

DTU



10060 Physics (Polyteknisk grundlag)

Thermodynamics: Temperature & Heat

Coffee first!



(Discuss with your neighbour)

How does the Moka work?

Key concepts:

- Heat
- Temperature
- Boiling
- Expansion
- Convection

Inside a moka pot

How pressure is used to produce the perfect cup of coffee

Time for a cup

A characteristic sputtering sound can be heard as the last of the water boils through into the top chamber – the signal that the coffee is ready to serve.

Escaping the chamber

Once the coffee is fully saturated, the water continues to boil up through the metal filter and into the top funnel.

Preparation

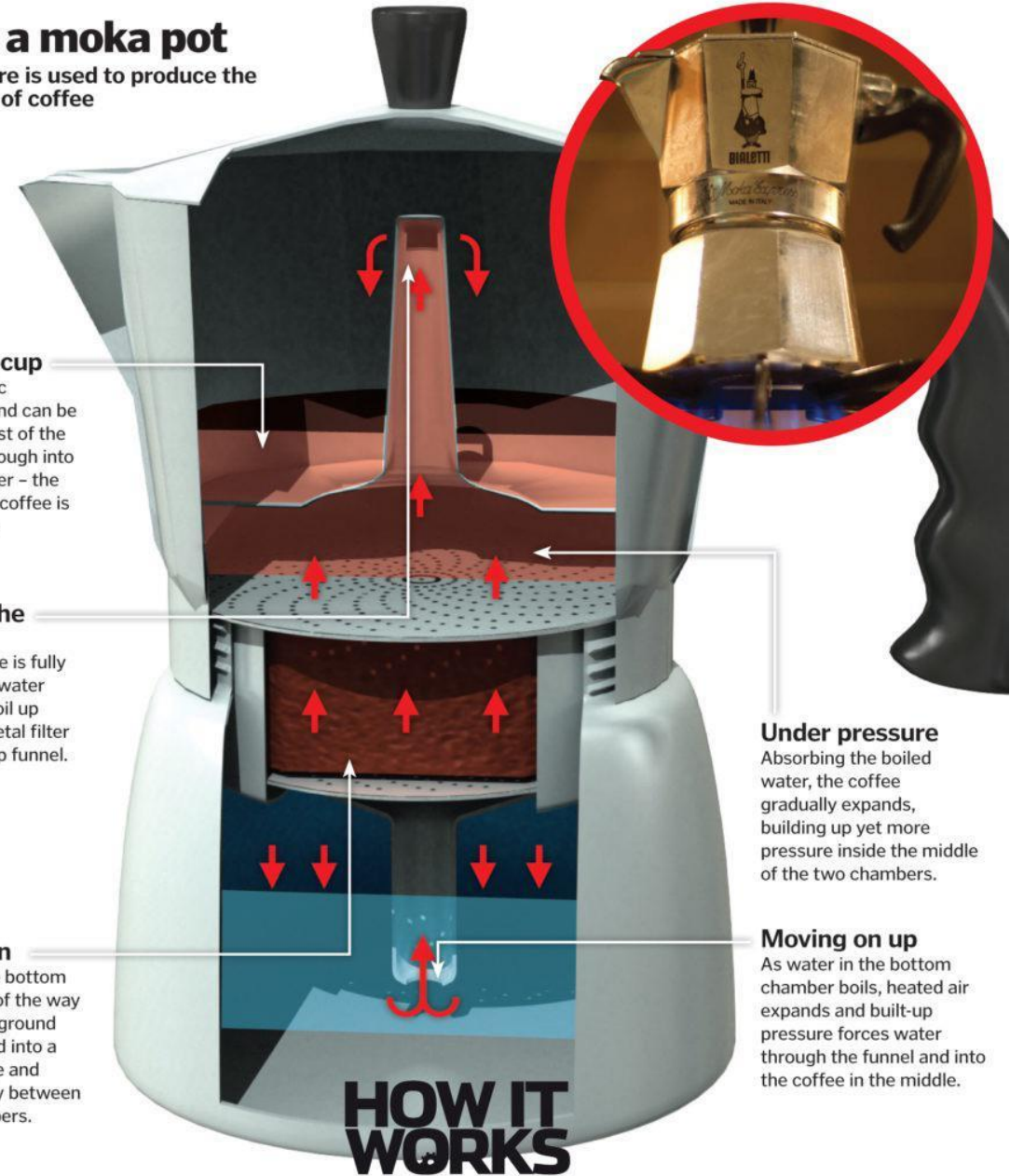
After filling the bottom chamber part of the way to the top, the ground coffee is placed into a separate cradle and screwed tightly between the two chambers.

Under pressure

Absorbing the boiled water, the coffee gradually expands, building up yet more pressure inside the middle of the two chambers.

Moving on up

As water in the bottom chamber boils, heated air expands and built-up pressure forces water through the funnel and into the coffee in the middle.



What we will cover in the next 5 Lectures

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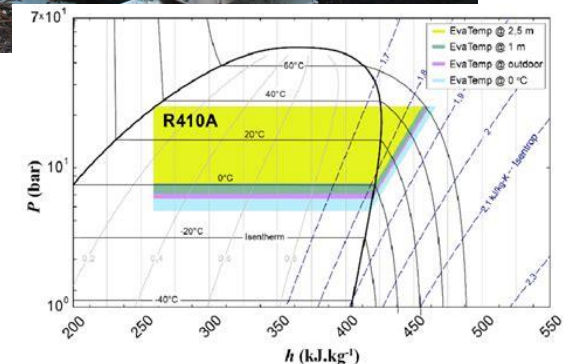
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5: Sustainability Theme

Heat Pumps



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Temperature

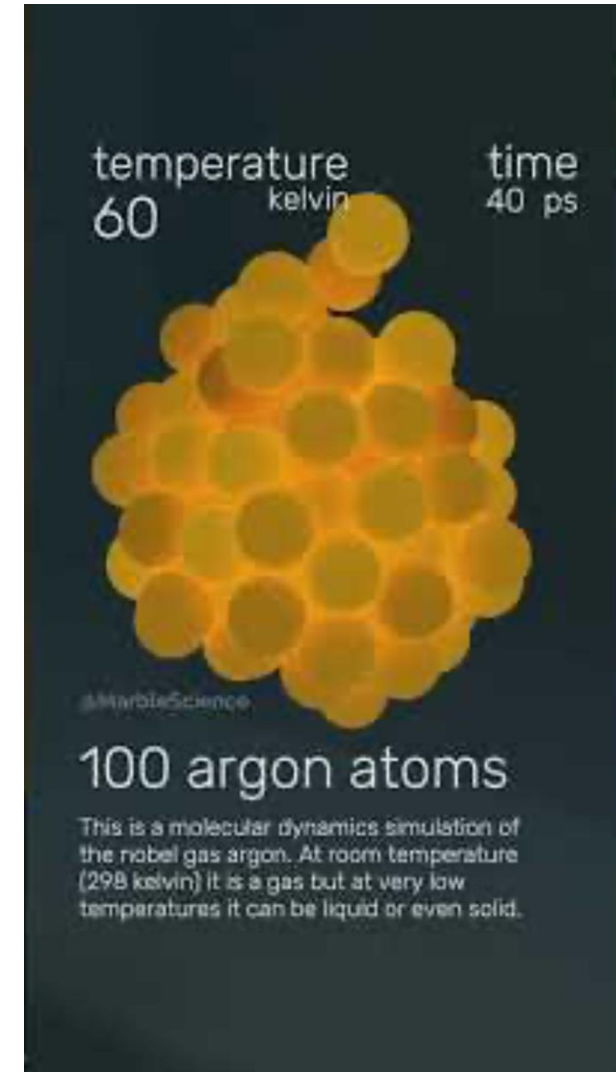
Temperature

- Temperature is an observable which quantifies how “hot” or “cold” a system is
- Its definition is operationally defined as the quantity we measure with a thermometer

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Microscopic Interpretation



<https://www.youtube.com/shorts/rHUYYGdByAA?feature=share>

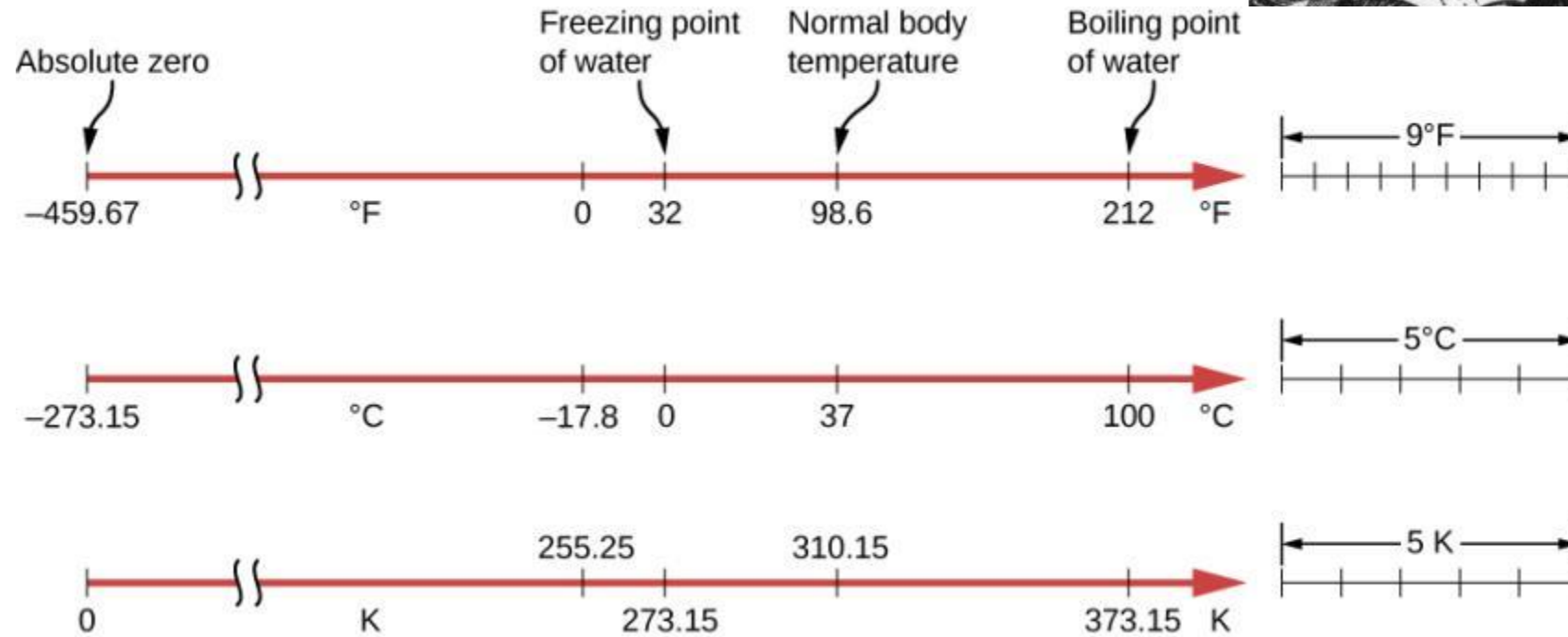
Temperature Scales

The Farenheit scale:

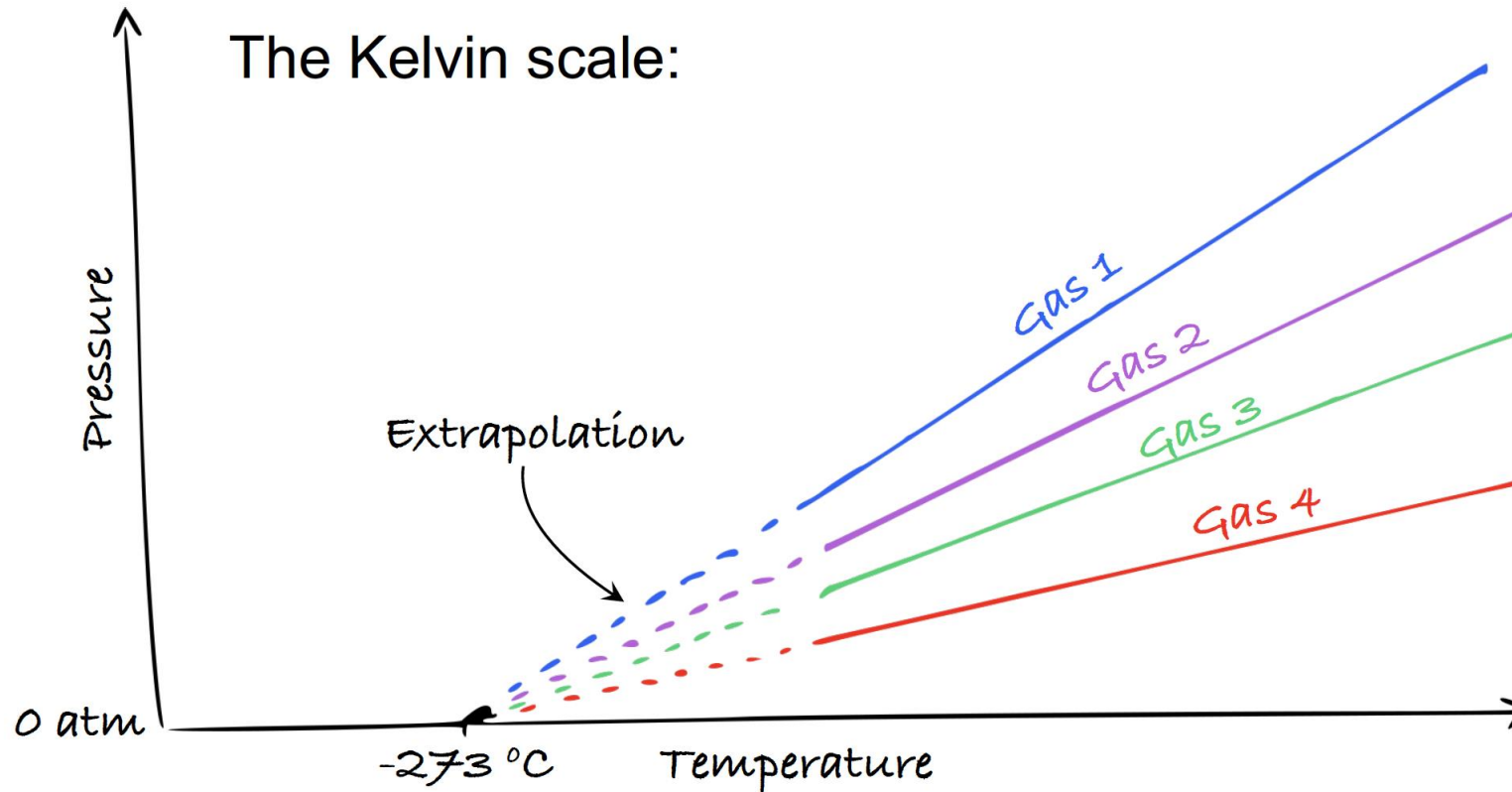
Farenheit's
armpit = 96°F



Freezing water = 32°F



The absolute zero



* K is an SI unit and it is defined with in reference to the triple point of water (the point where vapor, liquid and ice coe xist)

Life skill: Temperature conversion

Fahrenheit to Celsius: $T_C = \frac{5}{9} (T_F - 32^\circ F)$

Celsius to Fahrenheit: $T_F = \frac{9}{5} T_C + 32^\circ F$

Celsius to Kelvin: $T_K = T_C + 273.15^\circ C$

Kelvin to Celsius: $T_C = T_K - 273.15^\circ C$

Different types of thermometers



(a)

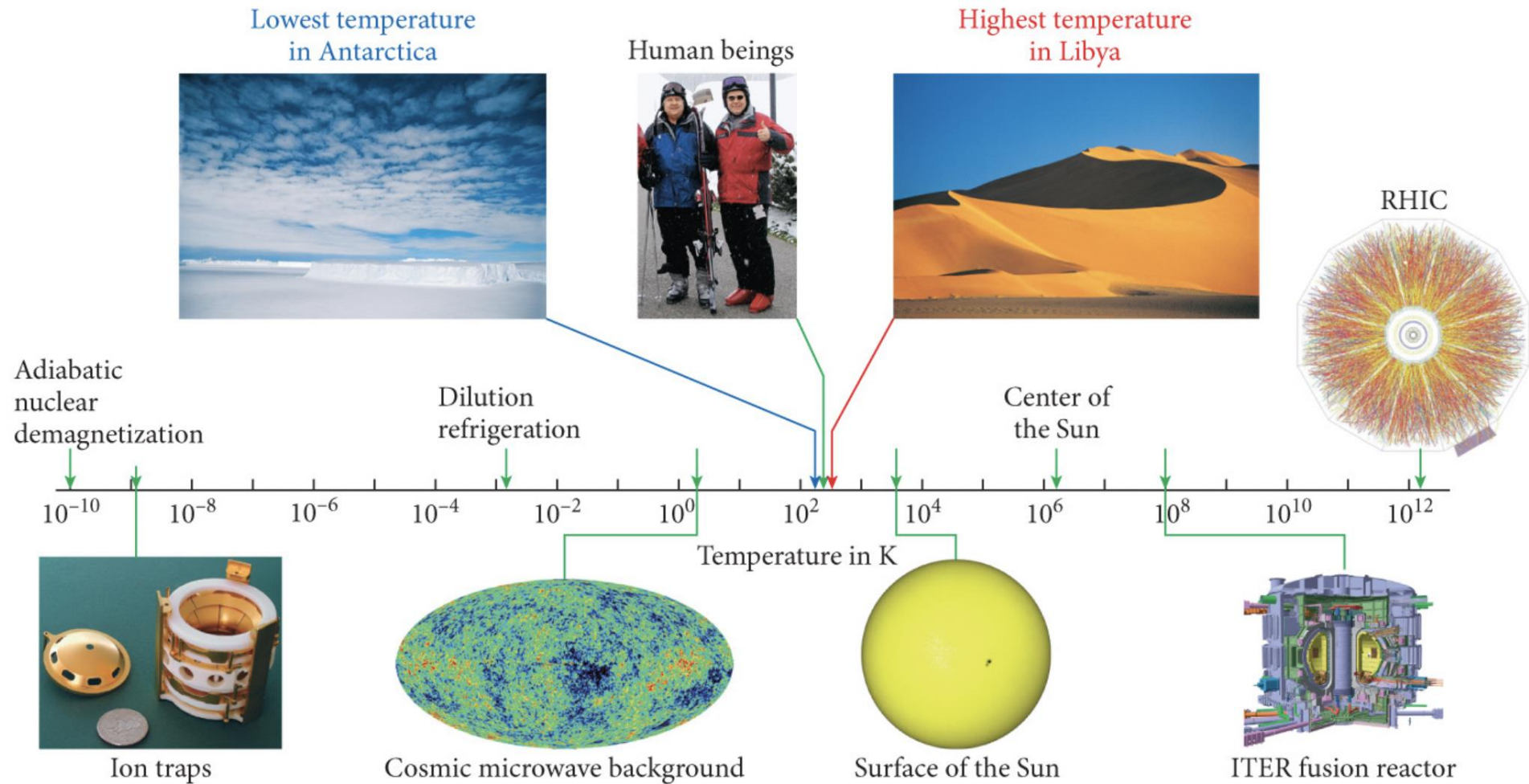


(b)

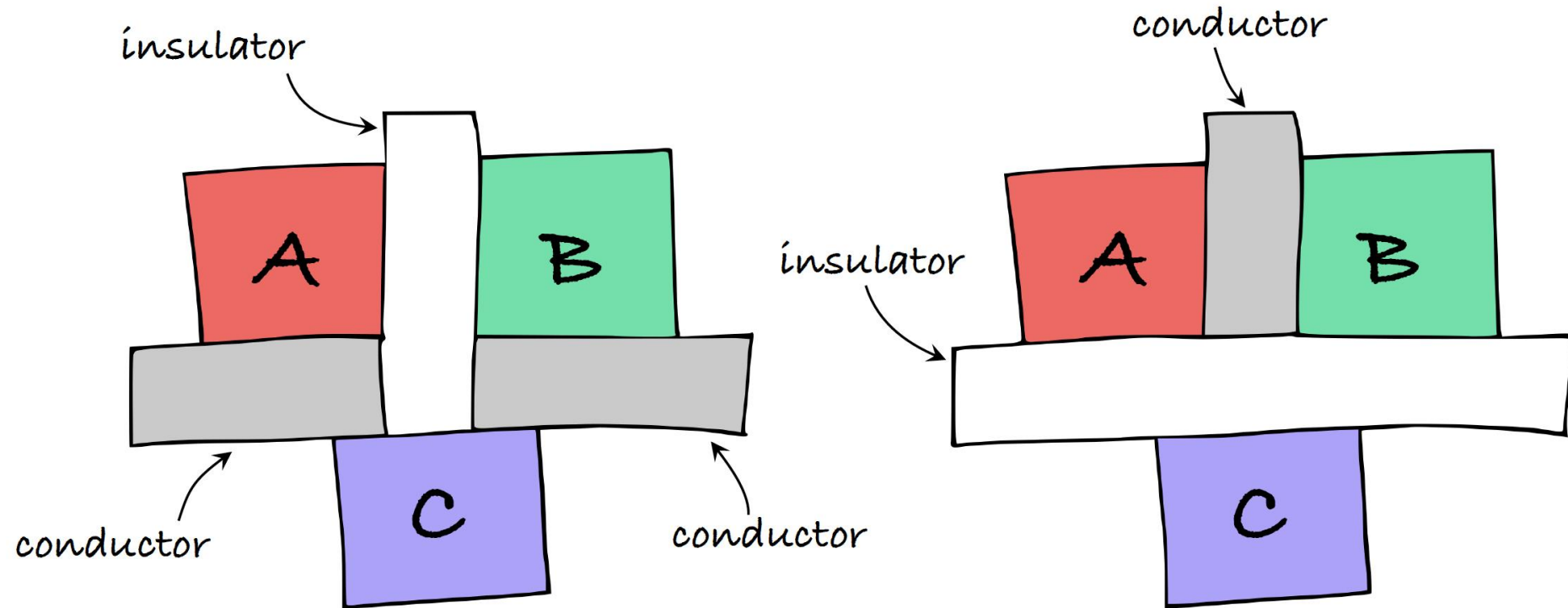


(c)

Hot and Cold



Zeroth Law of Thermodynamics



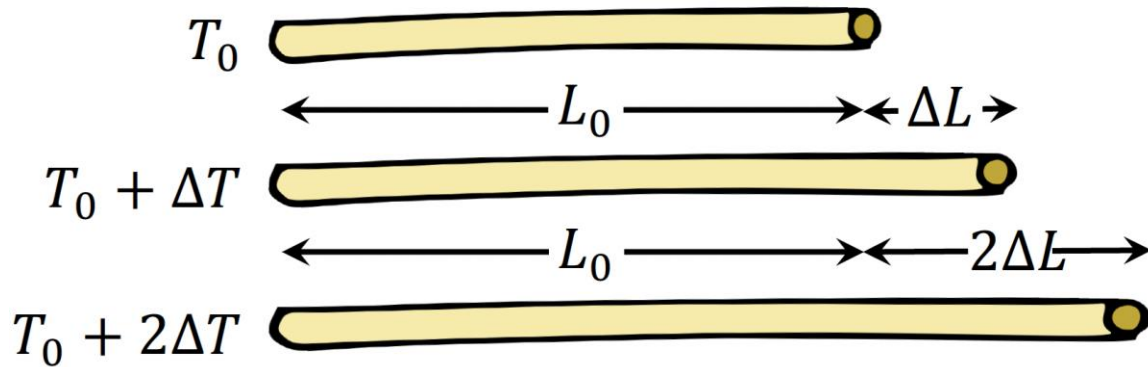
Question time: What is this?



Thermal expansion

Linear Thermal expansion

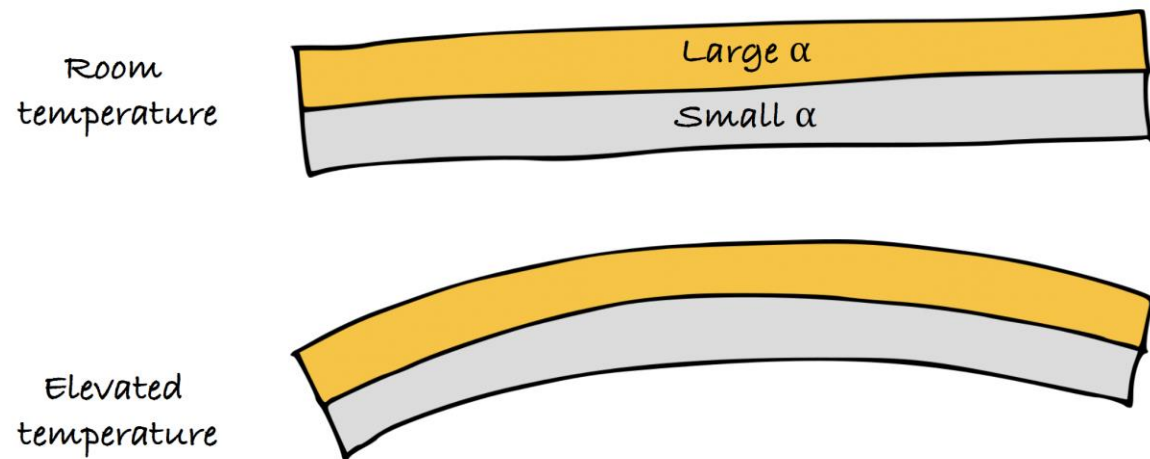
$$\Delta L = \alpha \Delta T L_0$$



Material	α ($10^{-6} \text{ }^\circ\text{C}^{-1}$)
Aluminum	22
Brass	19
Concrete	15
Copper	17
Diamond	1
Gold	14
Lead	29
Plate glass	9
Rubber	77
Steel	13
Tungsten	4.5

Residual Stress and Strain

Old Thermostat



Tempered Glass



Tempered Glass

Non Tempered Glass

Area and Volume expansion

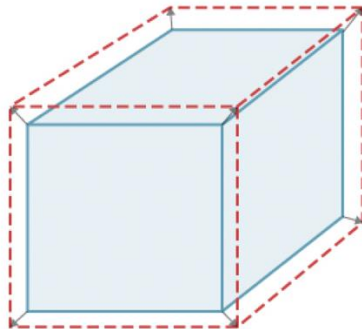
Area:

$$\Delta A = 2\alpha A \Delta T$$

Volume:

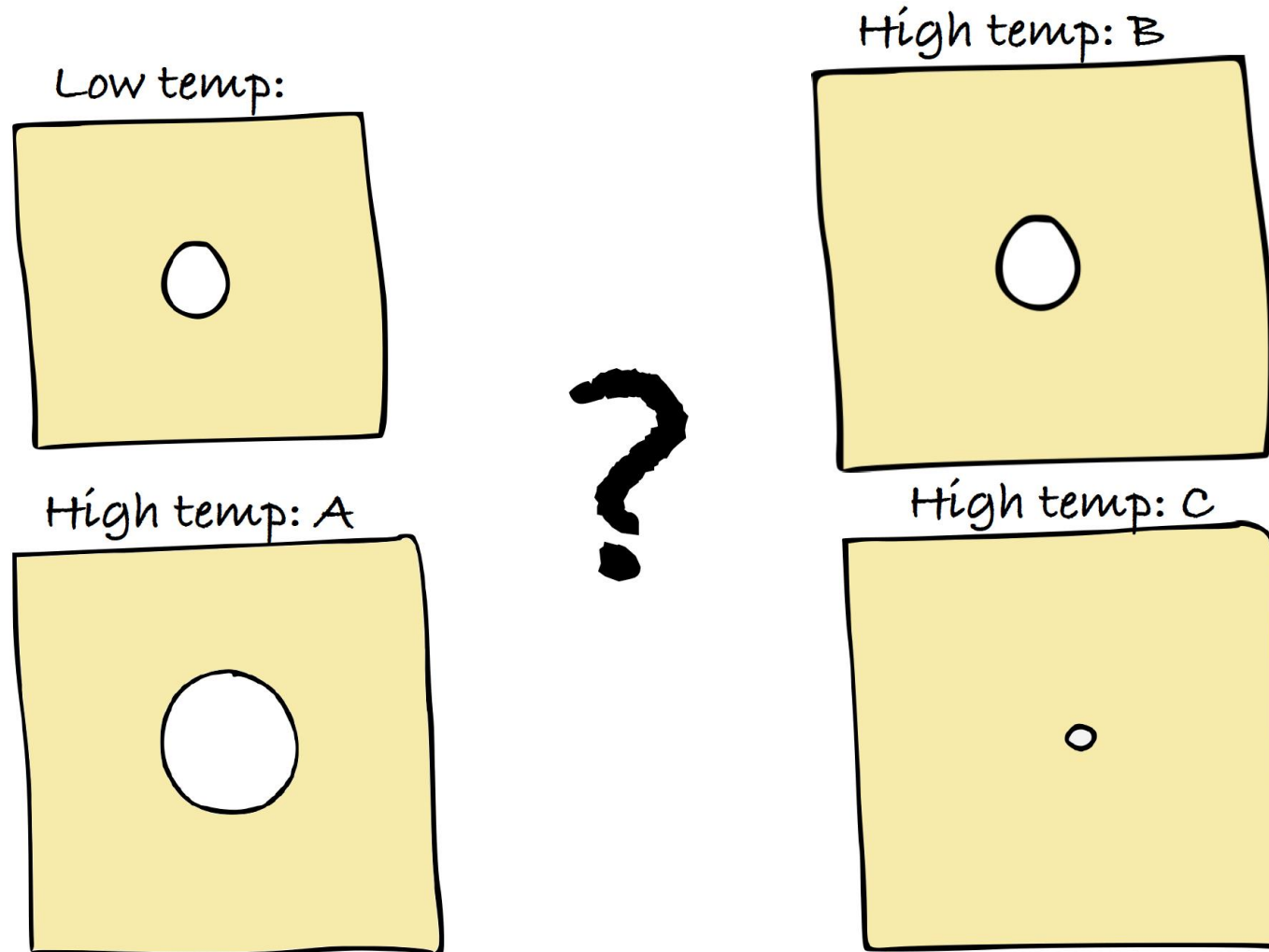
$$\Delta V = \beta V \Delta T$$

with $\beta = 3\alpha$

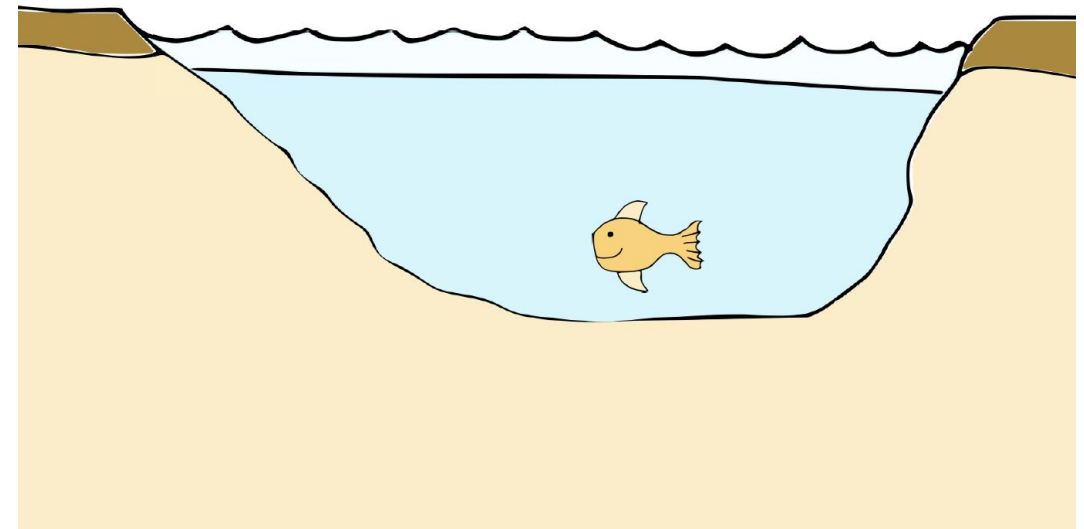
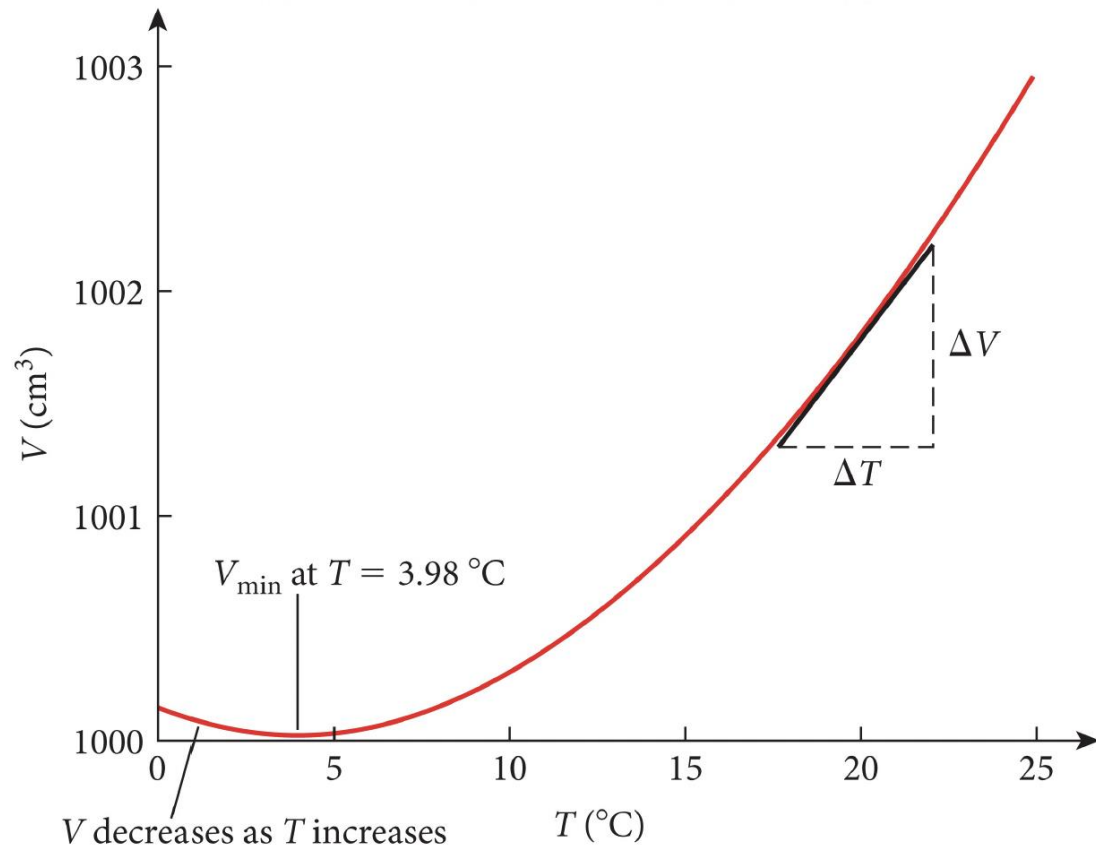


Material	β ($10^{-6} \text{ }^{\circ}\text{C}^{-1}$)
Mercury	181
Gasoline	950
Kerosene	990
Ethyl alcohol	750
Water (1 $^{\circ}\text{C}$)	-47.8
Water (4 $^{\circ}\text{C}$)	0
Water (7 $^{\circ}\text{C}$)	45.3
Water (10 $^{\circ}\text{C}$)	87.5
Water (15 $^{\circ}\text{C}$)	151
Water (20 $^{\circ}\text{C}$)	207

Question time: How does this object expand?



Negative thermal expansion: Water





Does a vacuum have a temperature?

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Heat

Difference between heat and temperature

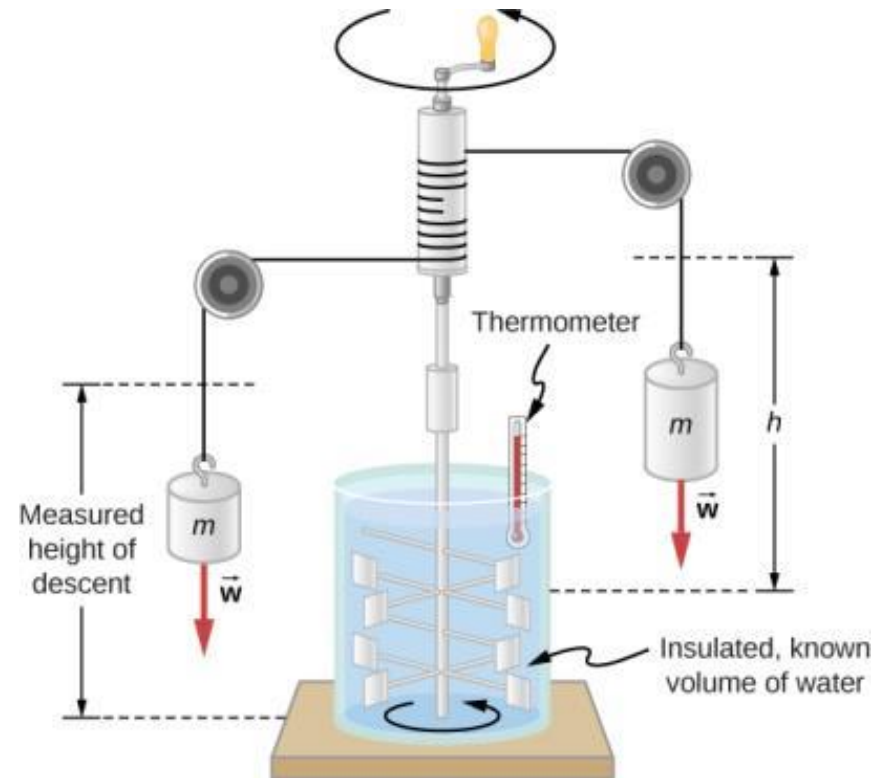
- Temperature is a measure of the kinetic energy in the material
- Heat is the transfer of energy from a hot to a cold system

Heat transfer modifies the **internal energy** of a system, i.e. the sum of the kinetic energy of the atoms composing an object and the potential energy associated to their attraction and repulsion forces

Heat and Work

Mechanical equivalent of heat

$$1.000 \text{ kcal} = 4186 \text{ J.}$$



Joule's experiment established the equivalence of heat and work. As the masses descended, they caused the paddles to do work, $W = mgh$, on the water. The result was a temperature increase, ΔT , measured by the thermometer. Joule found that ΔT was proportional to W and thus determined the mechanical equivalent of heat.

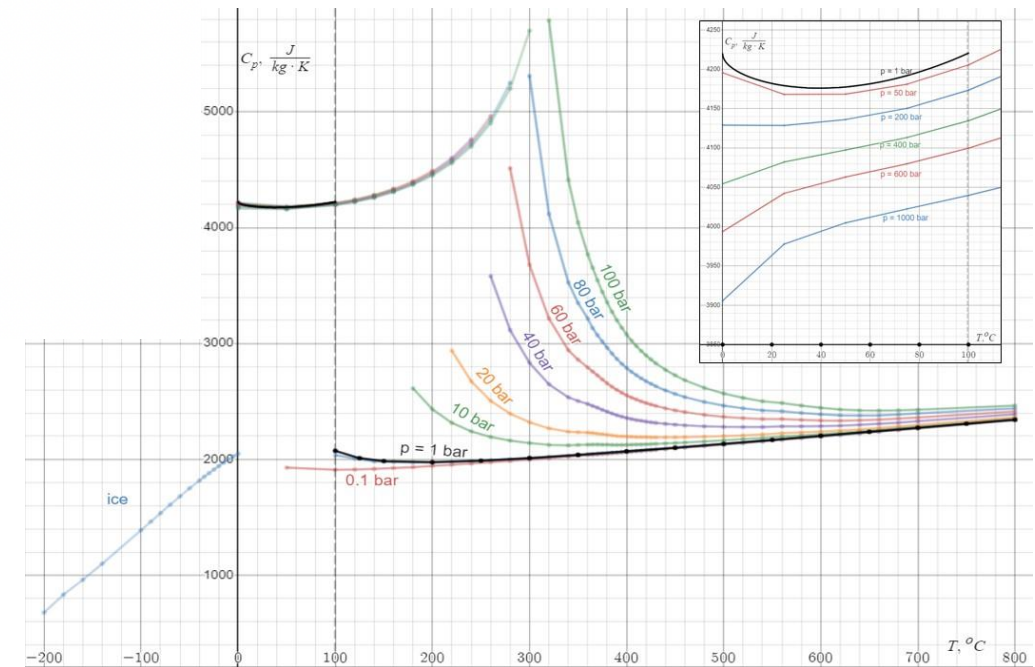
Heat: definition

Specific heat of what we're heating (J/kg/K)

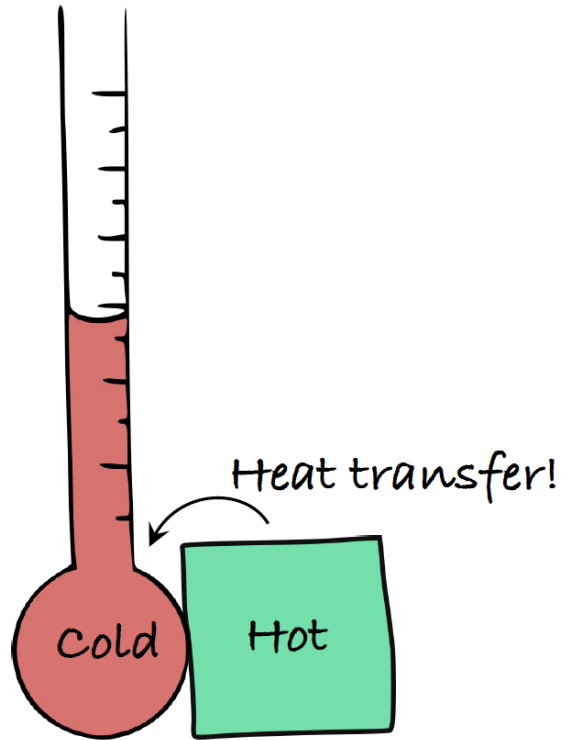
Heat (J) $\rightarrow Q = \underbrace{cm}_{\substack{\text{Heat capacity} \\ (\text{J/K})}} \Delta T$ \leftarrow change in temperature (K)

Mass of what we're heating (kg)

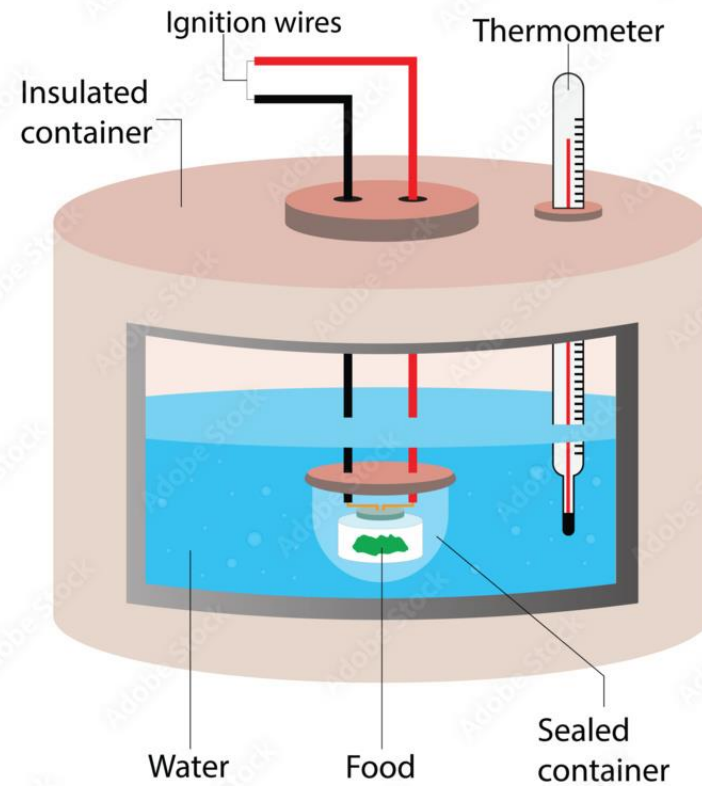
* c in general depends on temperature



Calorimeter Problem



Calorimeter



$$Q_{\text{cold}} + Q_{\text{hot}} = 0.$$

Problem Time

Steel Cube



m_s, T_s

+

Water



m_w, T_w

$T_{eq} = ?$

Problem Time

Ice Cube



m_i, T_i

+

Water



m_w, T_w

$T_{eq} = ?$

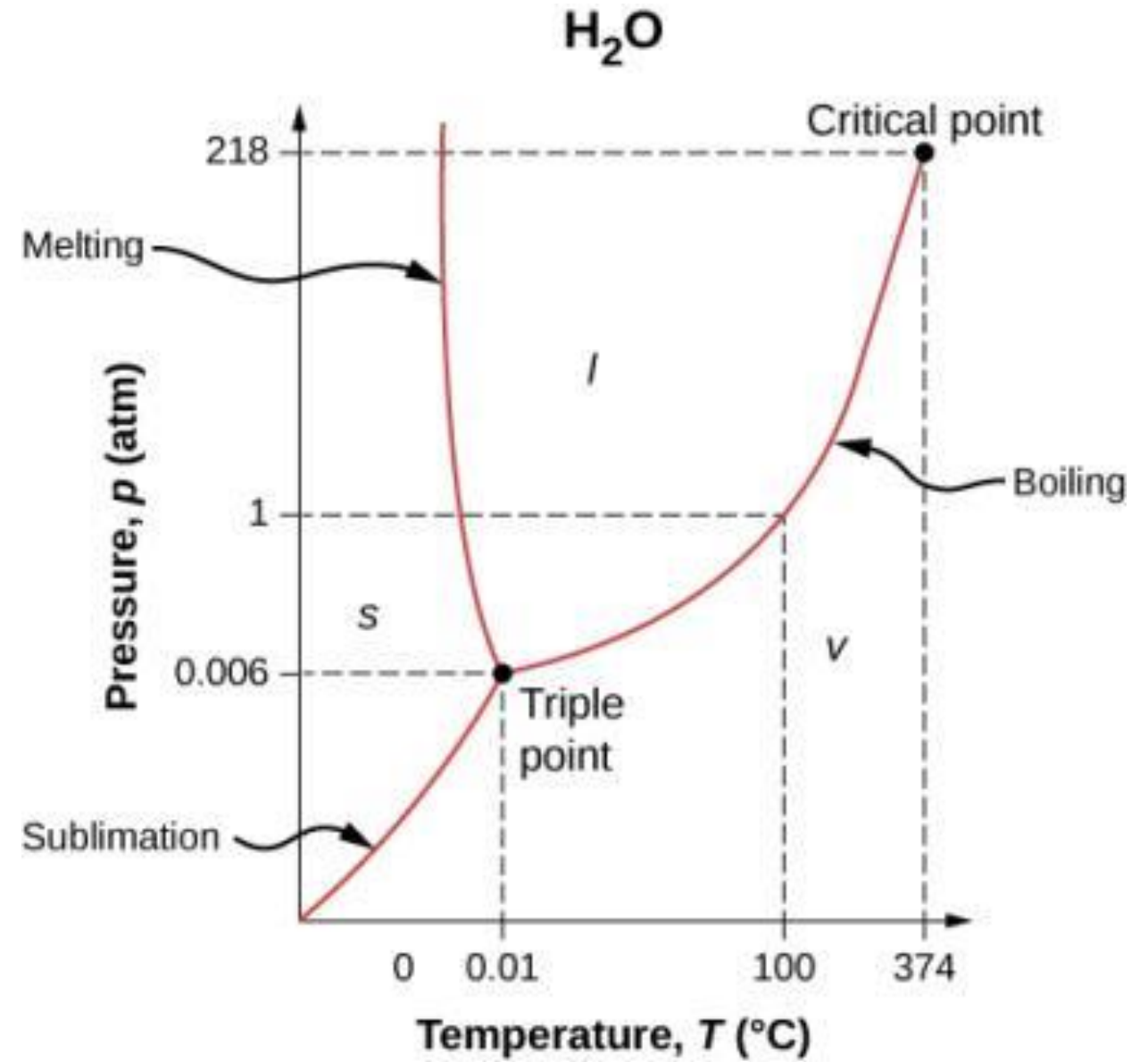
Phase Diagram



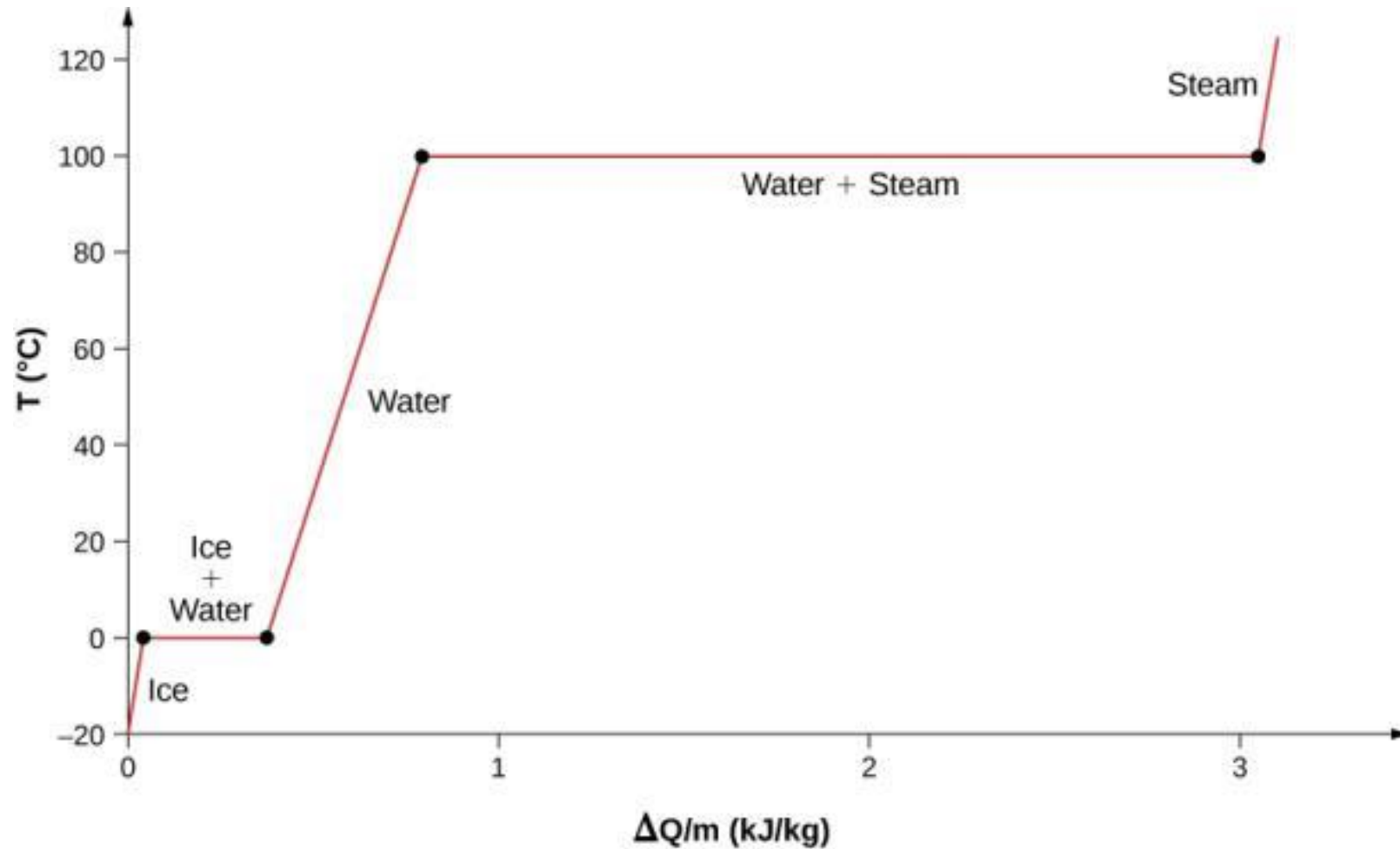
(b)



(a)



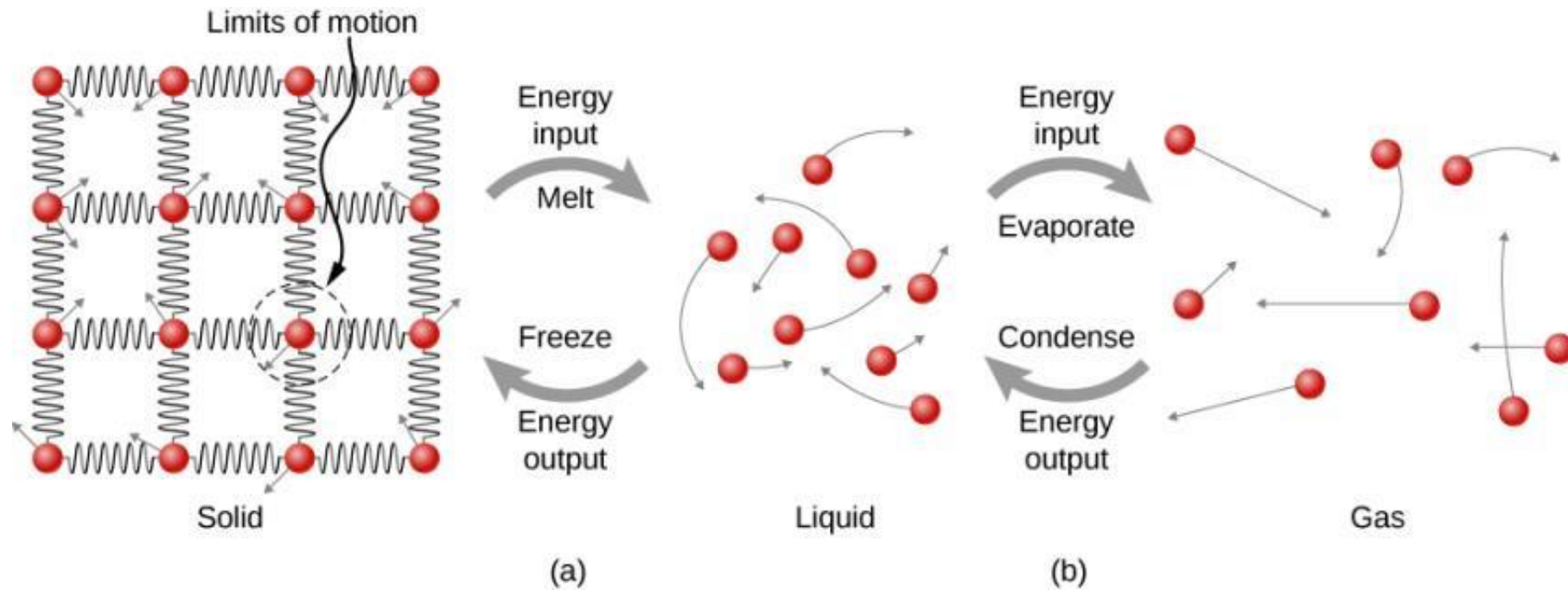
How does water heat up?



Latent Heat

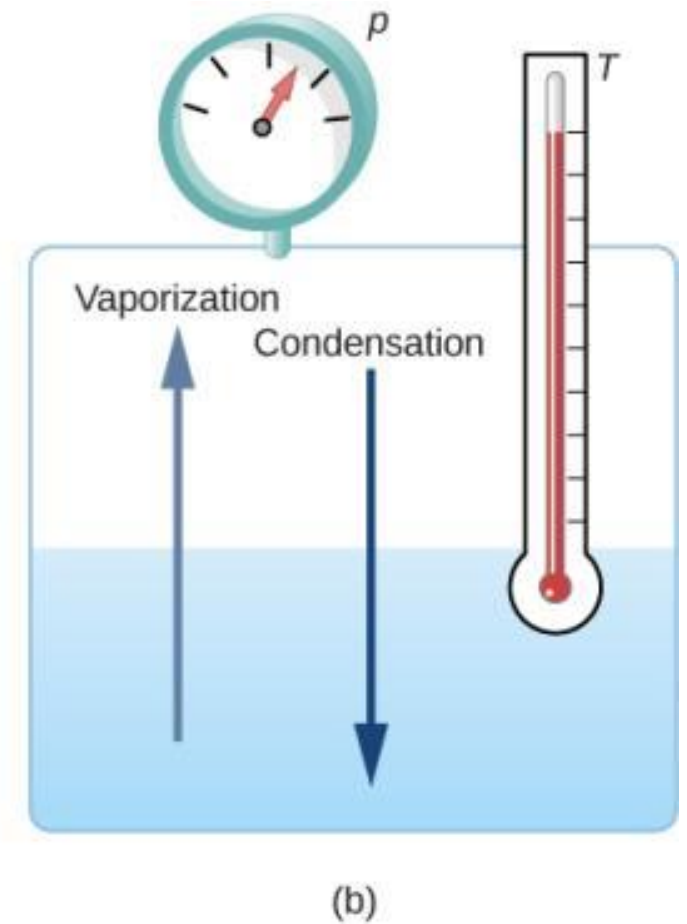
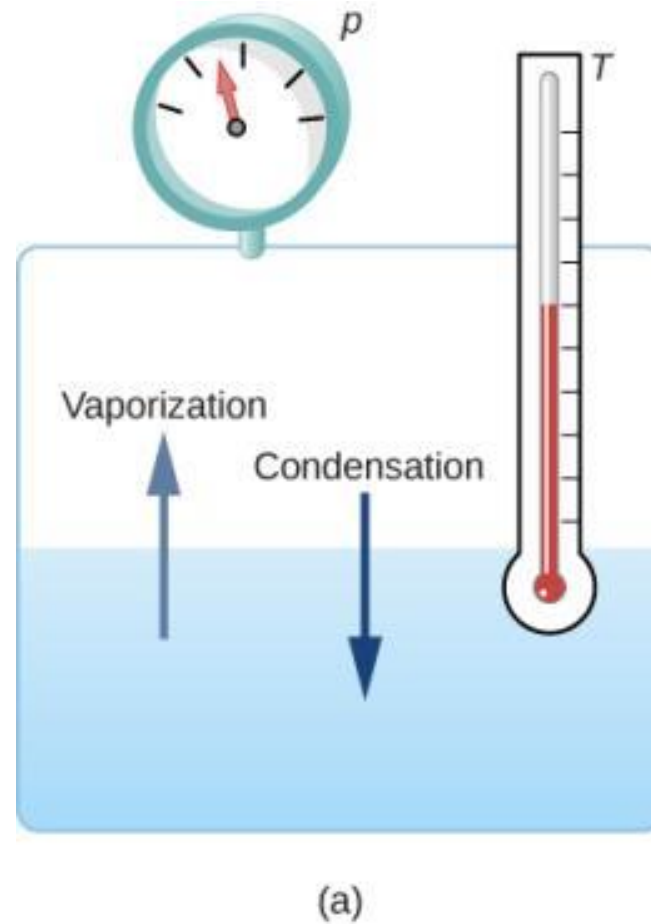
$$Q = mL_f(\text{melting/freezing})$$

$$Q = mL_v(\text{vaporization/condensation})$$



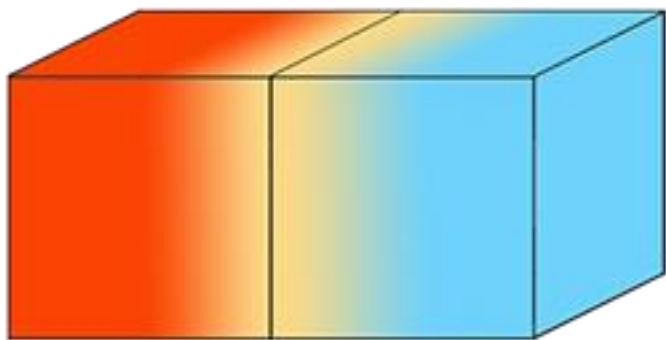
Liquid and Gas at equilibrium: a note of care

The boiling point of a liquid at a given pressure is the temperature at which its vapor pressure equals the ambient pressure.

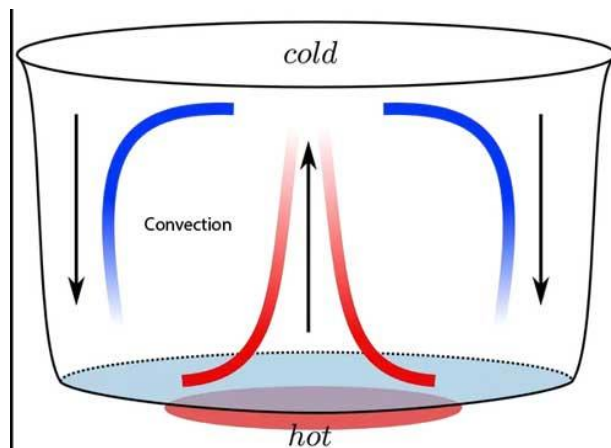


Heat propagation

Conduction



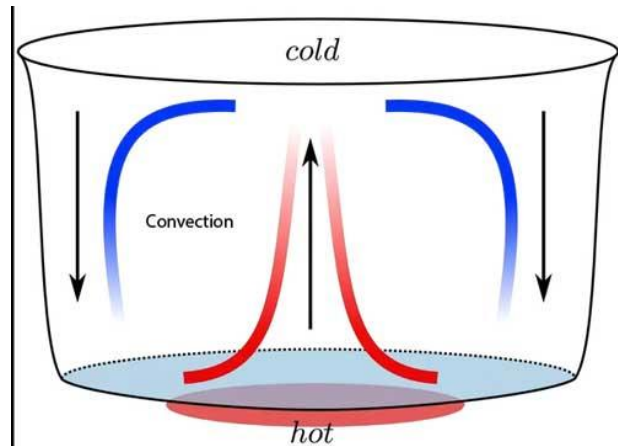
Convection



Radiation



Convection

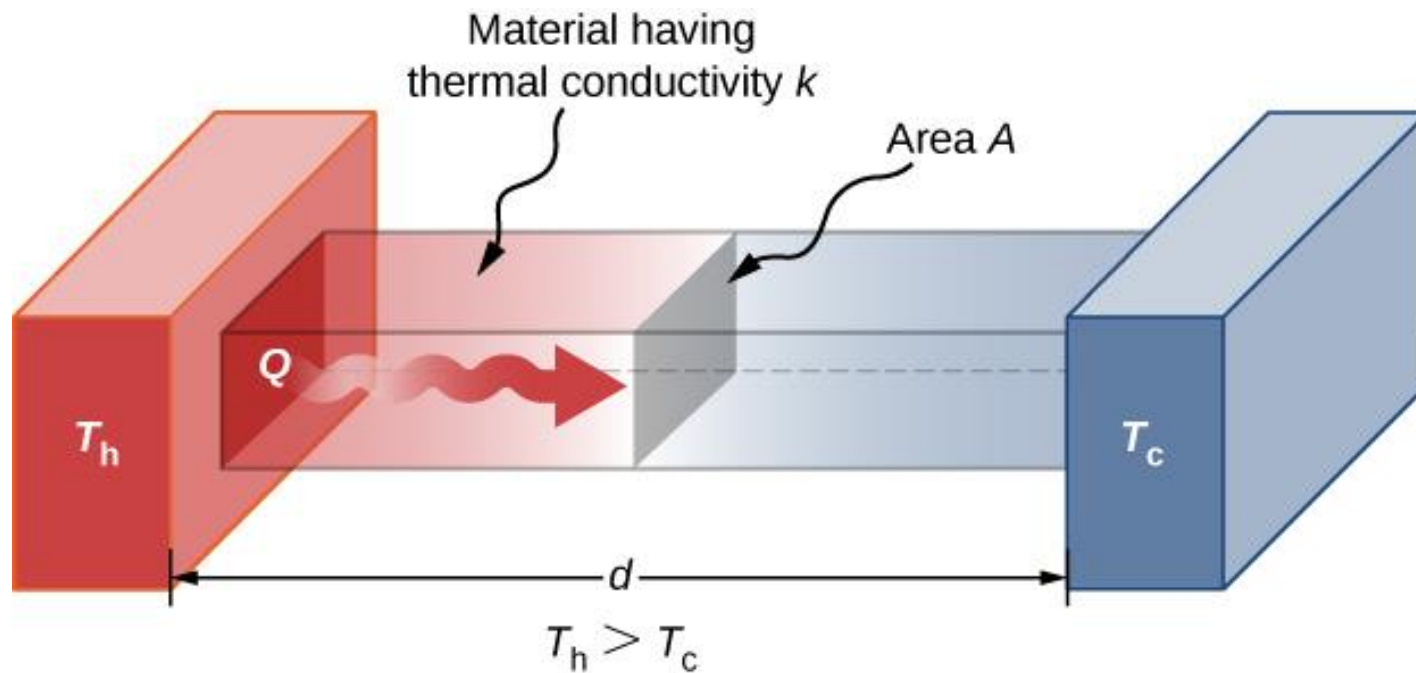


- Cumulus clouds are caused by water vapor that rises because of convection. The rise of clouds is driven by a positive feedback mechanism. (credit: “Amada44”/Wikimedia Commons)

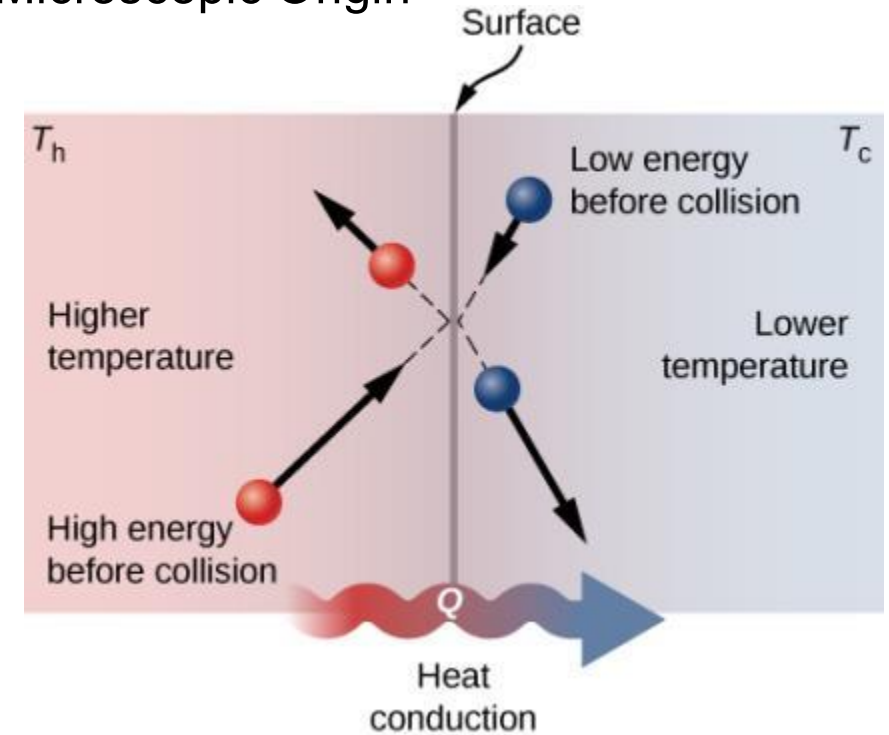
Conduction

Rate of heat transfer

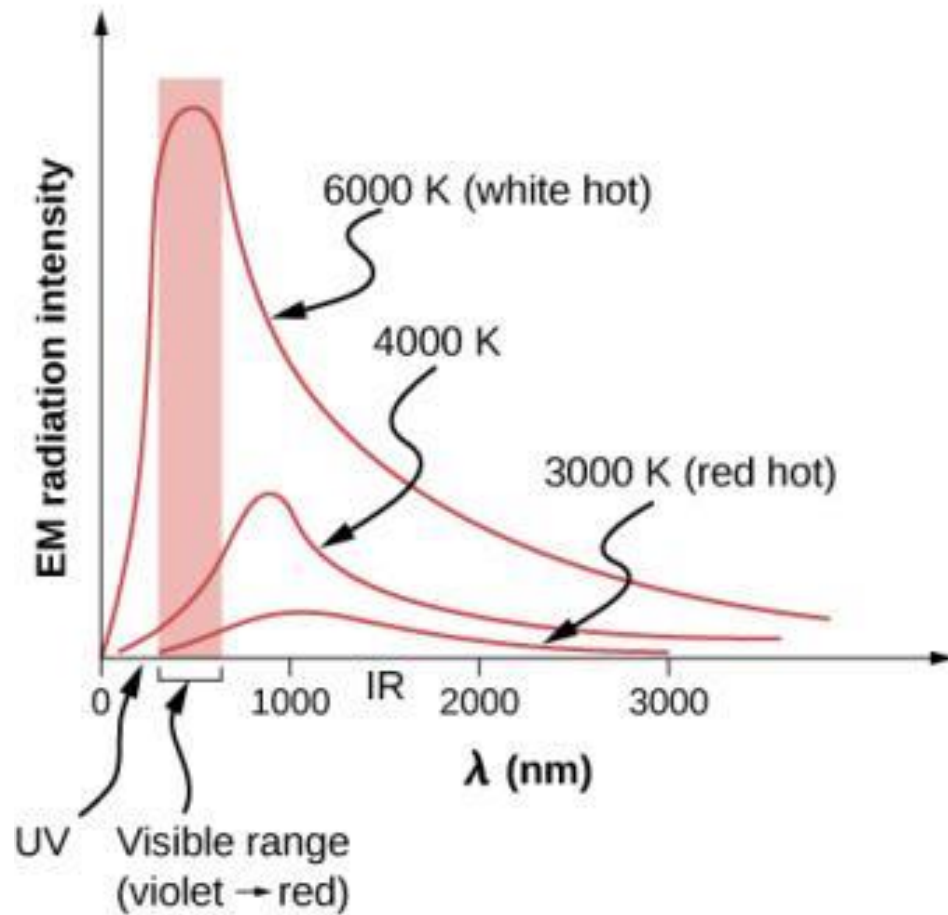
$$P = \frac{dQ}{dt} = \frac{kA(T_h - T_c)}{d}$$



Microscopic Origin



Radiation



(a)



(b)

Stephan-Boltzmann law

$$P = \sigma A e T^4$$

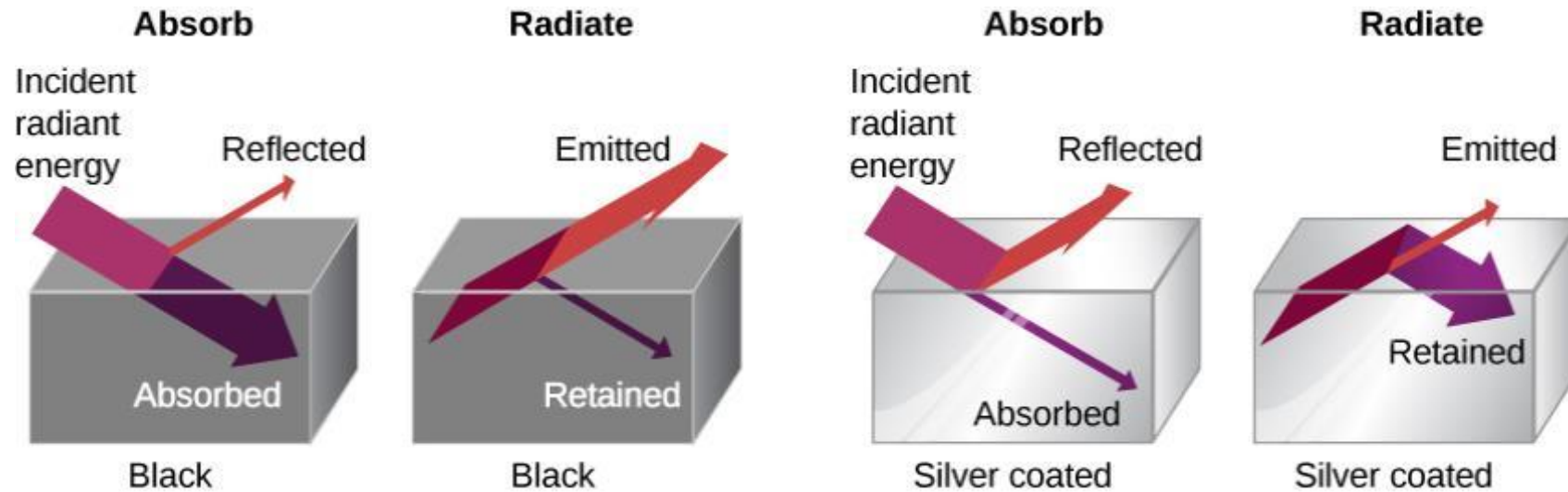
Stephan-Boltzmann constant

$$\sigma = 5.67 \times 10^{-8} \text{ J/s} \cdot \text{m}^2 \cdot \text{K}^4$$

Net heat transfer rate

$$P_{\text{net}} = \sigma e A (T_2^4 - T_1^4)$$

Radiation



A black object is a good absorber and a good radiator, whereas a white, clear, or silver object is a poor absorber and a poor radiator.