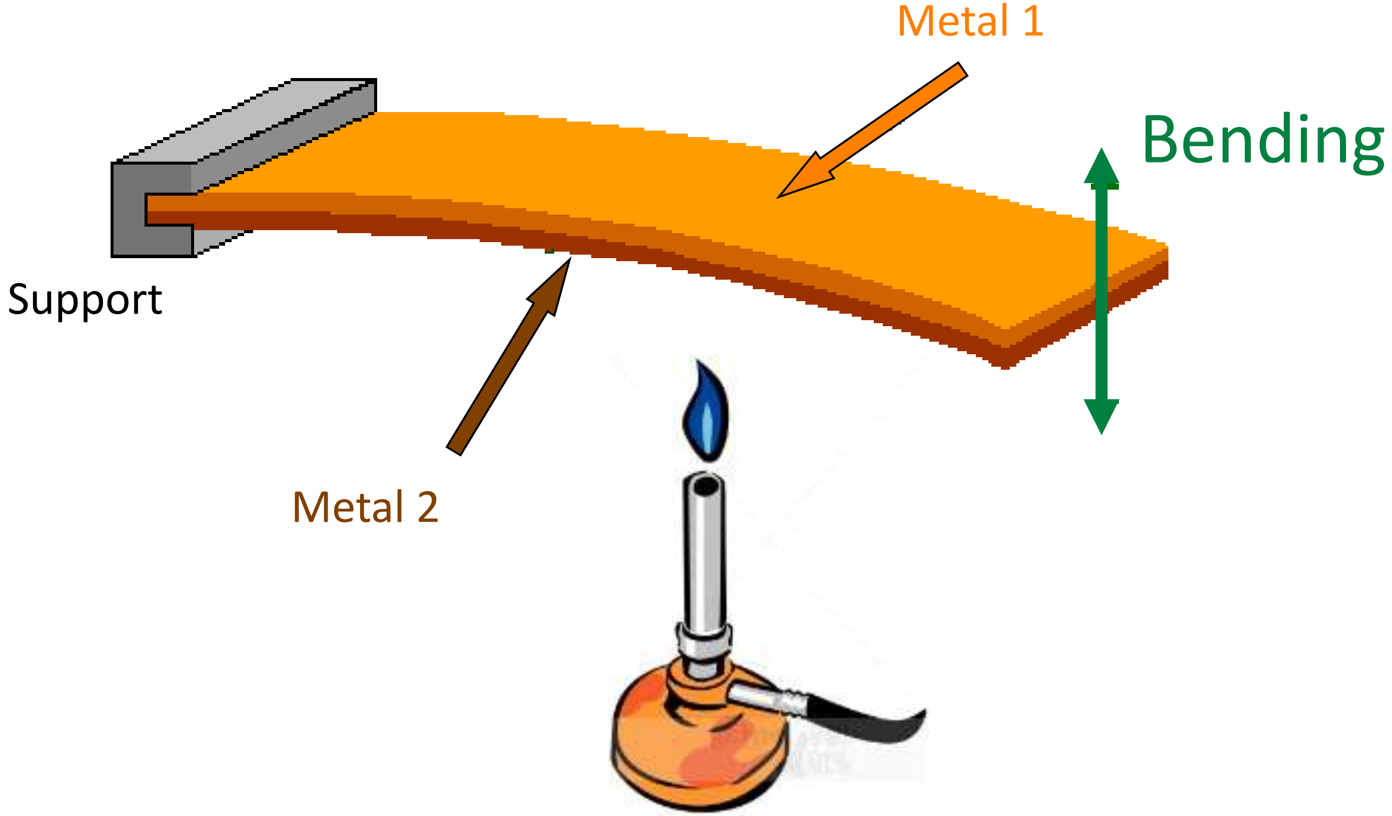
Expansion upon phase change: Pot Holes

Water expands when it freezes! Ice is *<u>less dense</u>* than the water from which it freezes.



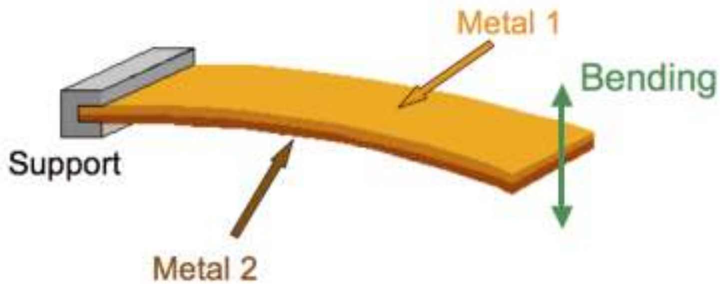
Thermal expansion

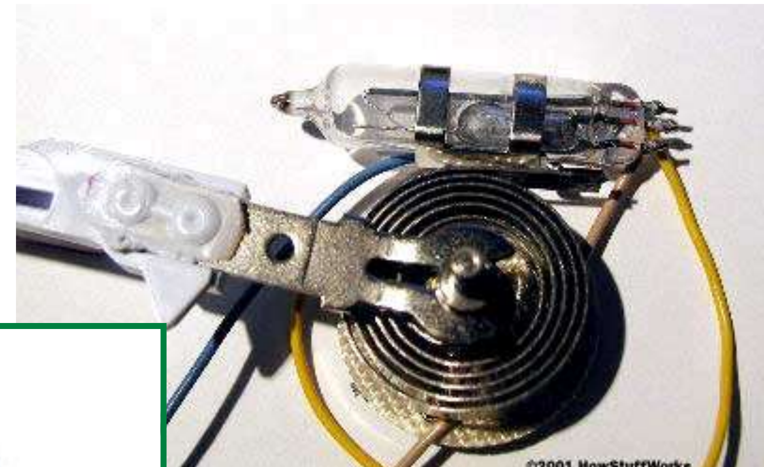
Bi-metallic strip



Video: Bi-metallic strip

Thermal expansion: bimetallic strip





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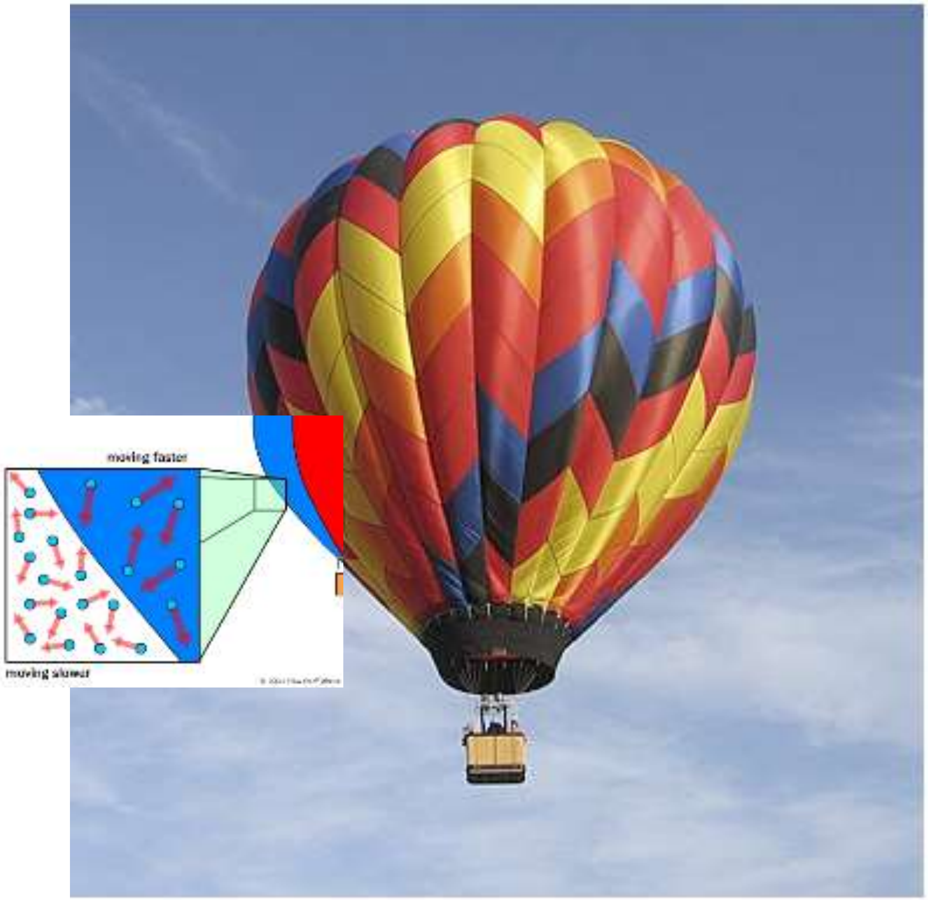
Thermal Expansion of a Gas



Can a hot air balloon lift more on a hot day or a cold day?

Video: Cooling balloon

Thermal expansion of a liquid

Galileo thermometer

Kerosene vapor

Kerosene liquid

Temp. increases

$\Downarrow$

Kerosene expands

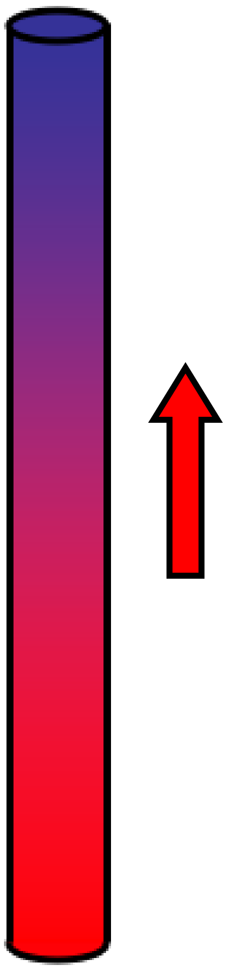
$\Downarrow$

Boyancy reduced

$\Downarrow$

Swimmers fall

Thermal conductivity



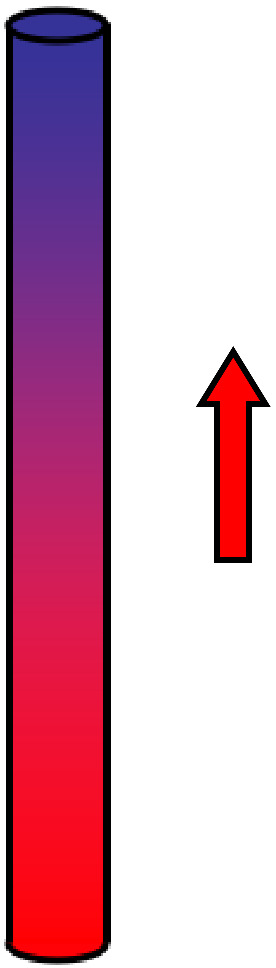
Rate of heat flow is proportional to:

- the temperature difference
- the cross sectional area
- 1/length

The proportionality constant is different for different materials.

It is called the “thermal conductivity” of the material.

Thermal conductivity



Rate of heat flow is proportional to the "thermal conductivity" of the material

High thermal conductivity:

- Silver
- Copper
- Aluminum

Low thermal conductivity:

- Stainless steel
- Wood
- Wool
- Styrofoam

Clicker Question

A cylindrical copper rod connects a hot reservoir to a cold reservoir. If we replace the rod by another cylindrical copper rod that is four times as long but has twice the diameter as the original rod, the amount of heat that flows from the hot to the cold reservoir

A. quadruples.
B. doubles.
C. stays the same
D. is reduced by half
E. is reduced by one quarter.
F. something else.

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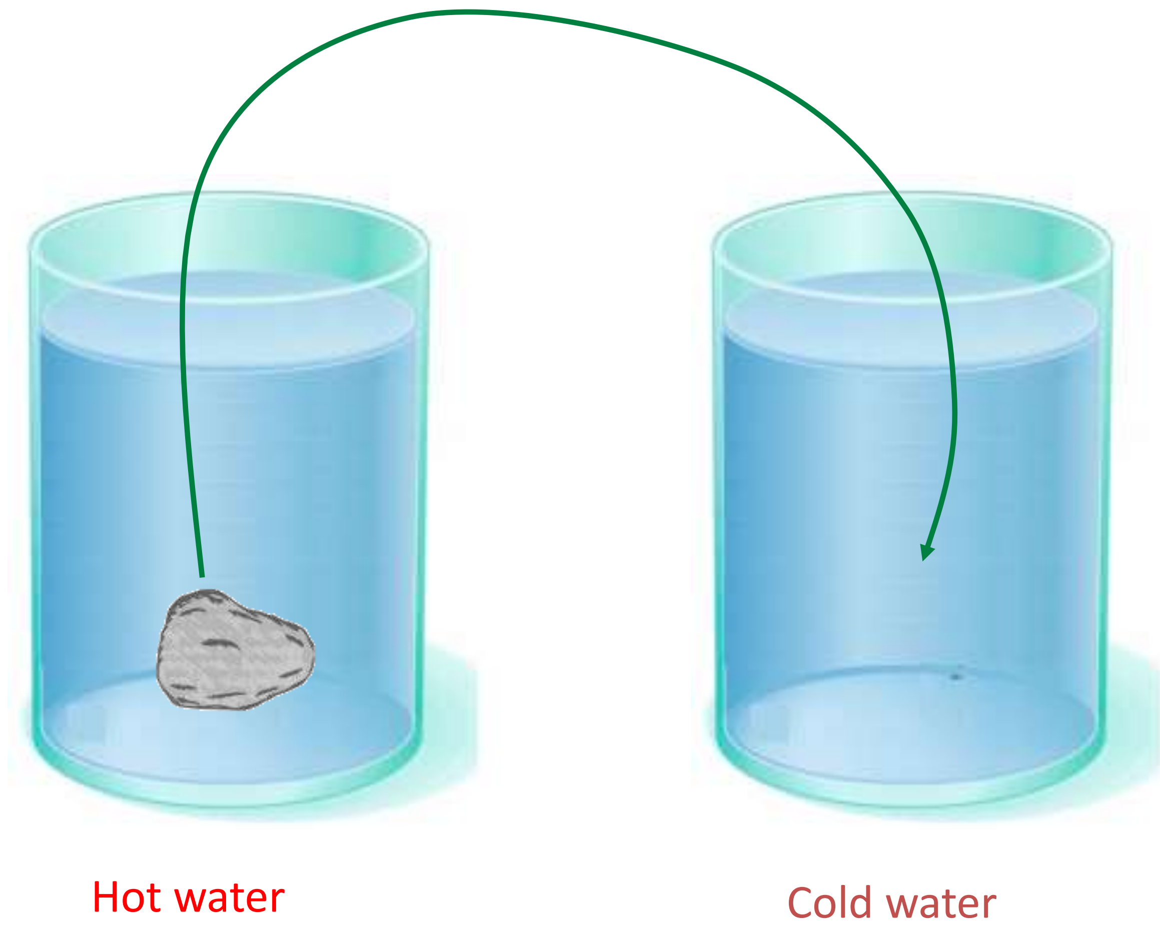
Specific heat

How much thermal energy is needed to raise the temperature of the material?

Specific heat *C*



Specific heat C

For an amount of material of mass m, the amount of heat needed to raise its temperature by an amount ΔT is:

$$\text{Heat} = C \times m \times \Delta T$$

Units of C are kcal / kg / °C

Specific heat *C*

Specific Heats (at 20^0 C and 1 atm pressure)

Substance	Specific Heat c $kcal/kg^0C$
Aluminum	0.22
Copper	0.093
Glass	0,20
Iron or Steel	0.11
Lead	0.031
Marble	0.21
Silver	0.056
Wood	0.4
Mercury	0.033
Alcohol	0.58
Water	1.00
Ice	0.50
Human Body	0.83
Protein	0.4

Coincidence?

No: definition of kcal!

Clicker Question

How much heat (in kcal) is required to heat 5 liters of water from freezing temperature to room temperature (20 degrees Celsius)? The density of water is 1 kg/liter.

Clicker Question

How much heat (in kcal) is required to heat 5 liters of water from freezing temperature to room temperature (20 degrees Celsius)? The density of water is 1 kg/liter.

It takes **100 kcal** of heat:

$$\text{Heat} = C \times m \times \Delta T$$

Q = 1kcal/degree/kg * 5 kg * 20 degrees = 100 kcal

Specific heat C

The only
unknown

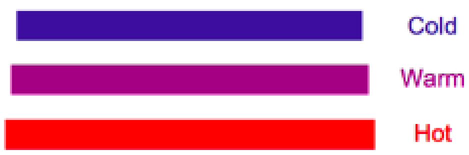
$$m_{\mathrm{metal}} \boxed{C_{\mathrm{metal}}} \left(T^{\mathrm{metal}}_{\mathrm{initial}} - T_{\mathrm{final}}\right) = m_{\mathrm{water}} C_{\mathrm{water}} \left(T_{\mathrm{final}} - T^{\mathrm{water}}_{\mathrm{initial}}\right)$$

Lab #3: Specific heat

Summary: Three Important Materials Properties

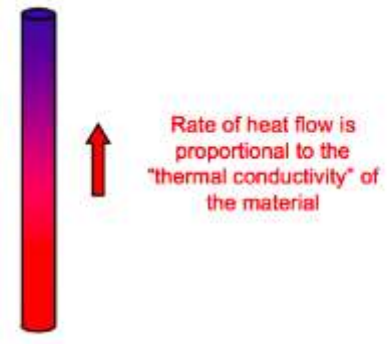
Thermal expansion

How much does the material expand as it gets hotter?



Thermal conductivity

How fast does heat travel in the material?



Specific heat

How much thermal energy is needed to raise the temperature of the material?

Clicker Question

We can tell a rod made of gold from a rod made of copper if we can measure its

A. thermal expansion coefficient
B. thermal conductivity
C. specific heat
D. density
E. all of the other answers

Clicker Question

We can tell a rod made of gold from a rod made of copper if we can measure its

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Direction of Heat Flow

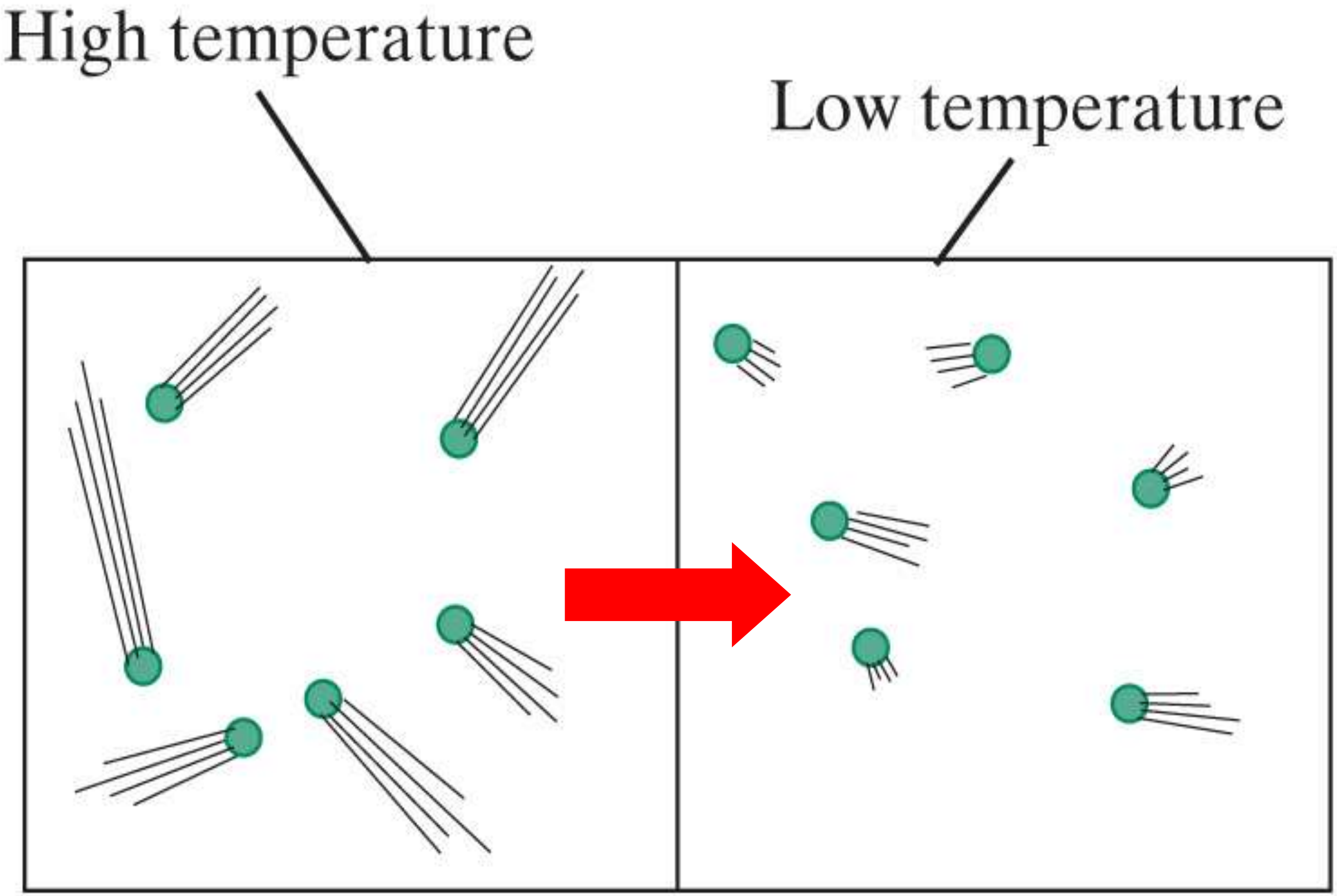
- Heat only flows from HOT objects to COLD objects.

- Thought experiment: Hot object and Cold object brought into contact.

    - Hot objects gets cooler, cold object gets warmer. HEAT FLOW from hot → cold.
    - Why does it never happen that HEAT FLOW from cold → hot?
    - This is a deep question related to the "direction of time".

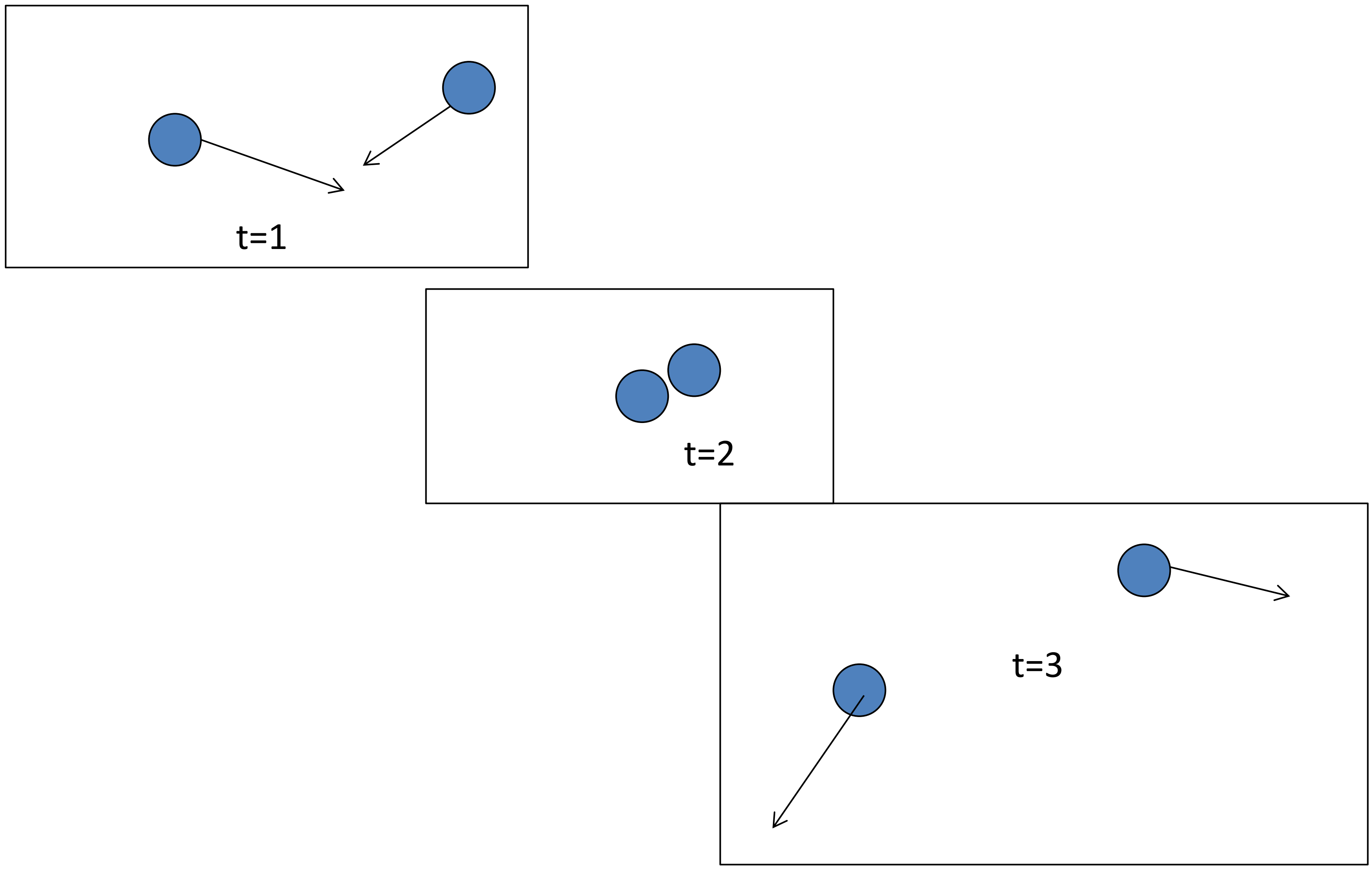
Thermodynamics

- The “arrow of time”
- The second law of thermodynamics
- Entropy
- Heat Engines



HEAT FLOW

But look at individual atoms



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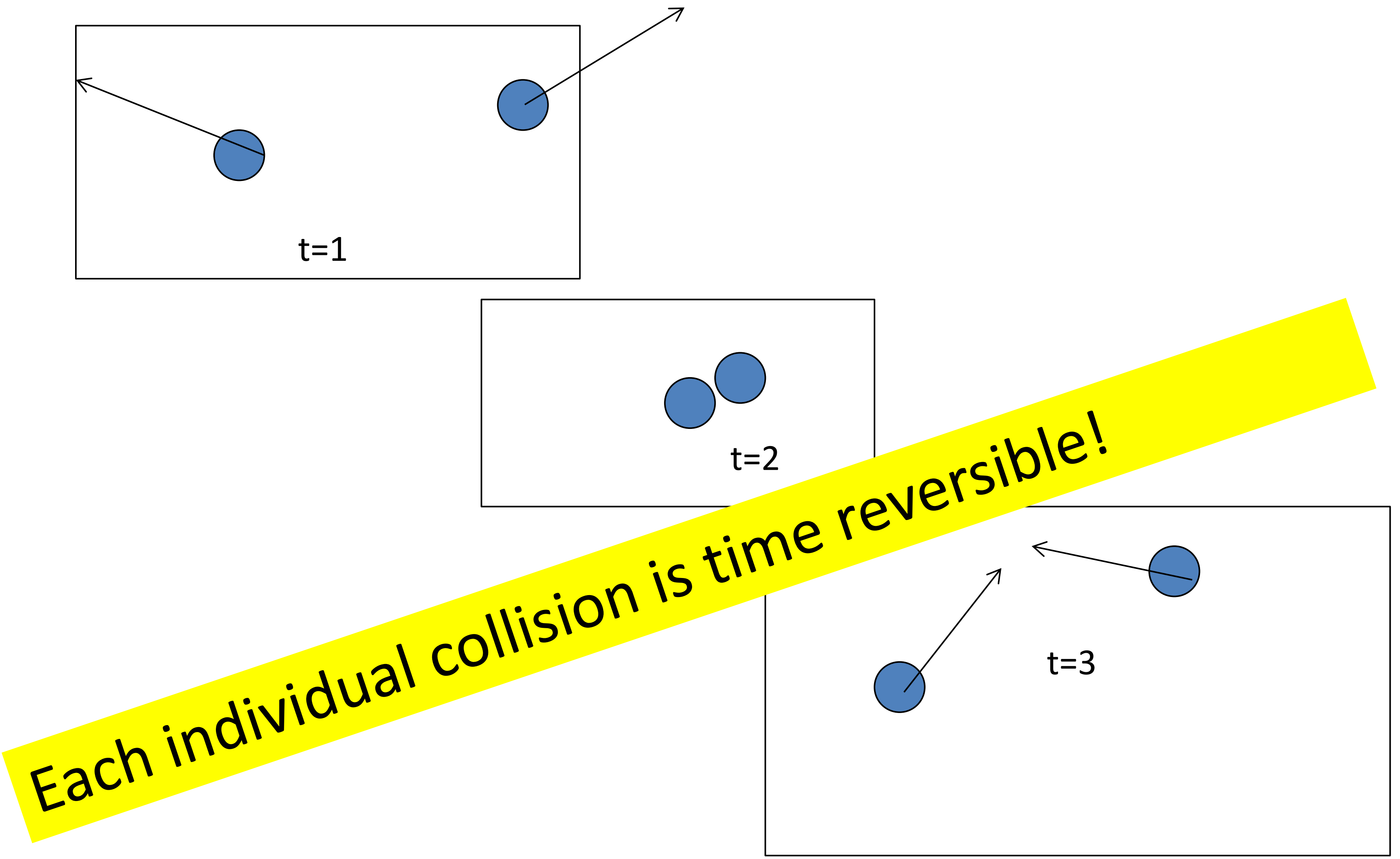
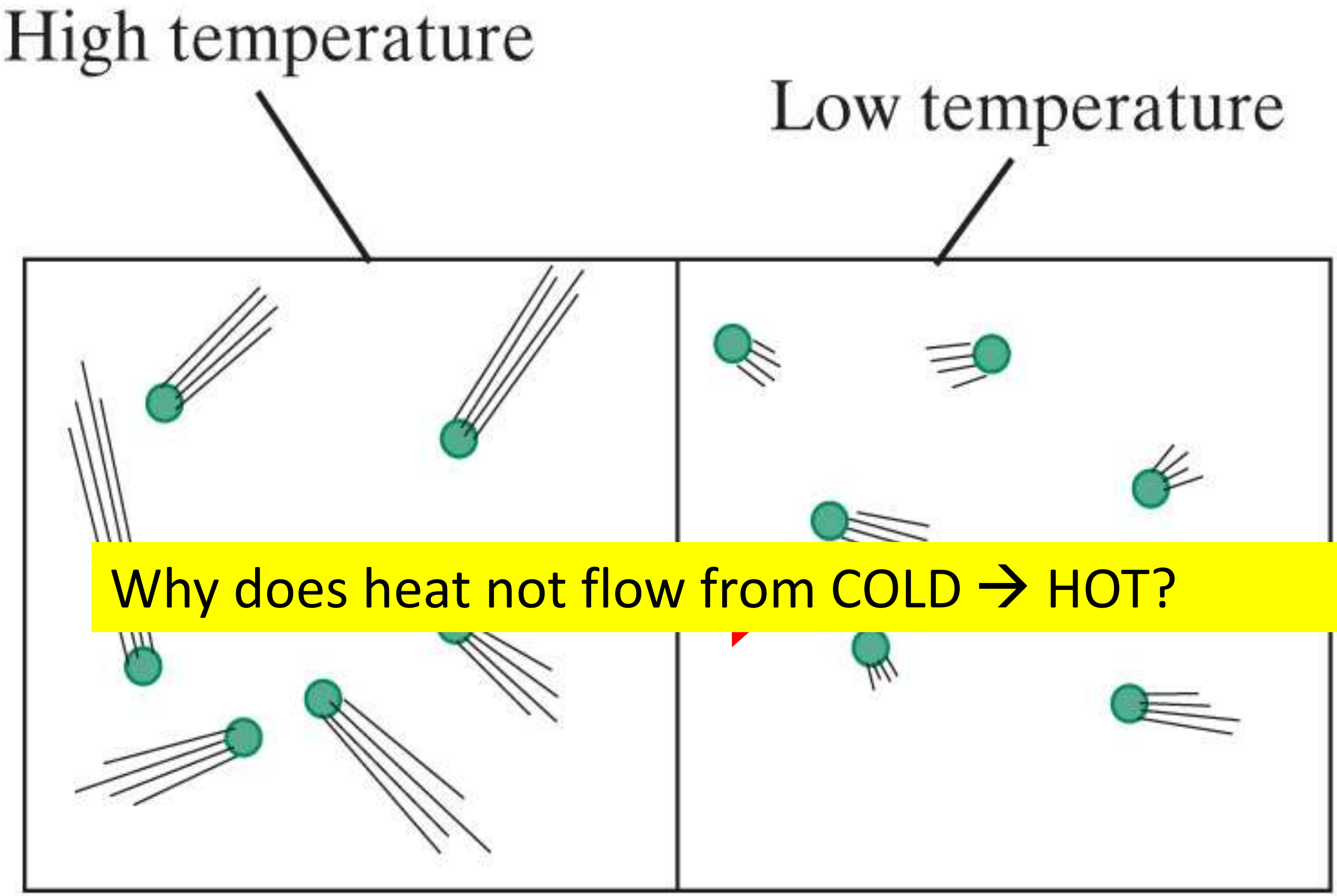




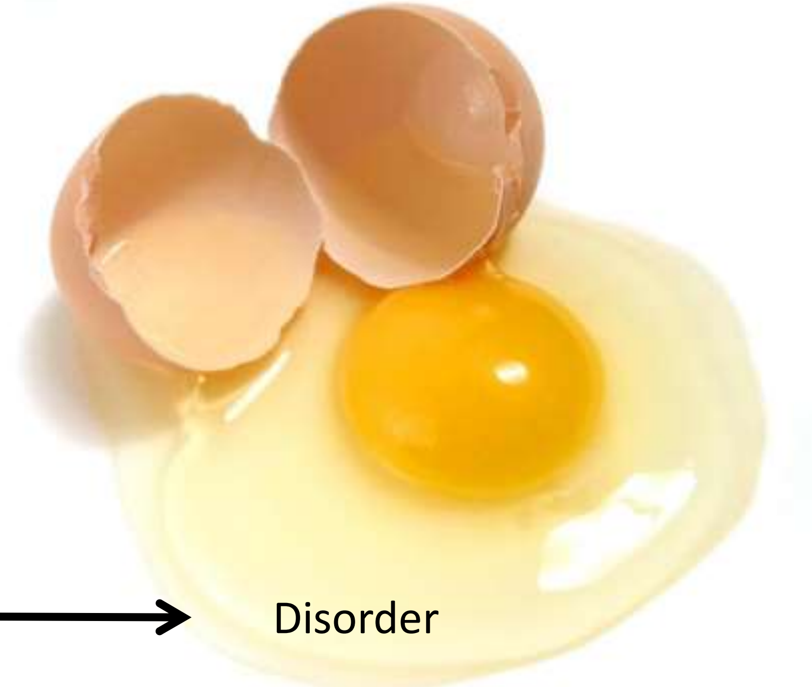
Why does heat not flow from COLD → HOT?

HEAT FLOW

Second Law of Thermodynamics

Nature always proceeds towards more microscopic disorder

(in physics we say Higher **Entropy**)

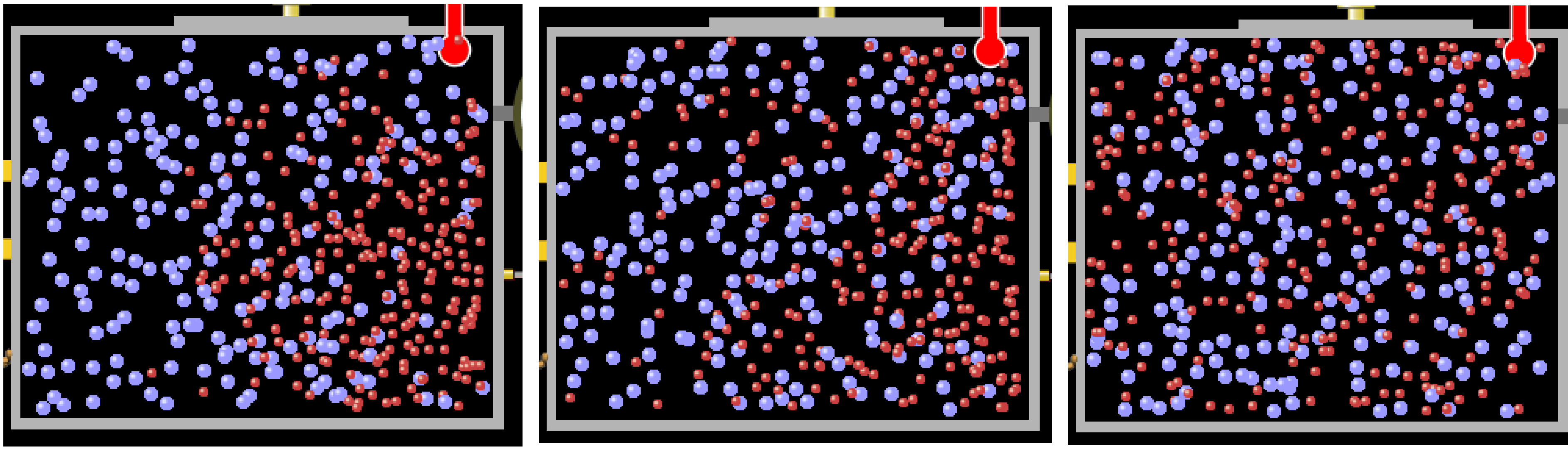


Order $\longrightarrow$ Disorder

time

Cannot go from Disorder to Order (Statistical Mechanics)

Time runs this way?

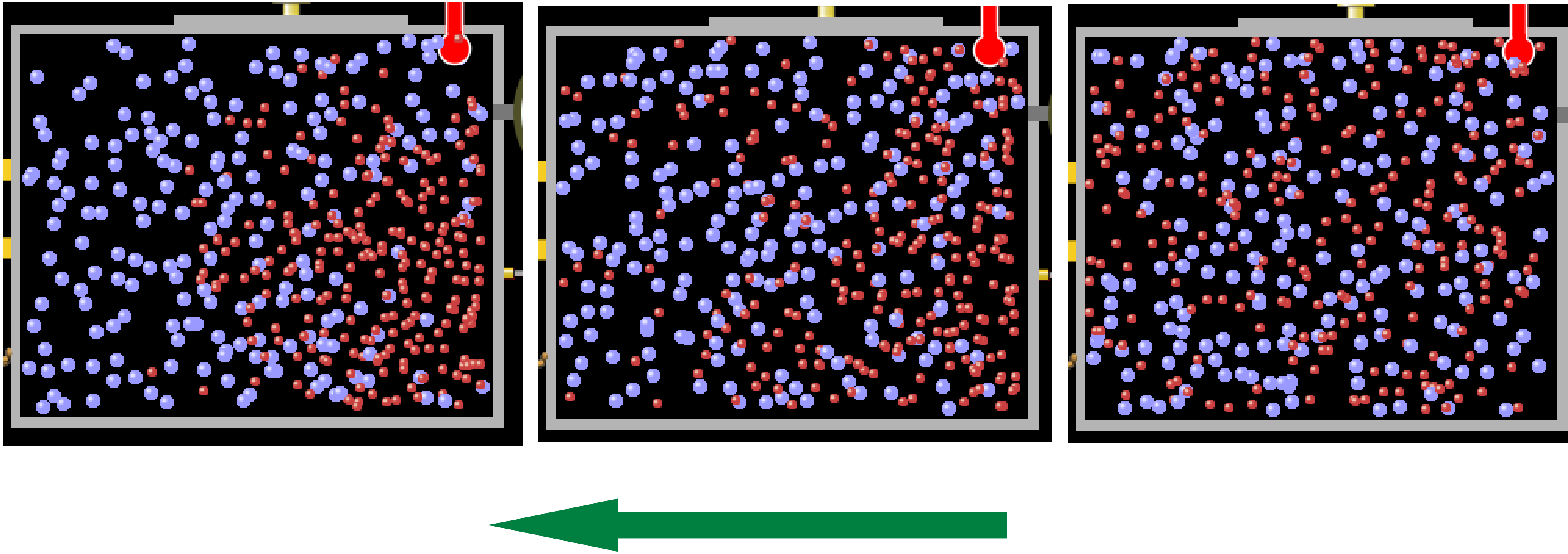


“order”

“disorder”

~~Time runs this way?~~

Possible, but unlikely!

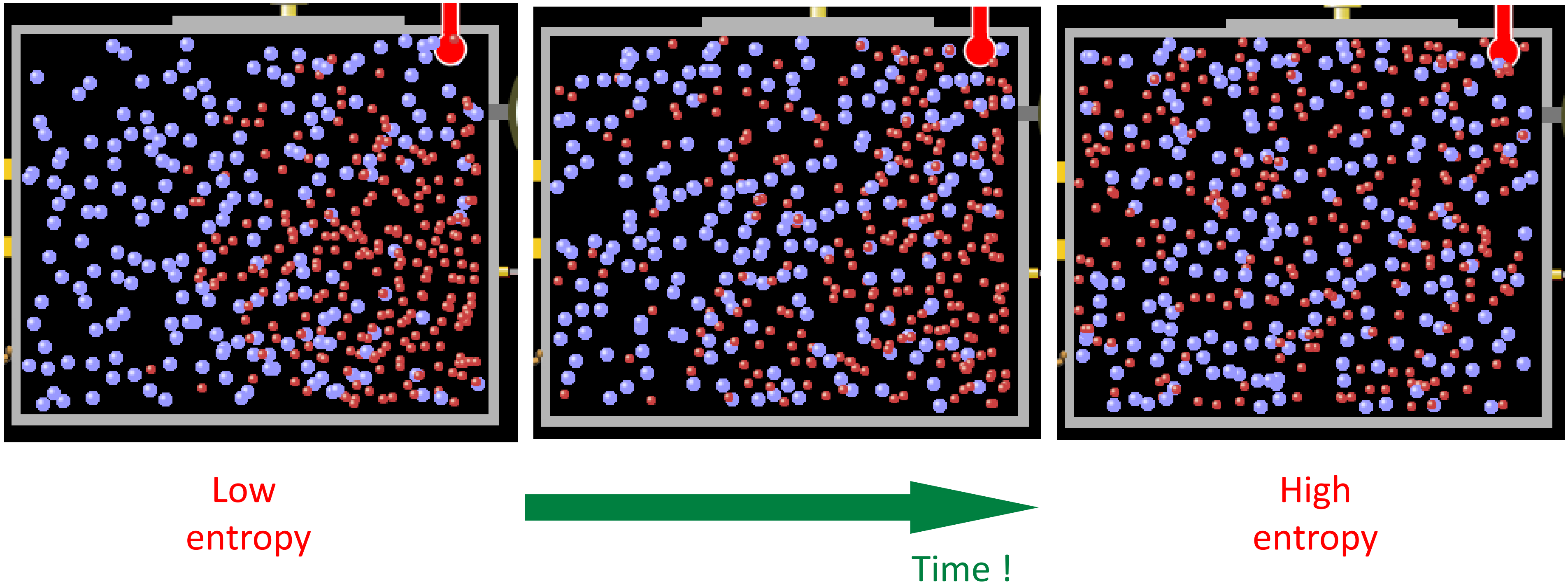


Time runs this way?

We need a physics principle that forbids this.

The <u>first law of thermodynamics</u> is a restatement of the law of conservation of energy, and does not forbid such a process.

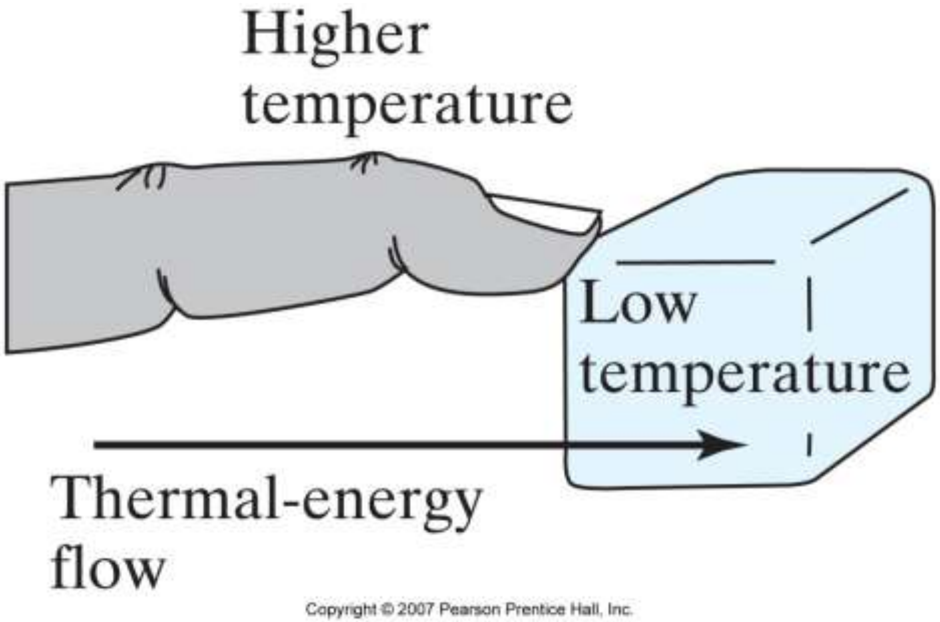
So, we come up with a principle, the <u>second law of thermodynamics</u>, which says that such time-reversed processes are so unlikely that they essentially never occur.

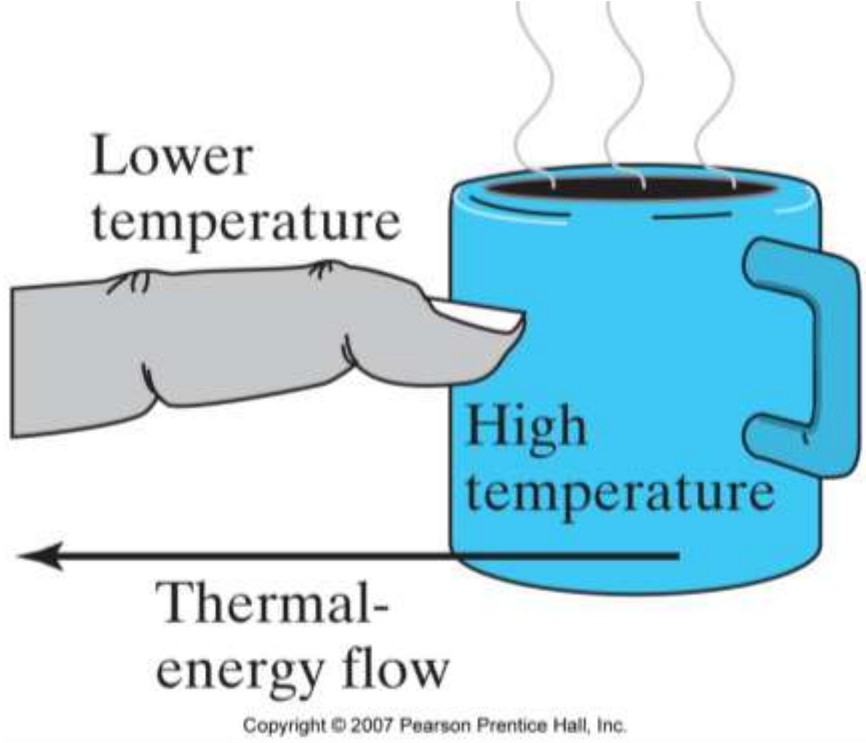


<u>Second law of thermodynamics</u>:

The total ***entropy***, which is a measure of the microscopic disorder, of all the participants in a process must stay the same or increase.


1967
DEPT. OF
ENTROPY
S. harris





Second law of thermodynamics:

(Another, equivalent, statement:)

Thermal energy flows spontaneously from higher to lower temperature, but not the other way.

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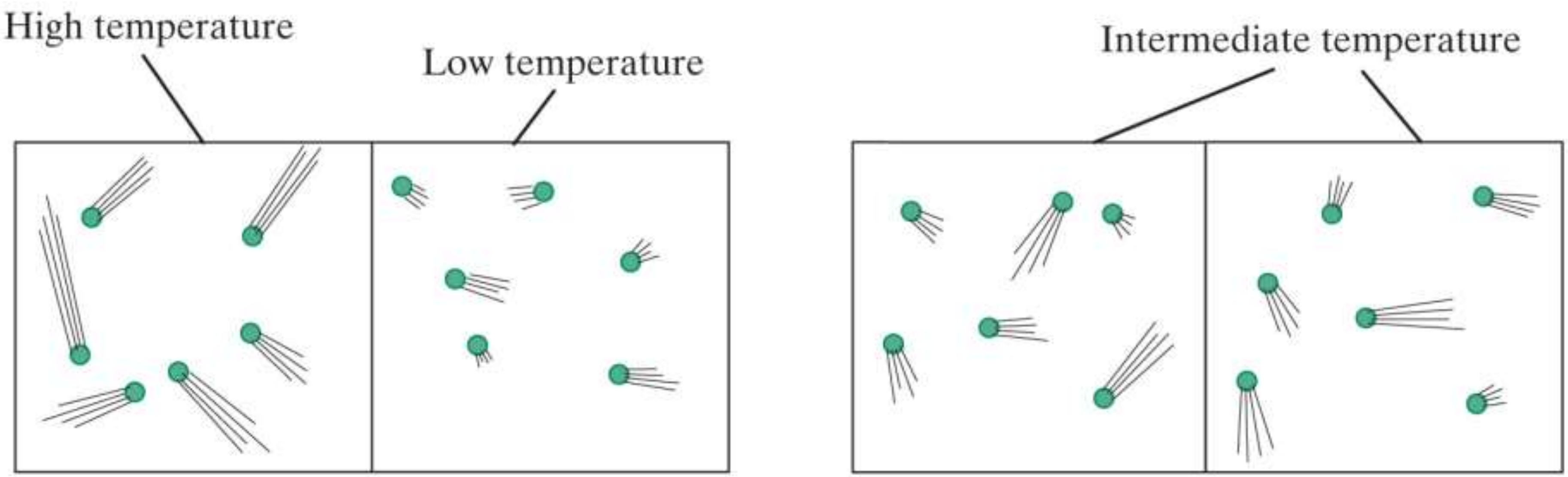


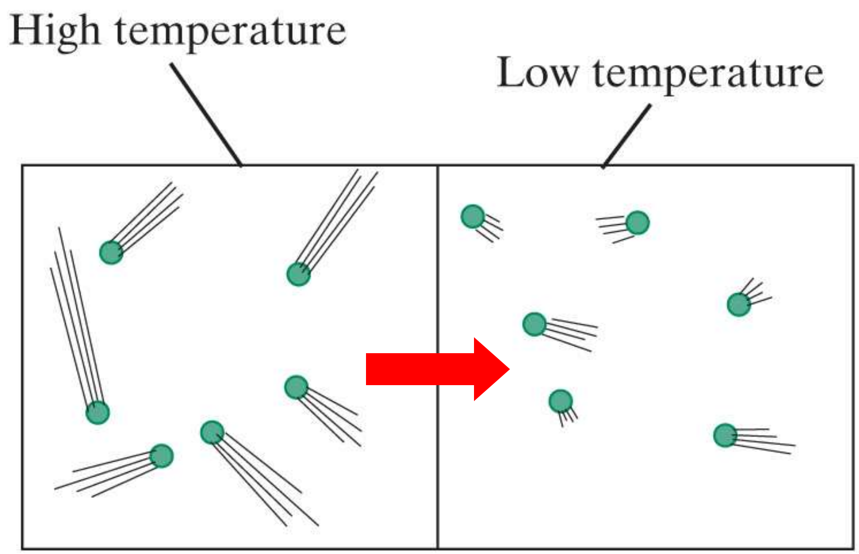
Lower entropy

Higher entropy

Entropy puzzle

I put a cup of water outside on a cold day in February, and it freezes. In doing so, it becomes more ordered; its entropy goes down.

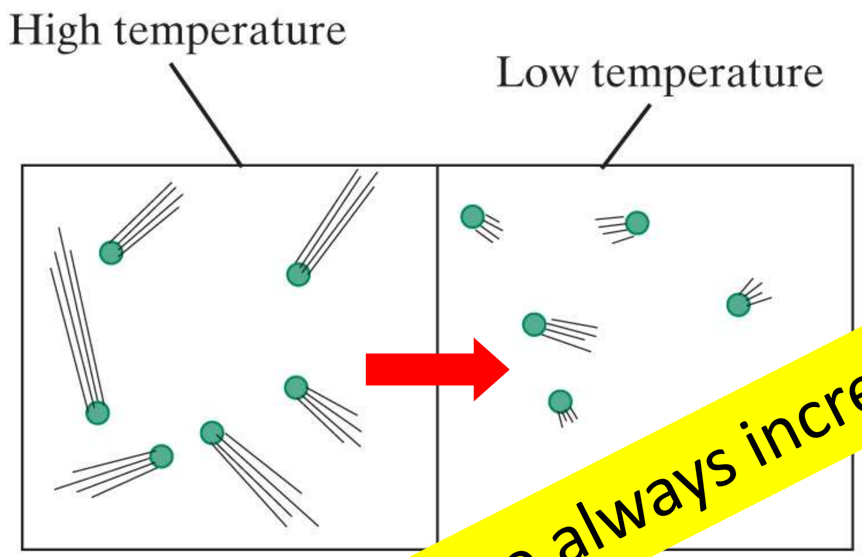
How is that consistent with the Second Law of Thermodynamics?



Heat flow raises overall entropy

A process can lower the entropy of one component if the entropy of others goes up more.

See, e.g., discussion about leaf in textbook.



Total entropy of the Universe always increases

Heat fl[...]es overall entropy

A[...]an lower the entropy of one component if the entropy of others goes u[...]ore.

See, e.g., discussion about leaf in textbook.

Clicker Question

Which laws of physics, if any, distinguish between the forward and backward direction in time?

A. The law of conservation of energy and the second law of thermodynamics.
B. The law of conservation of energy but not the second law of thermodynamics.
C. The law of conservation of entropy.
D. The second law of thermodynamics but not the law of conservation of energy.
E. No laws of physics can do that.

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Clicker Question

In any physical process,

A. The total entropy and the total energy always stay the same.
B. The total entropy decreases, and the total energy increases.
C. The total entropy increases or stays the same, while the total energy stays the same.
D. The total entropy decreases or stays the same, while the total energy stays the same.
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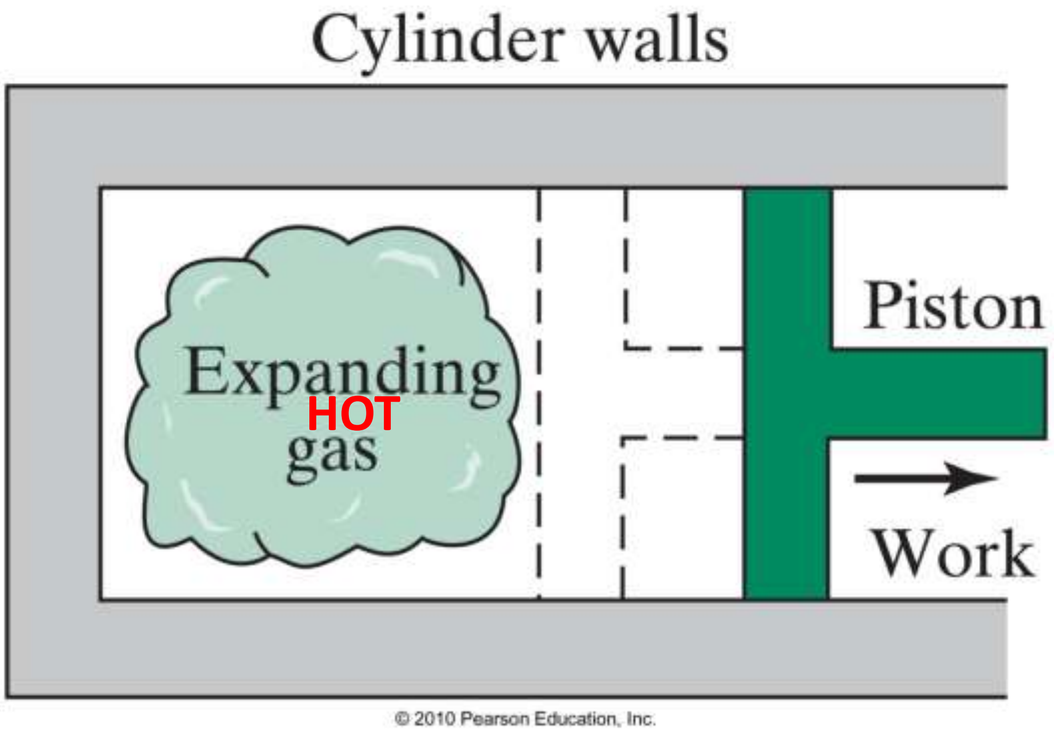
Heat Engines: Using Thermal Energy to Do Work

Creating thermal energy from other forms of energy is easy; all you have to do is rub your hands together.

How can we create other forms of energy – kinetic energy, say – from thermal energy?

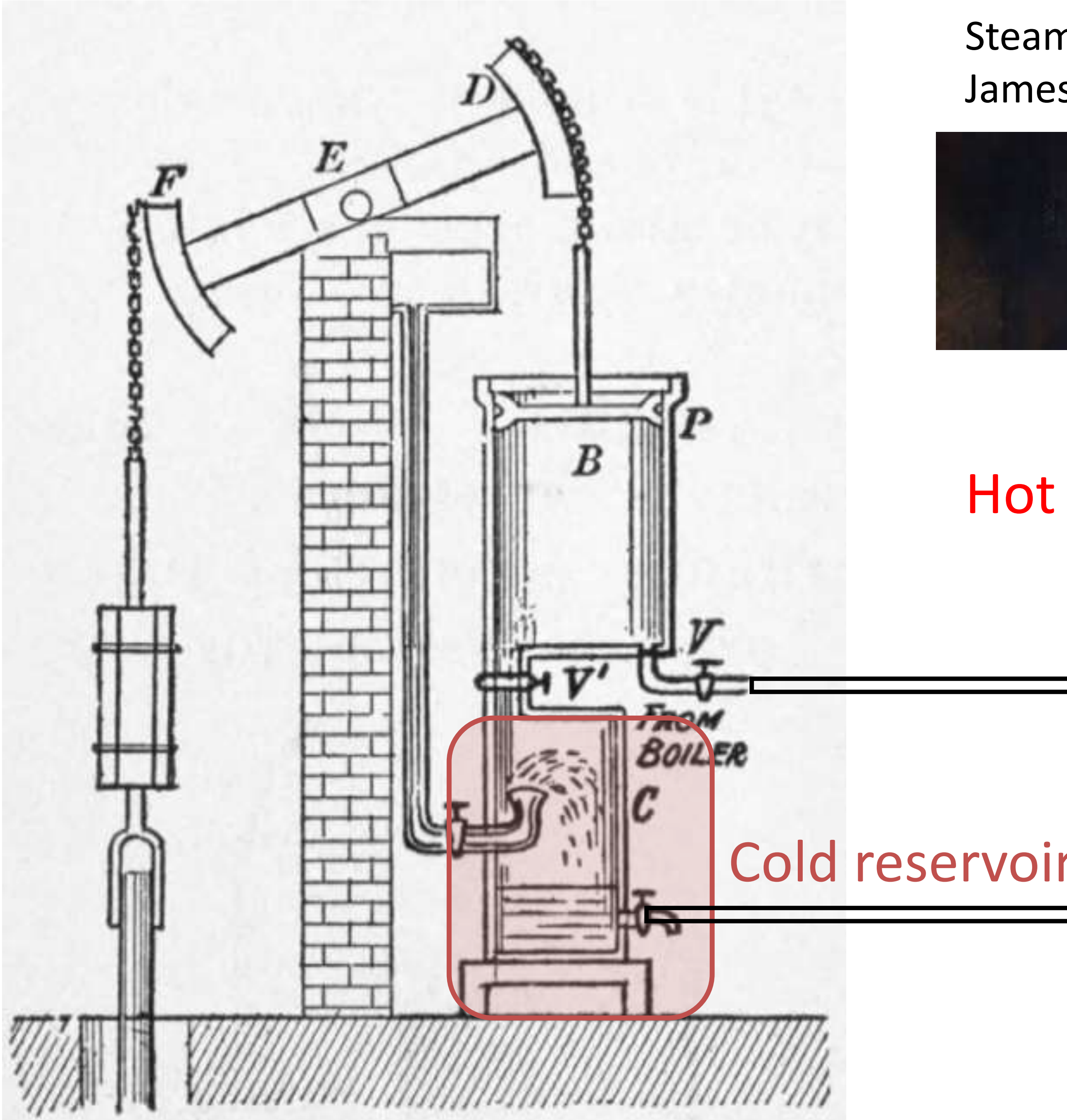
Heat Engines: Using Thermal Energy to Do Work

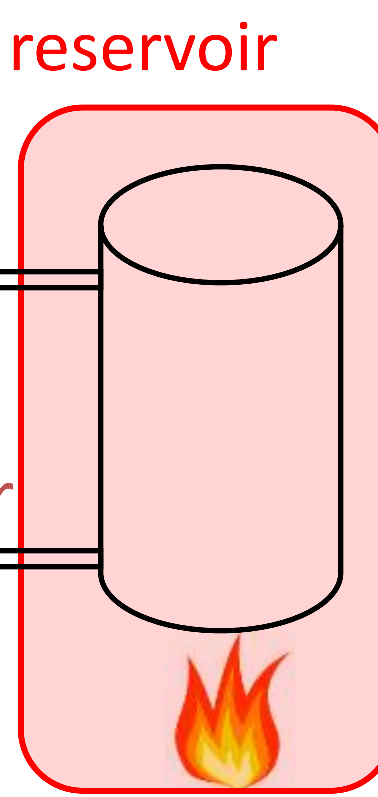
- Definition: a heat engine is any machine that converts thermal energy into mechanical forms of energy.
- How do we design such machines?



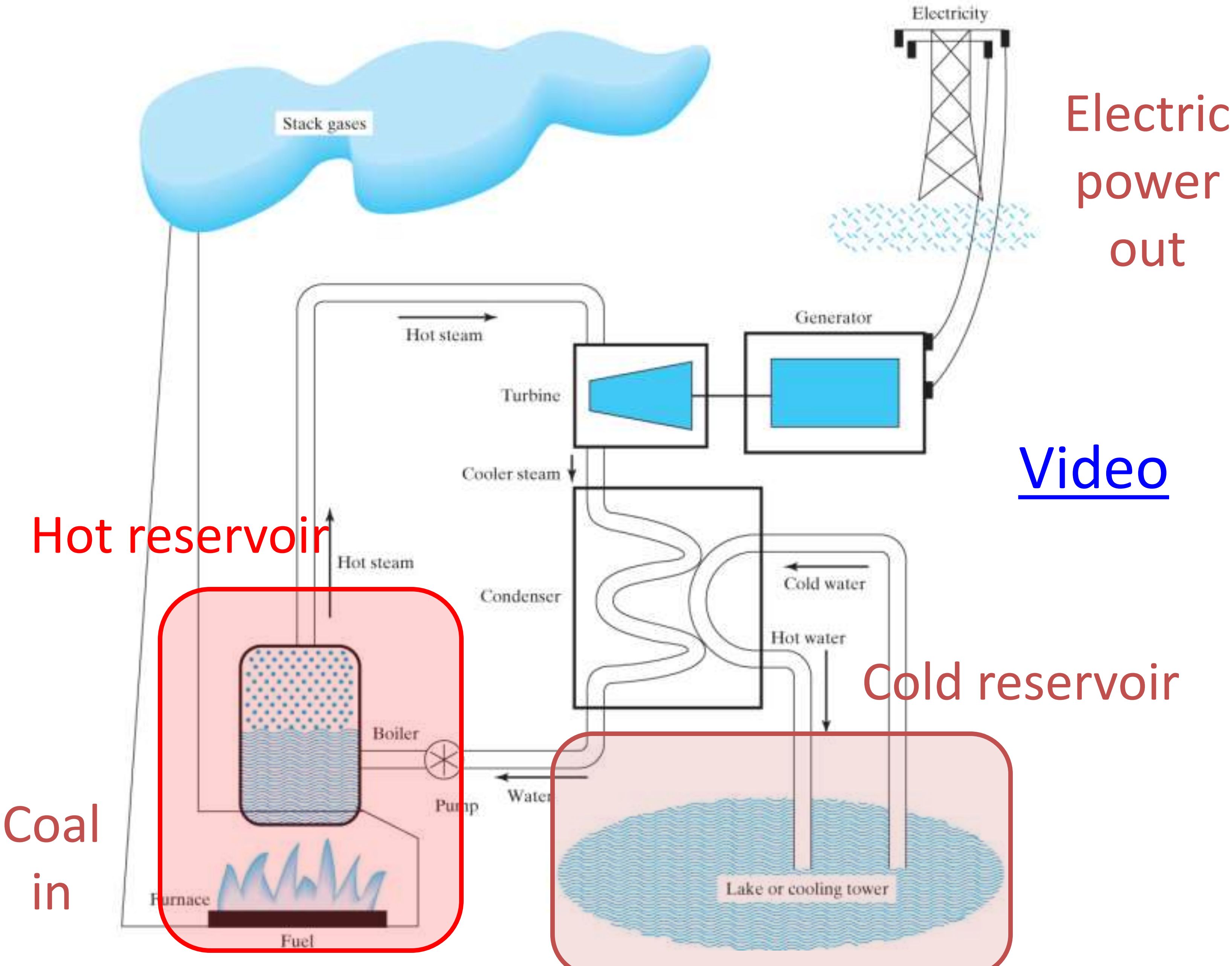
Basic principle of most heat engines

Steam engine:
James Watt





The Steam-Electric Power Plant



Internal Combustion Engine

- **Intake:** The intake valve opens, and fresh air (containing no fuel), is drawn into the cylinder.
- **Compression:** As the piston rises, the air is compressed, causing its temperature to rise. At the end of the compression stroke, the air is hot enough to ignite fuel.
- **Injection:** Near the top of the compression stroke, the fuel injector drives fuel into the cylinder. The fuel immediately ignites upon contact with the hot compressed air.
- **Power:** As the fuel burns, the gas in the cylinder heats and expands, driving the piston.
- **Exhaust:** The exhaust valve opens, and the exhaust is driven out of the cylinder