DTU

10060 Physics (Polyteknisk grundlag)

Thermodynamics: Temperature & Heat

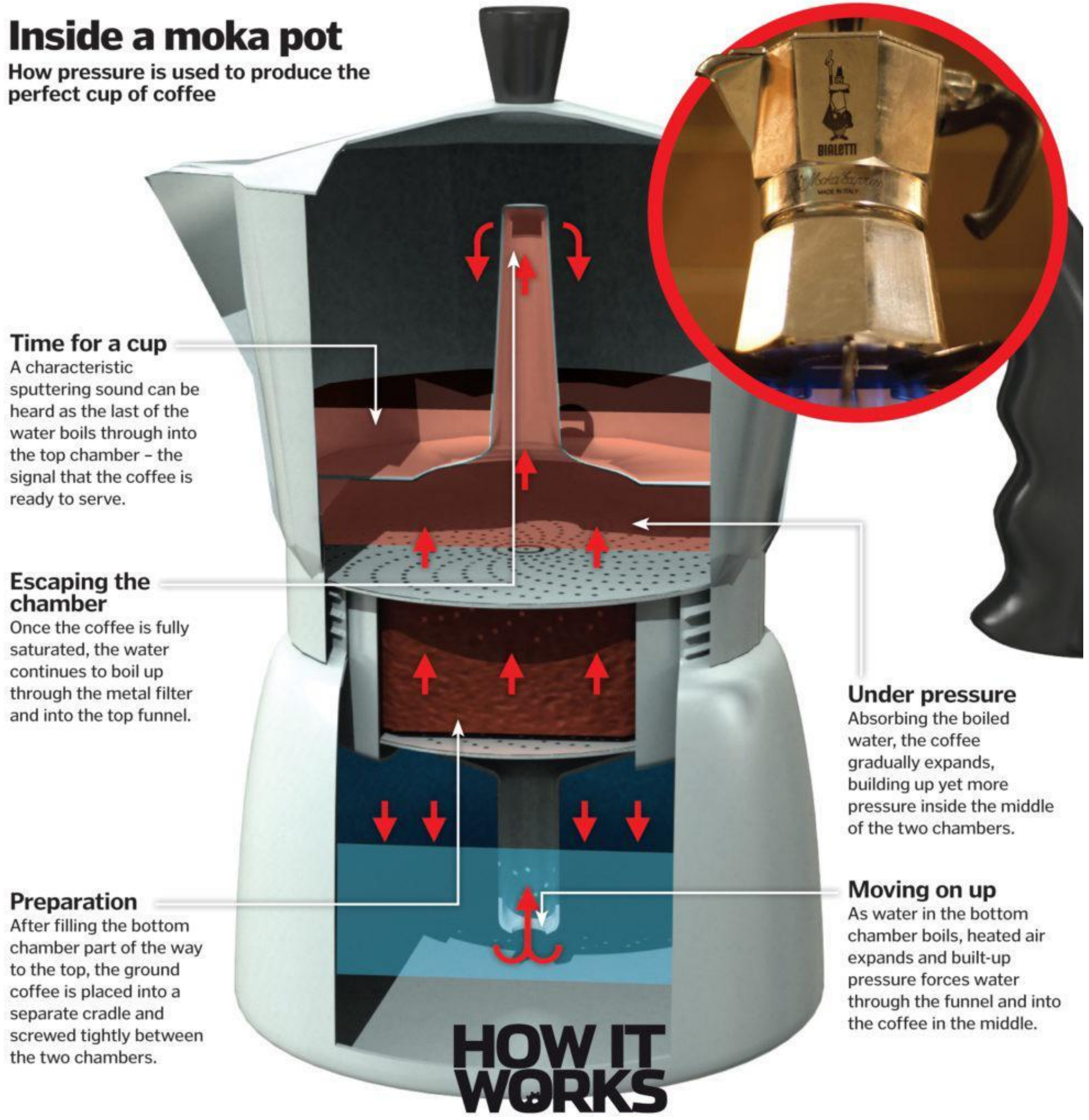
Coffee first!

(Discuss with your neighbour)

How does the Moka work?

Key concepts:

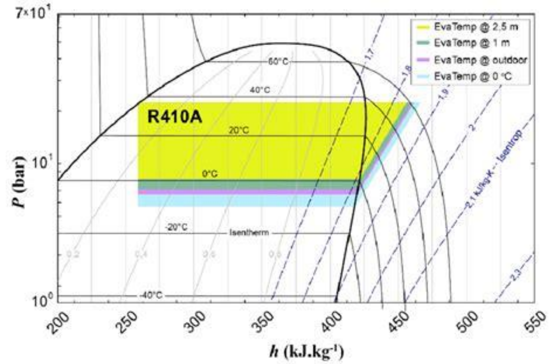
- Heat
- Temperature
- Boiling
- Expansion
- Convection



What we will cover in the next 5 Lectures

5: Sustainability Theme

Heat Pumps



10063 Physics (Polyteknisk grundlag)

Temperature

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- 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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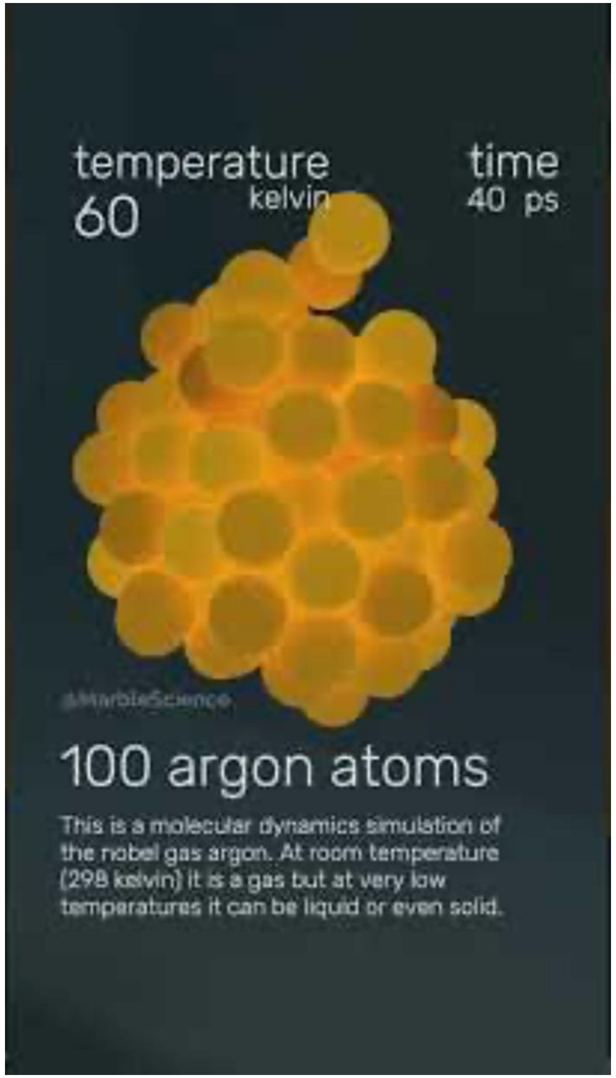
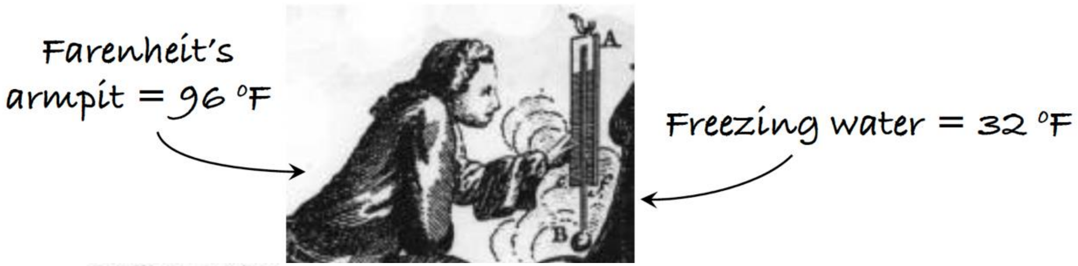
Microscopic Interpretation

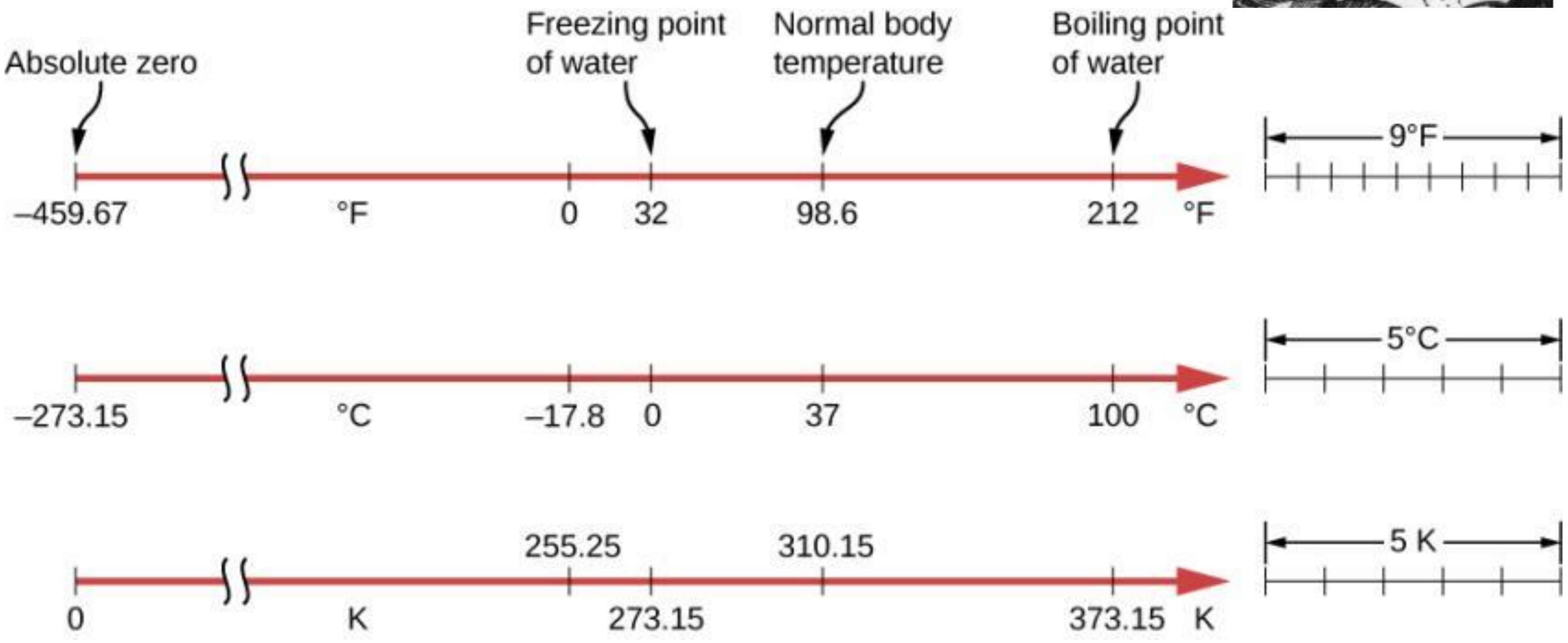


https://www.youtube.com/shorts/rHUYYGdByAA?feature=share

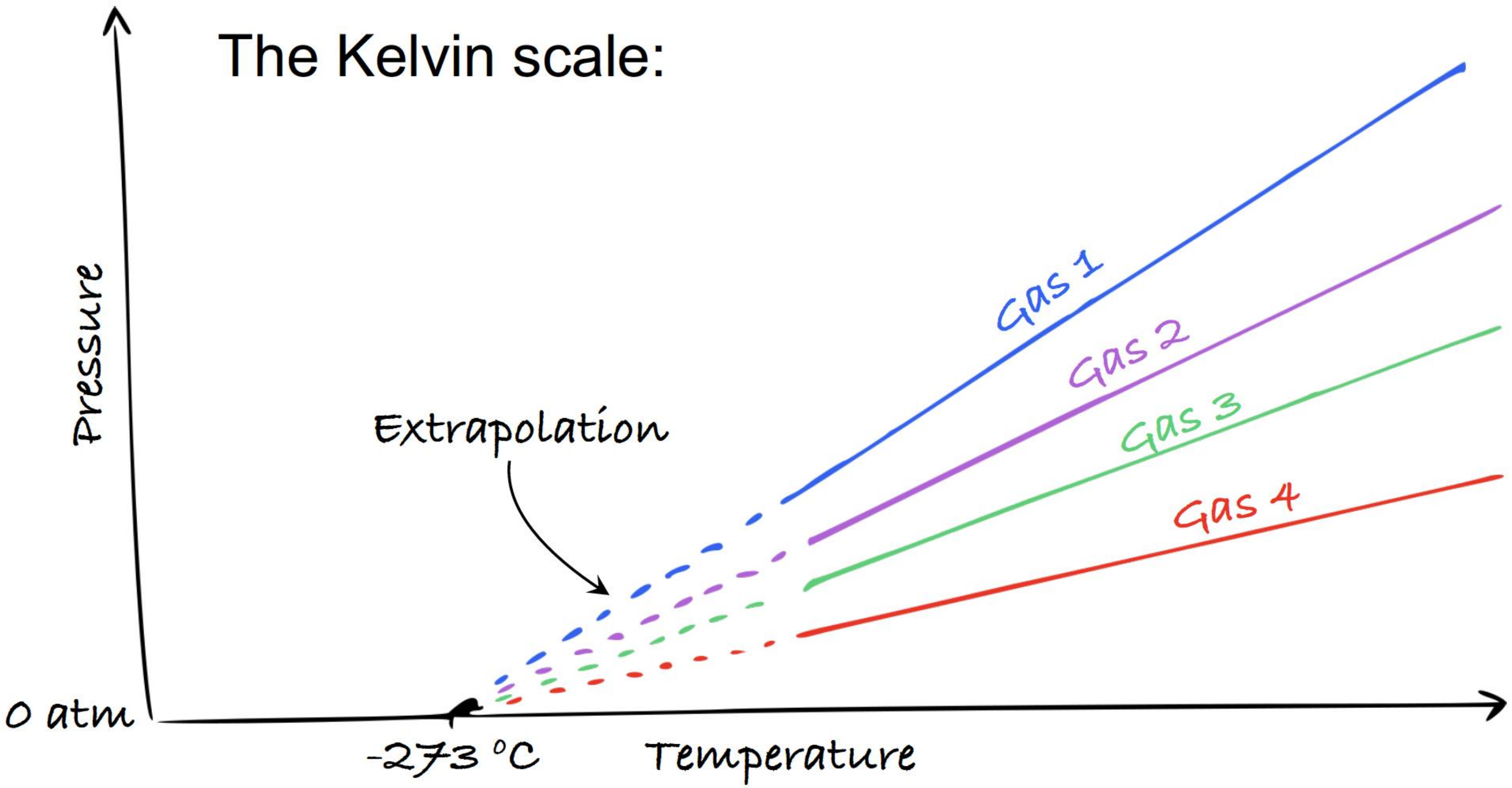
Temperature Scales

The Farenheit scale:





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 coexist)

Life skill: Temperature conversion

Farenheit to Celsius: $T_C = \frac{5}{9}(T_F - 32°F)$

Celsius to Farenheit: $T_F = \frac{9}{5}T_C + 32°F$

Celsius to Kelvin: $T_K = T_C + 273.15°C$

Kelvin to Celsius: $T_C = T_K - 273.15°C$

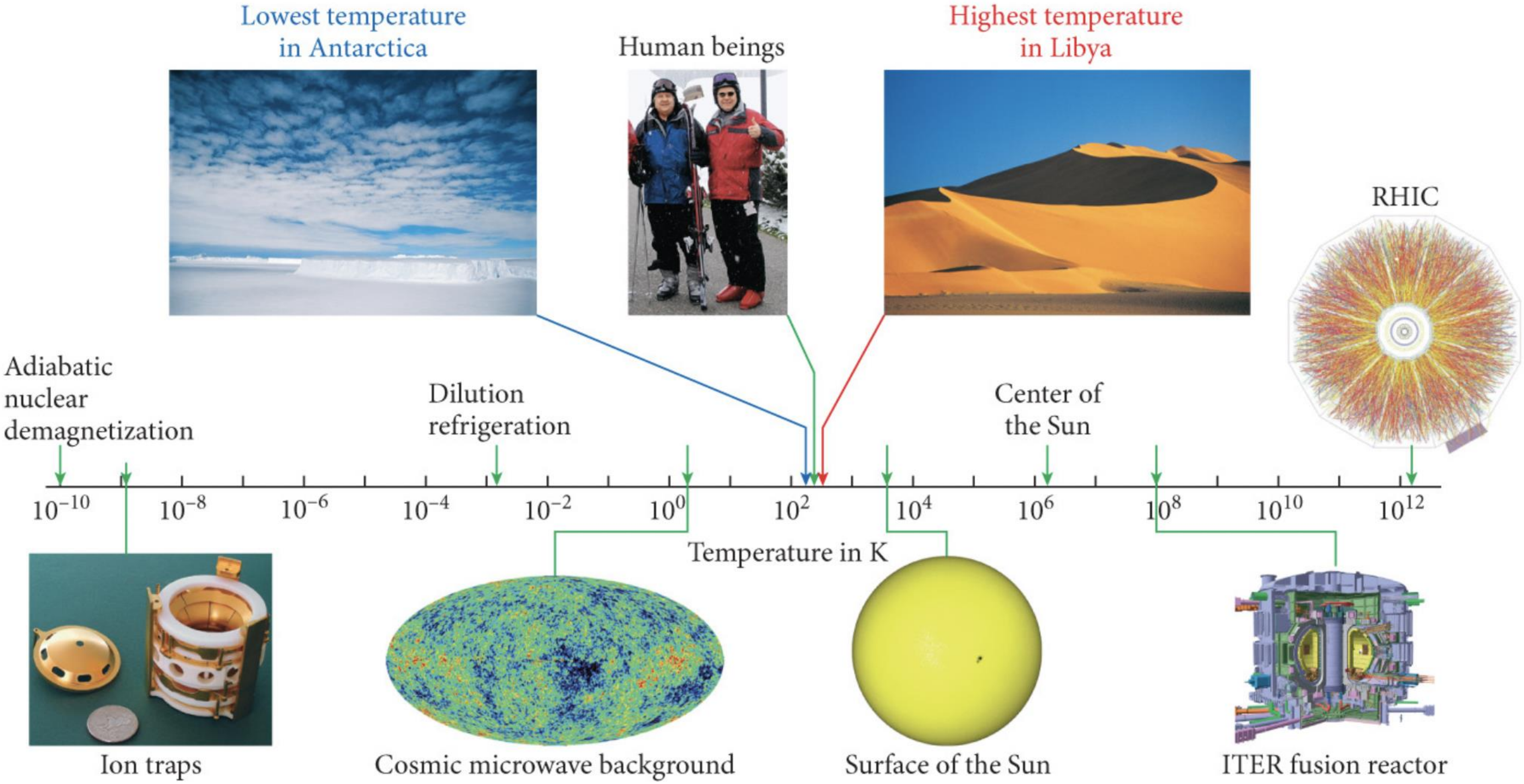
Different types of thermometers


(a)

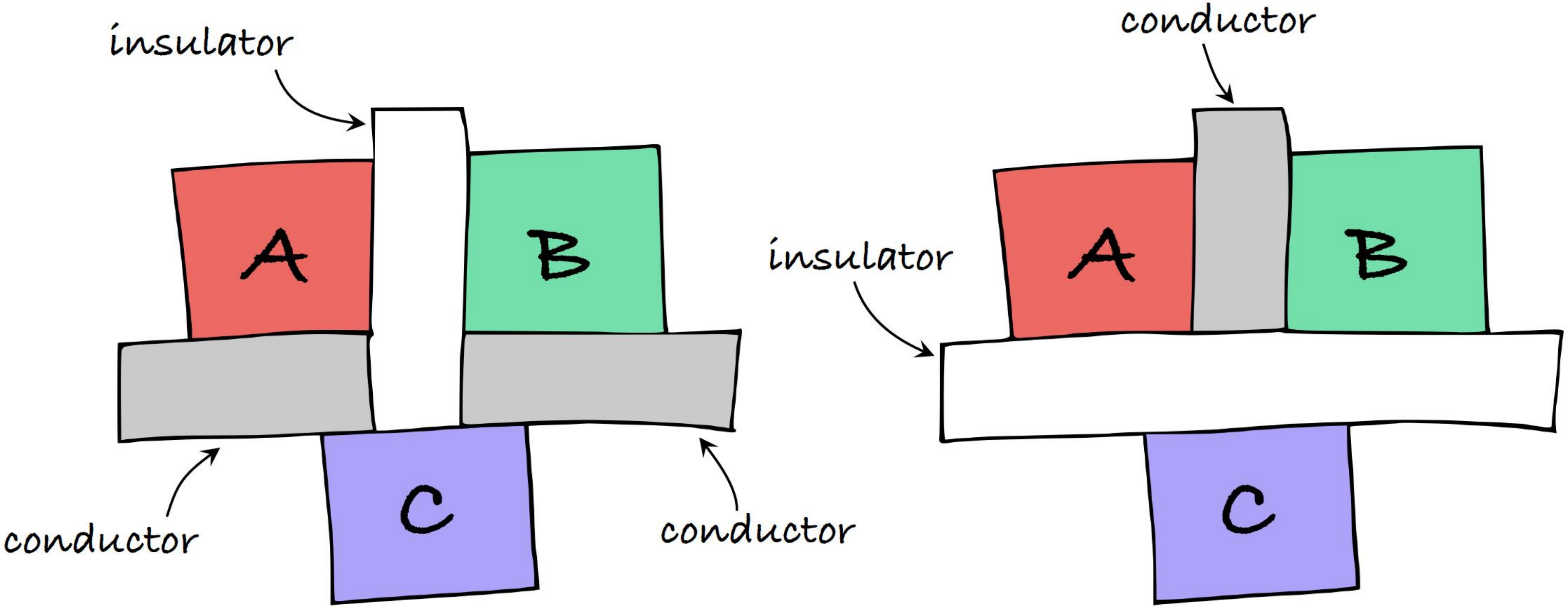

(b)


(c)

Hot and Cold


Lowest temperature in Antarctica
Human beings
Highest temperature in Libya
RHIC
Adiabatic nuclear demagnetization
Dilution refrigeration
Center of the Sun
10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12}
Temperature in K
Ion traps
Cosmic microwave background
Surface of the Sun
ITER fusion reactor

Zeroth Law of Thermodynamics

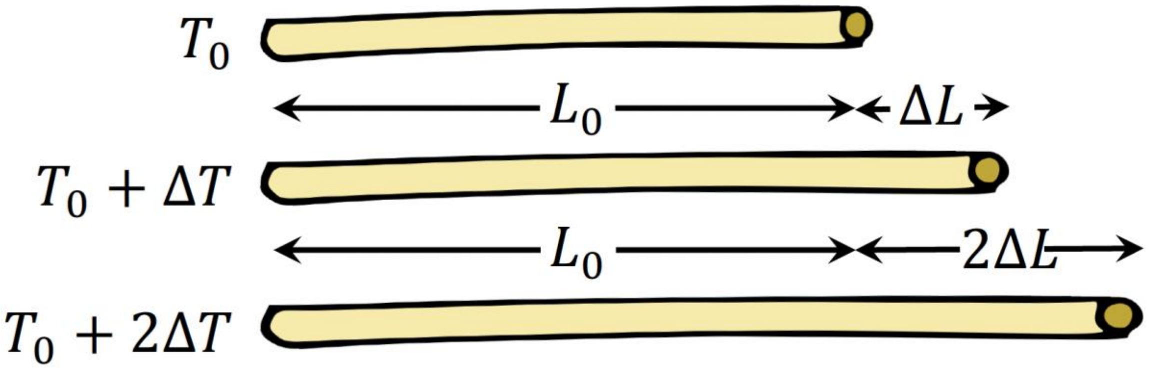


Question time: What is this?

Thermal expansion

Linear Thermal expansion

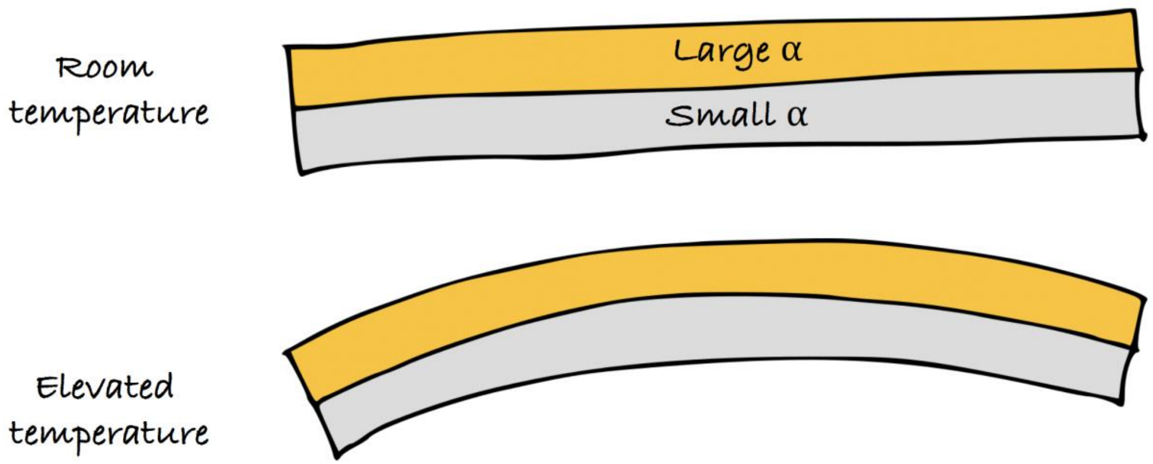
$$\Delta L = \alpha \Delta T L_0$$



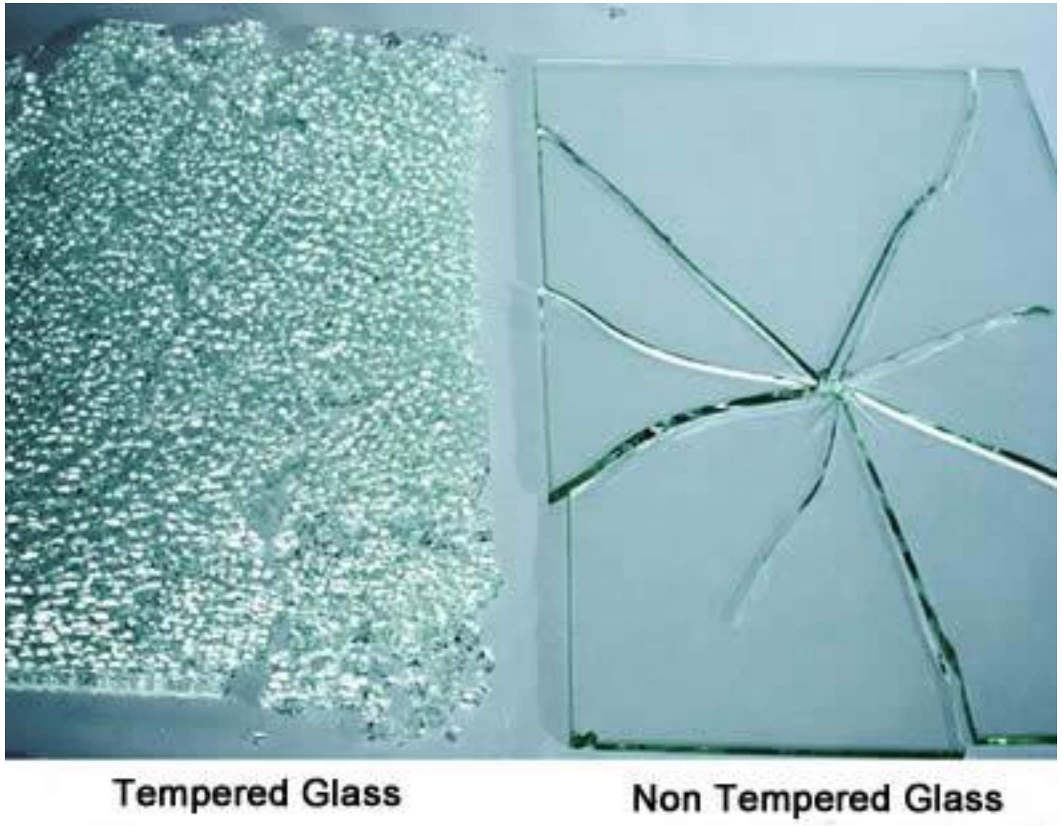
Material	α (10^{-6} °C^{-1})
Aluminum	22
Brass	19
Concrete	15
Copper	17
Diamond	1
Gold	14
Lead	29
Plate glass	9
Rubber	77
Steel	13
Tungsten	4.5

Residual Stress and Strain

Old Thermostat



Tempered Glass



Area and Volume expansion

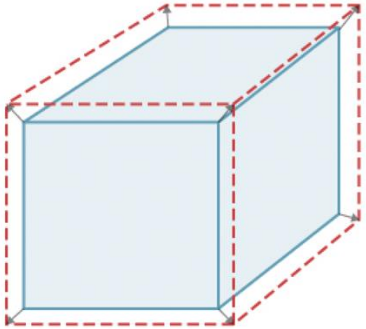
Area:

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

Volume:

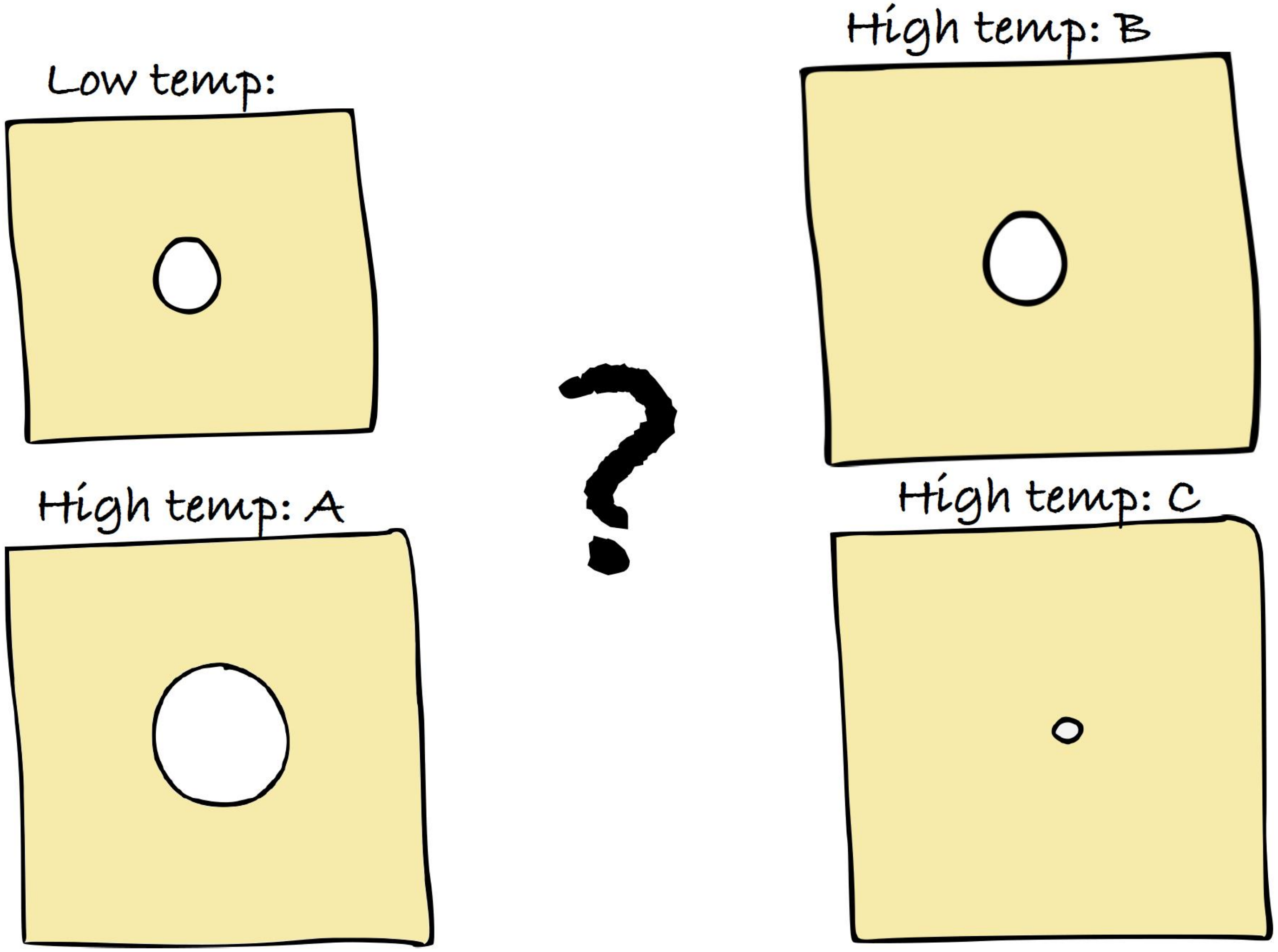
$$\Delta V = \beta V \Delta T$$

with $\beta = 3\alpha$

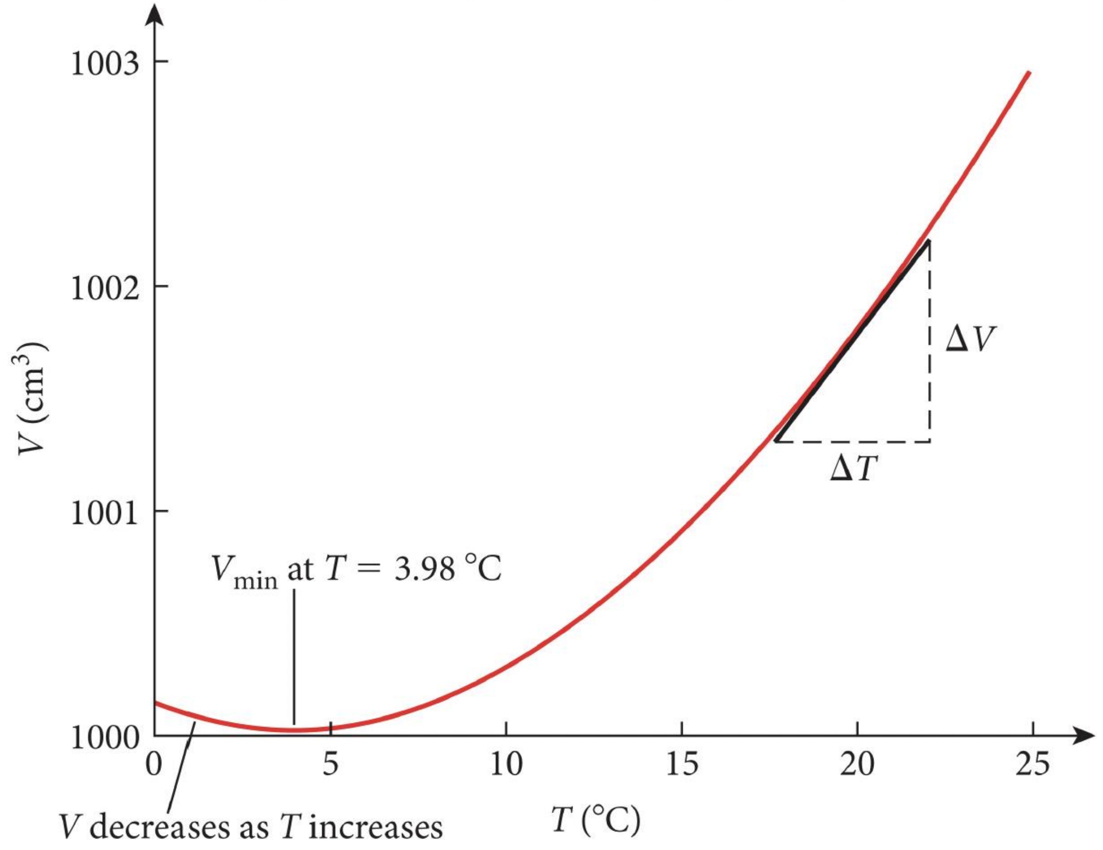


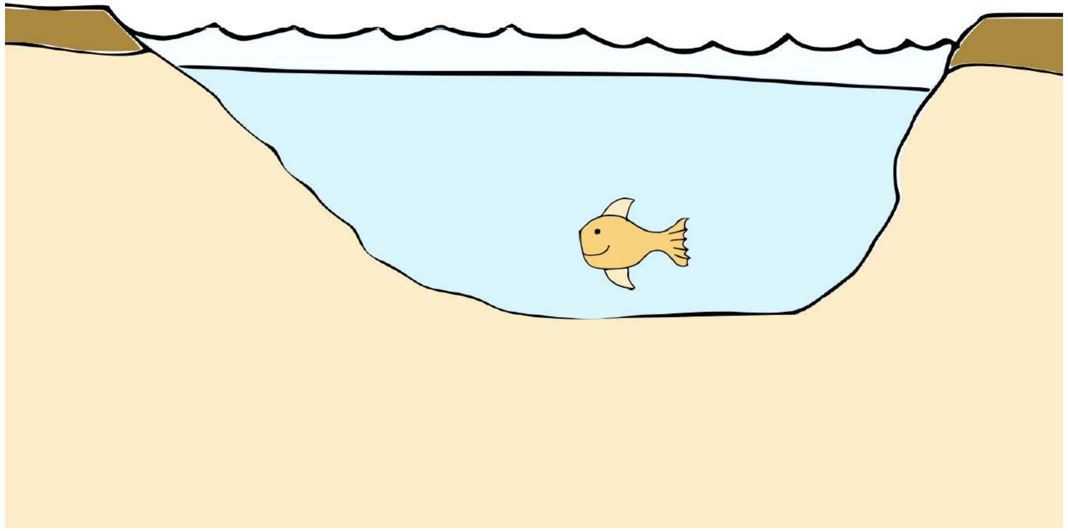
Material	β (10^{-6} °C^{-1})
Mercury	181
Gasoline	950
Kerosene	990
Ethyl alcohol	750
Water (1 °C)	–47.8
Water (4 °C)	0
Water (7 °C)	45.3
Water (10 °C)	87.5
Water (15 °C)	151
Water (20 °C)	207

Question time: How does this object expand?



Negative thermal expansion: Water





Does a vacuum have a temperature?

10063 Physics (Polyteknisk grundlag)

Heat

Difference between heat and temperature

- Temperature is a measure of the kinetic energy in the material

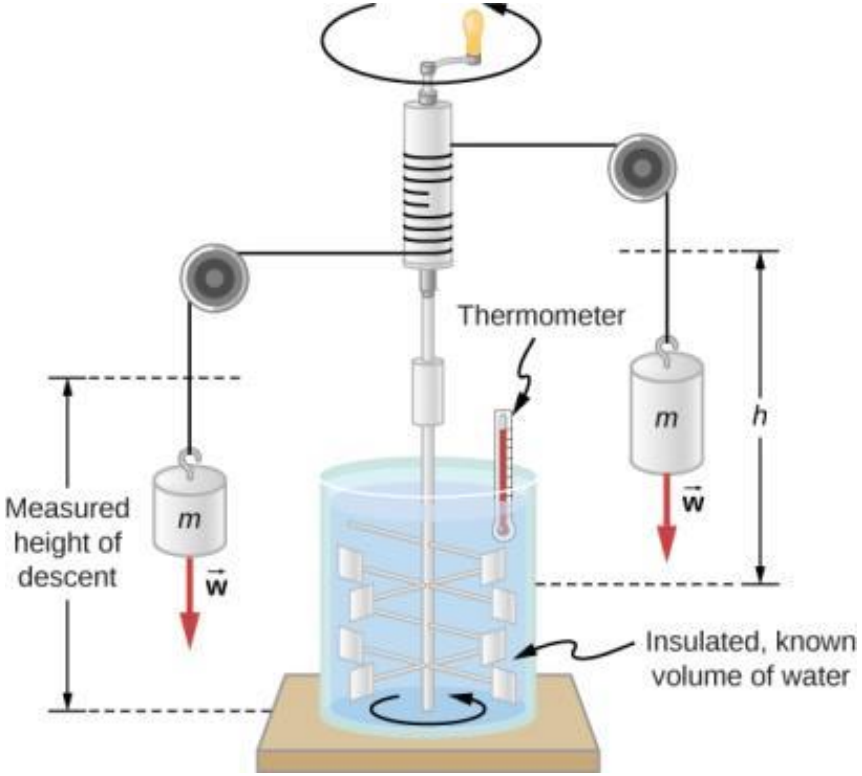
- Heat is the transfer of energy from a hot to a cold system

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)

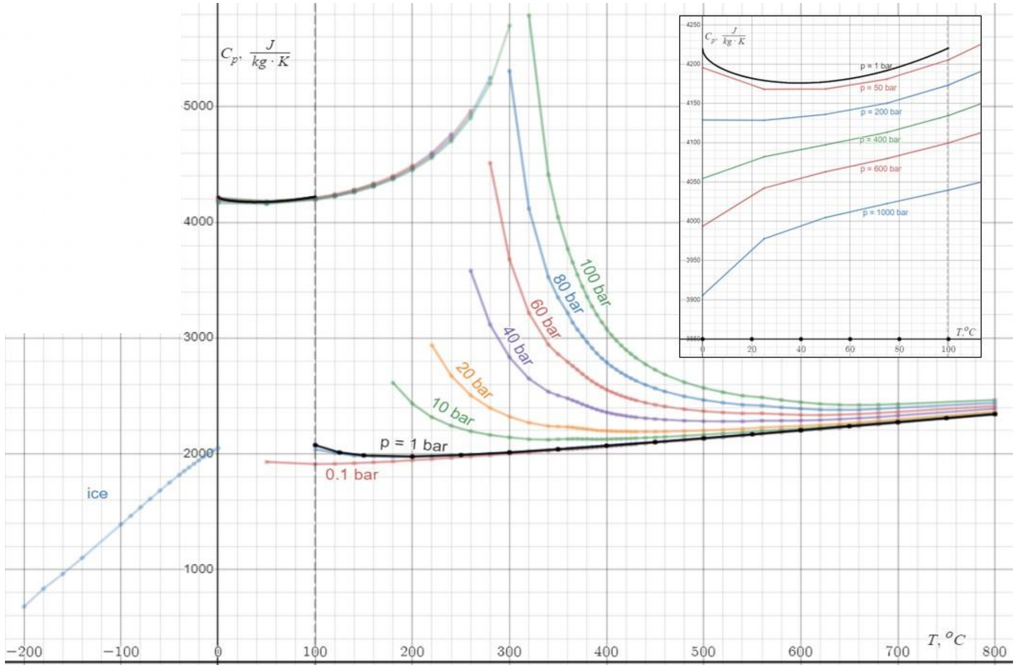
Heat (J) $\rightarrow$

$$Q = \underbrace{cm}_{\text{Heat capacity (J/K)}}\Delta T$$

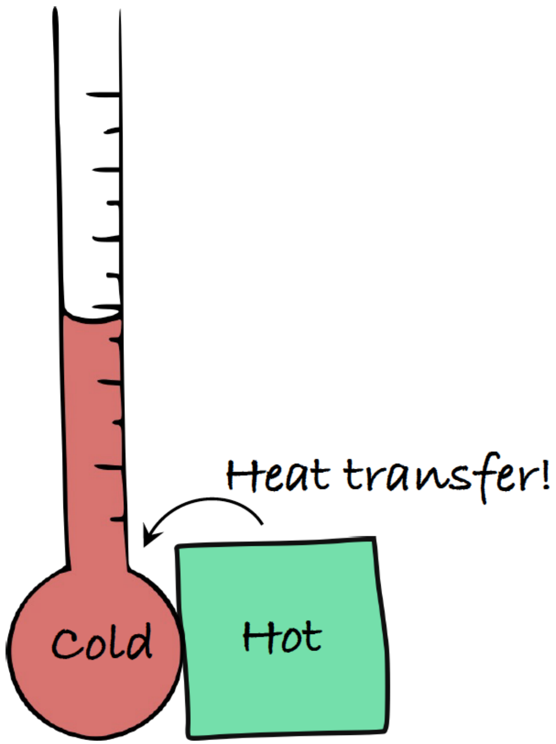
$\leftarrow$ Change in temperature (K)

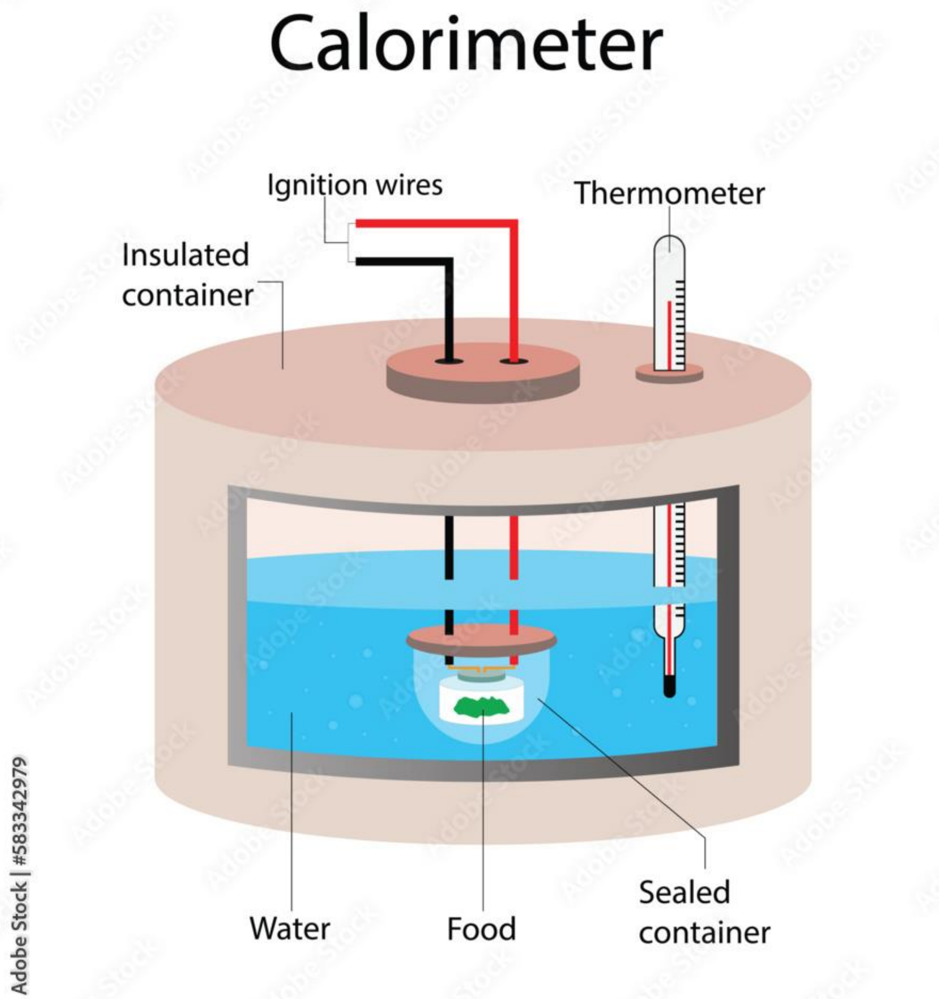
Mass of what we're heating (kg)

* c in general depends on temperature



Calorimeter Problem





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

Problem Time

Steel Cube

m_s , T_s

+

Water

m_w , T_w

$T_{eq} = ?$

Problem Time

Water

Ice Cube

$+$

$T_{eq} = ?$

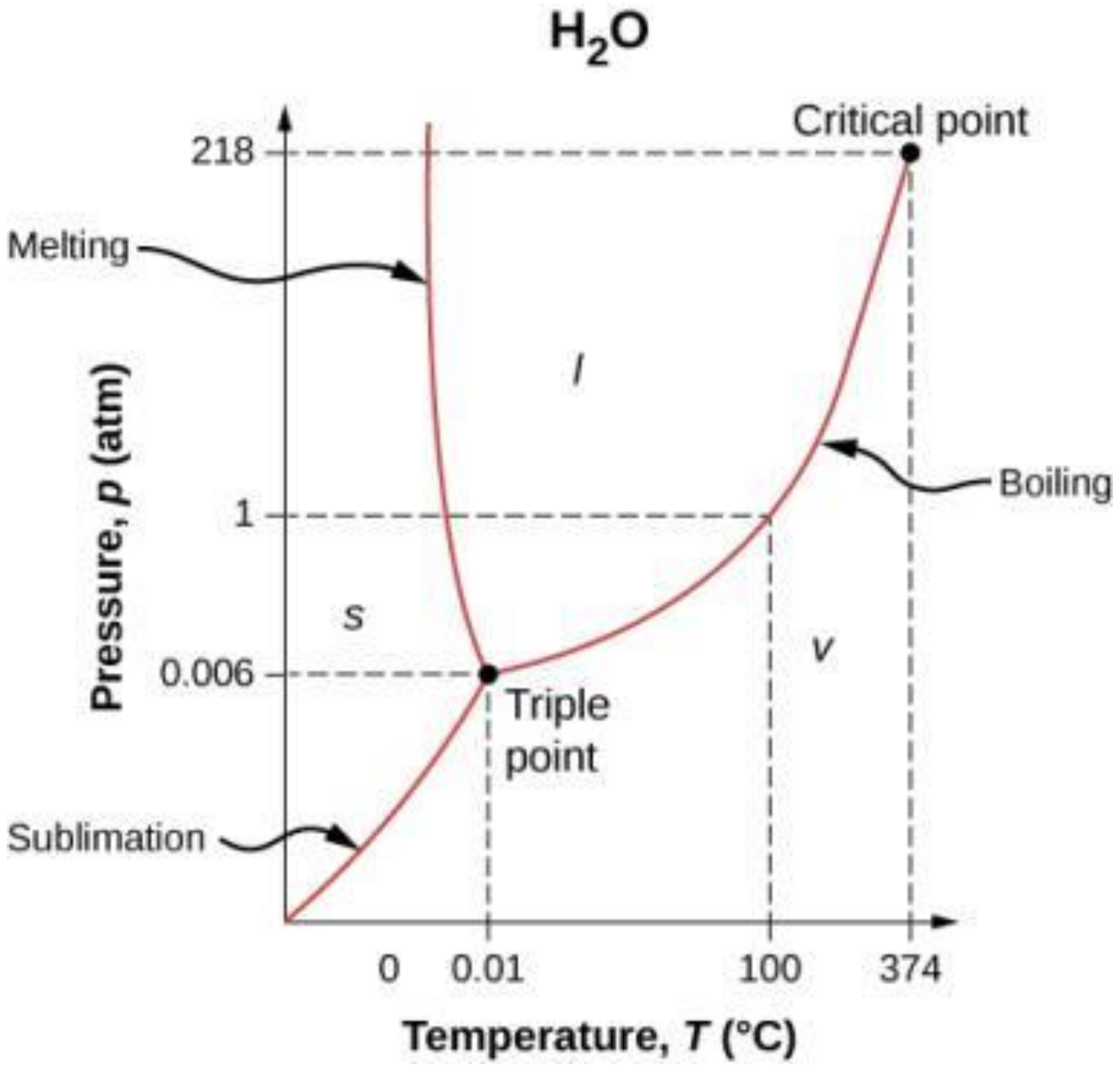
m_I , T_I

m_w , T_w

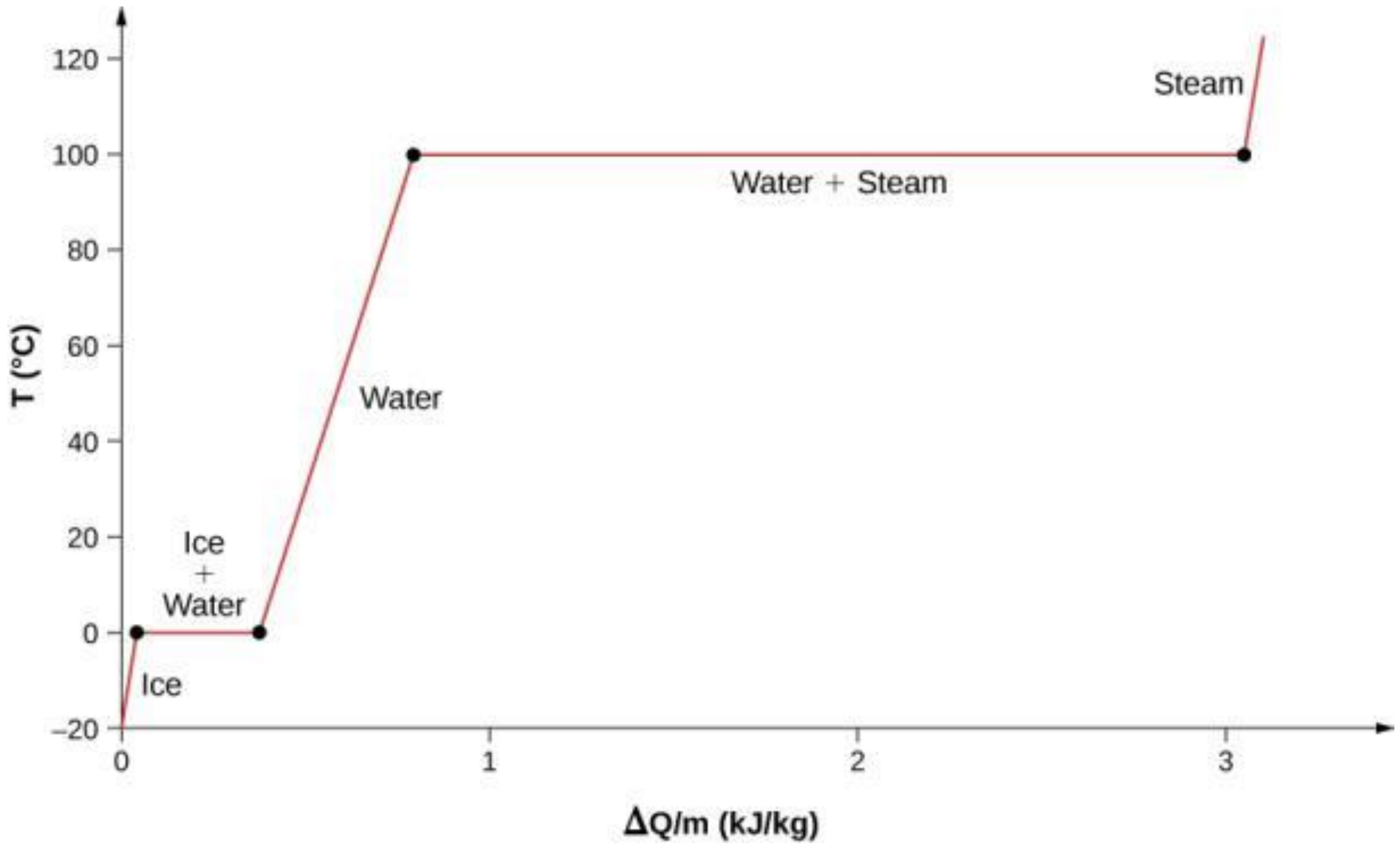
Phase Diagram

(b)

(a)



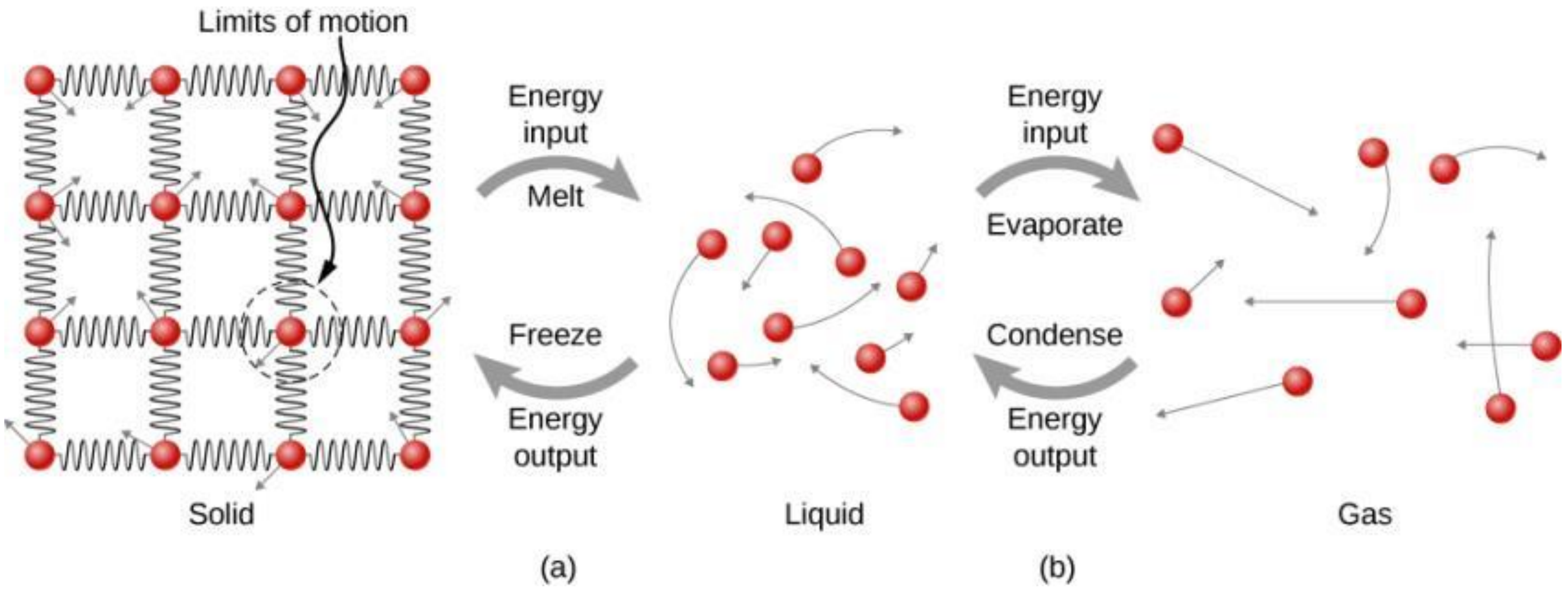
How does water heat up?



Latent Heat

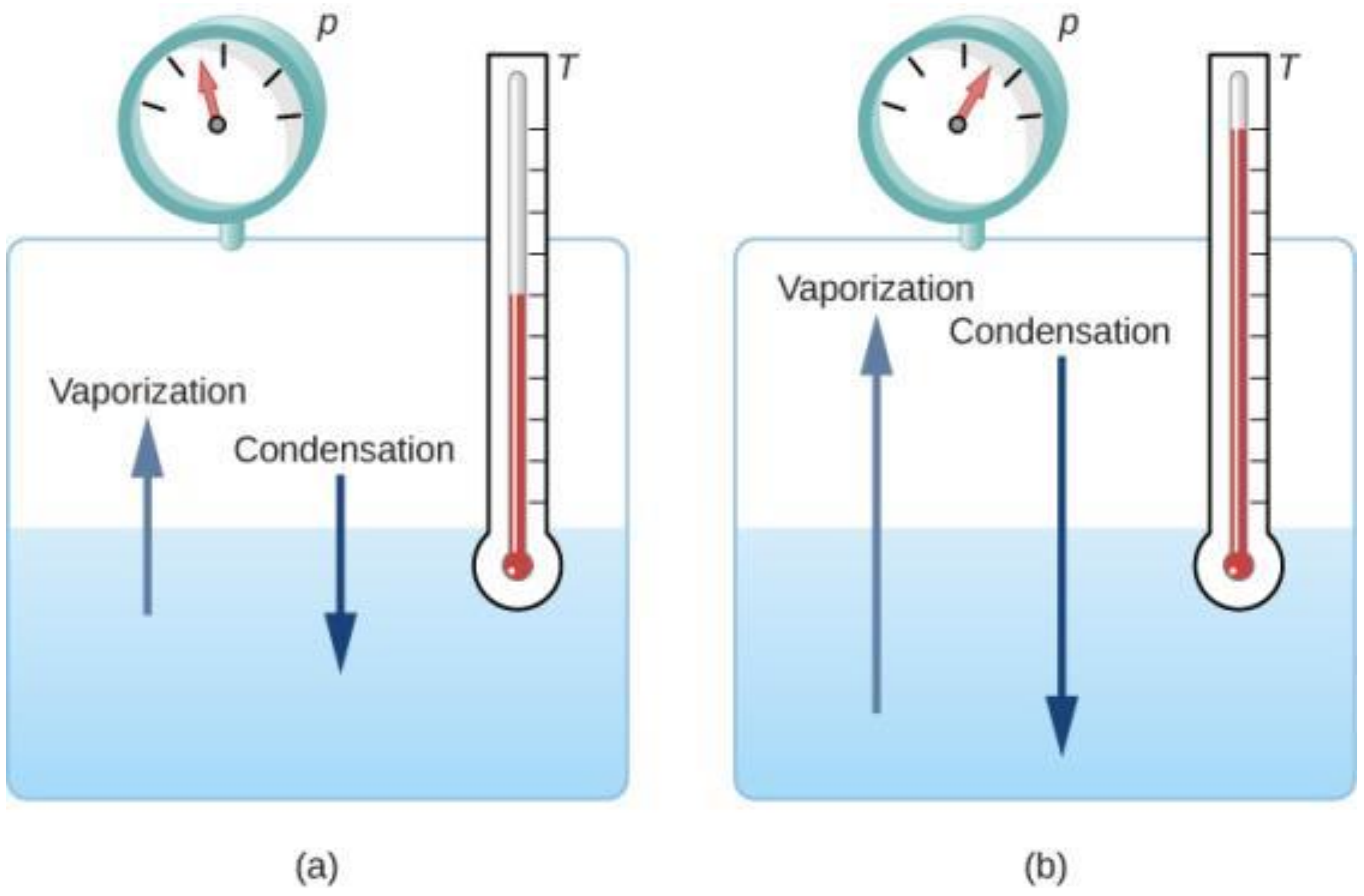
$$Q = mL_f \text{(melting/freezing)}$$

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



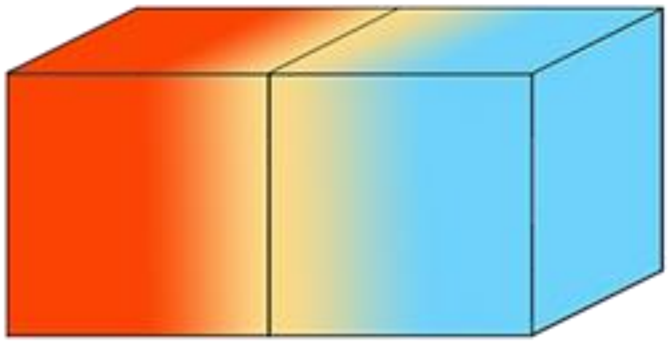
Liquid and Gas at equilibrium: a note of care

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

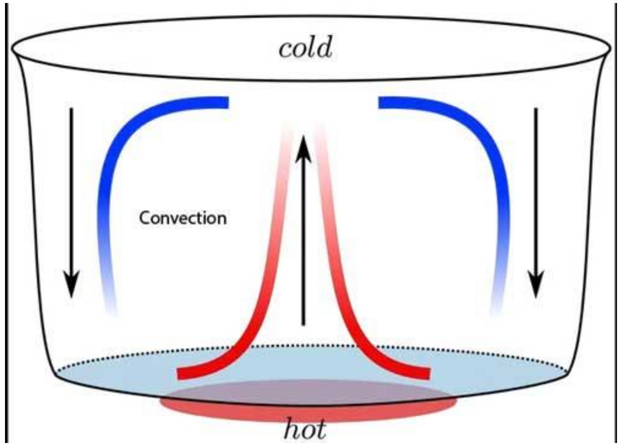


Heat propagation

Conduction

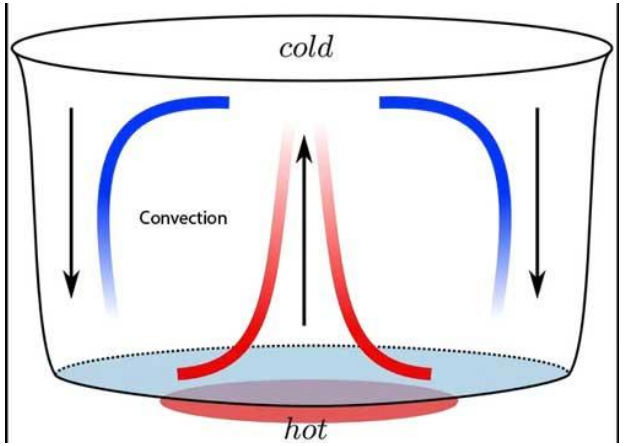


Convection



Radiation

Convection

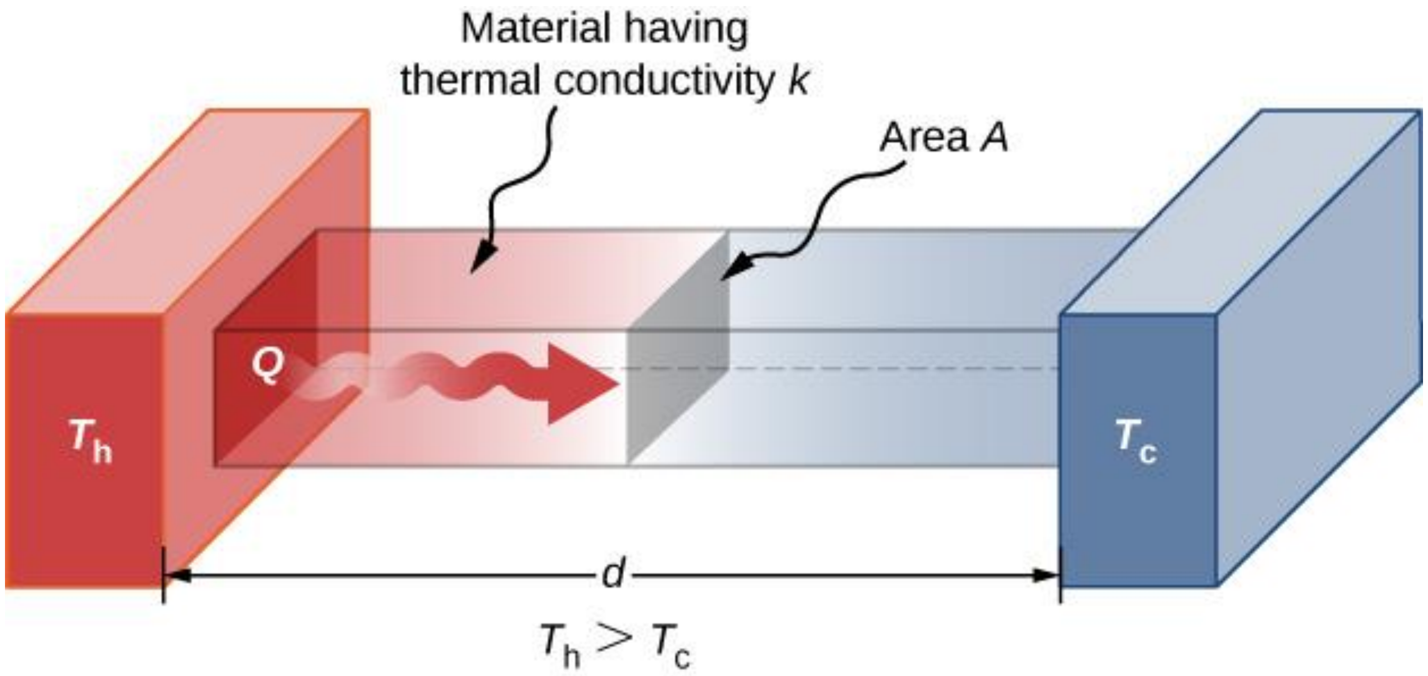


- Cumulus clouds are caused by water vapor that rises because of convection. The rise of clouds is driven by a positive feedback mechanism. (credit: “Amada44”/Wikimedia Commons)

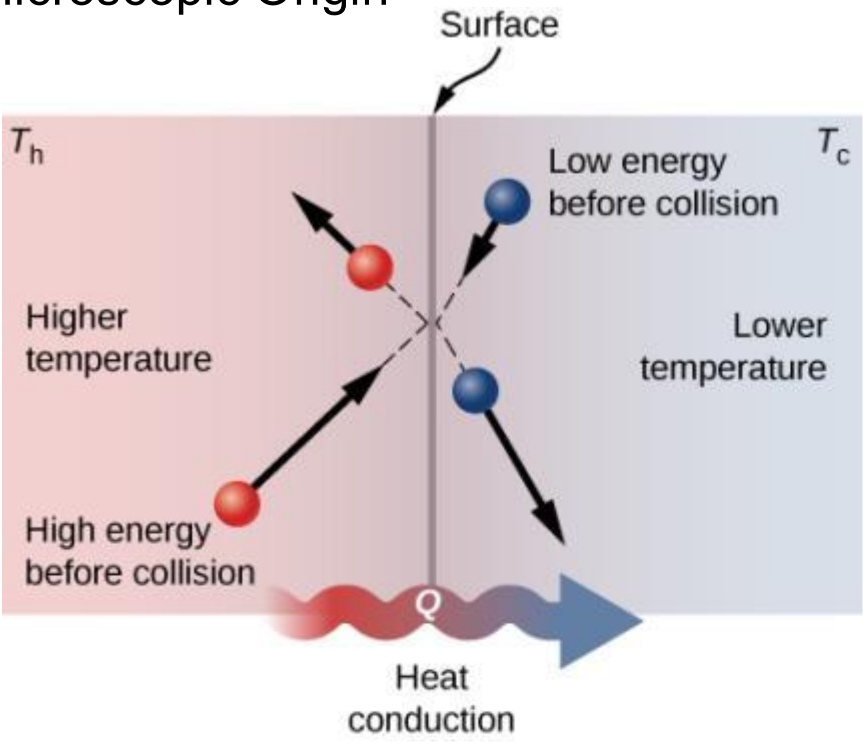
Conduction

Rate of heat transfer

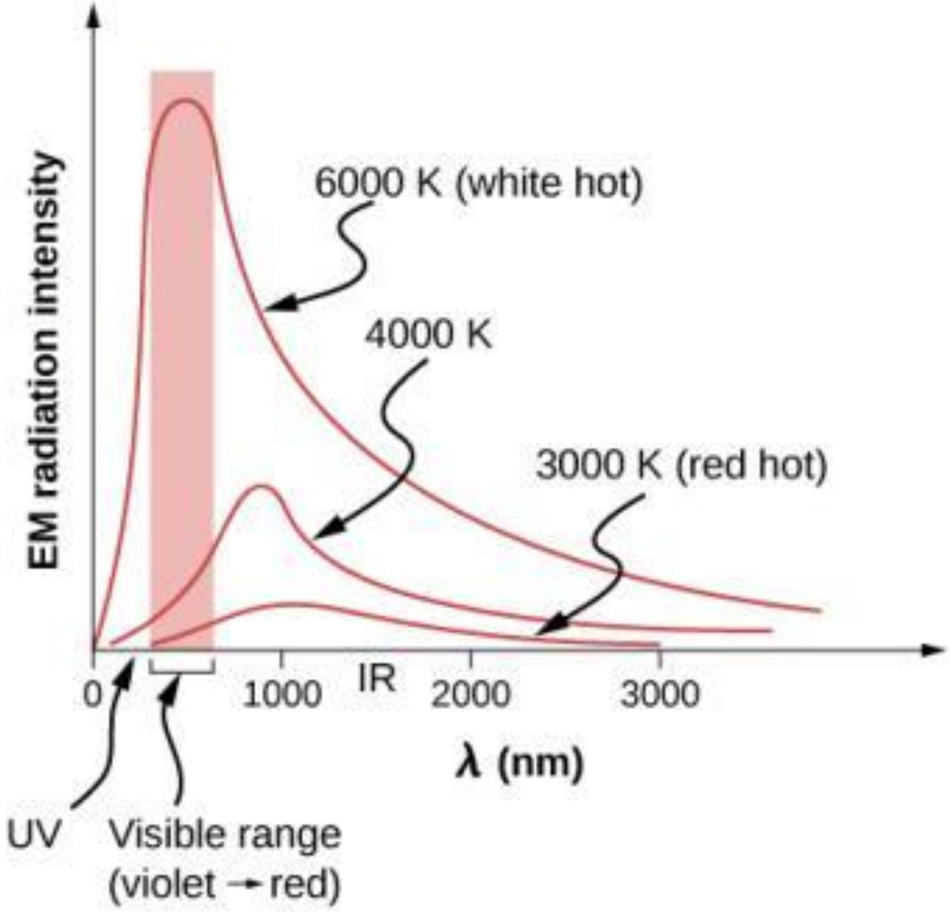
$$P = \frac{dQ}{dt} = \frac{kA\,(T_\mathrm{h} - T_\mathrm{c})}{d}$$



Microscopic Origin



Radiation



(a)


(b)

Stephan-Boltzmann law

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

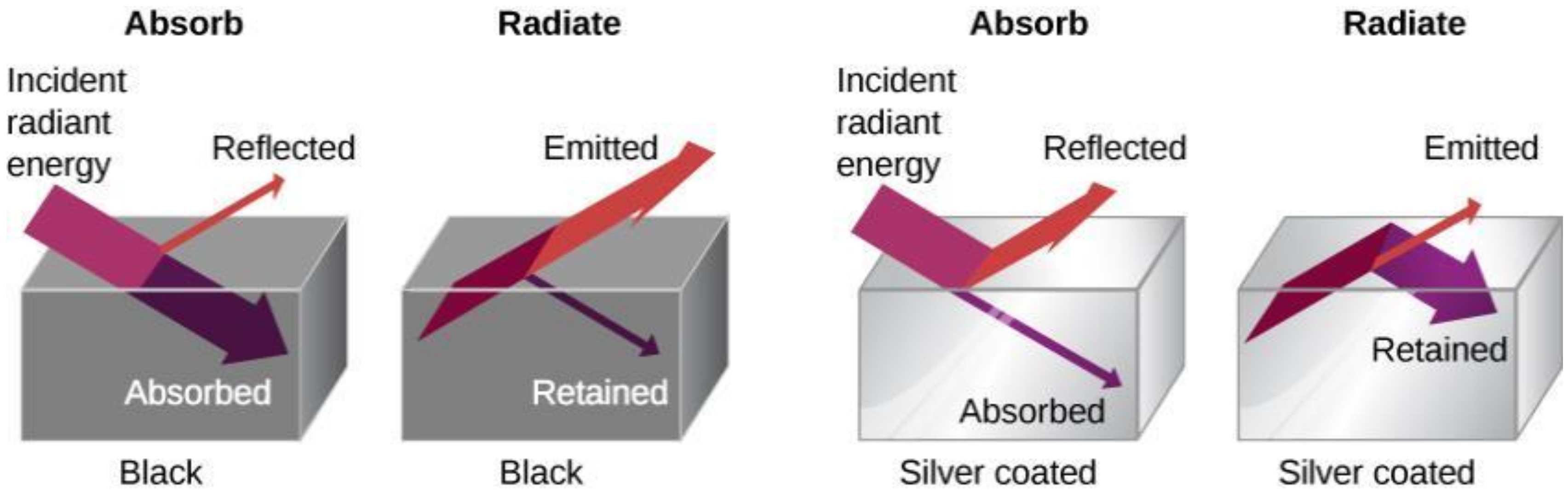
Stephan-Boltzmann constant

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

Net heat transfer rate

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

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.