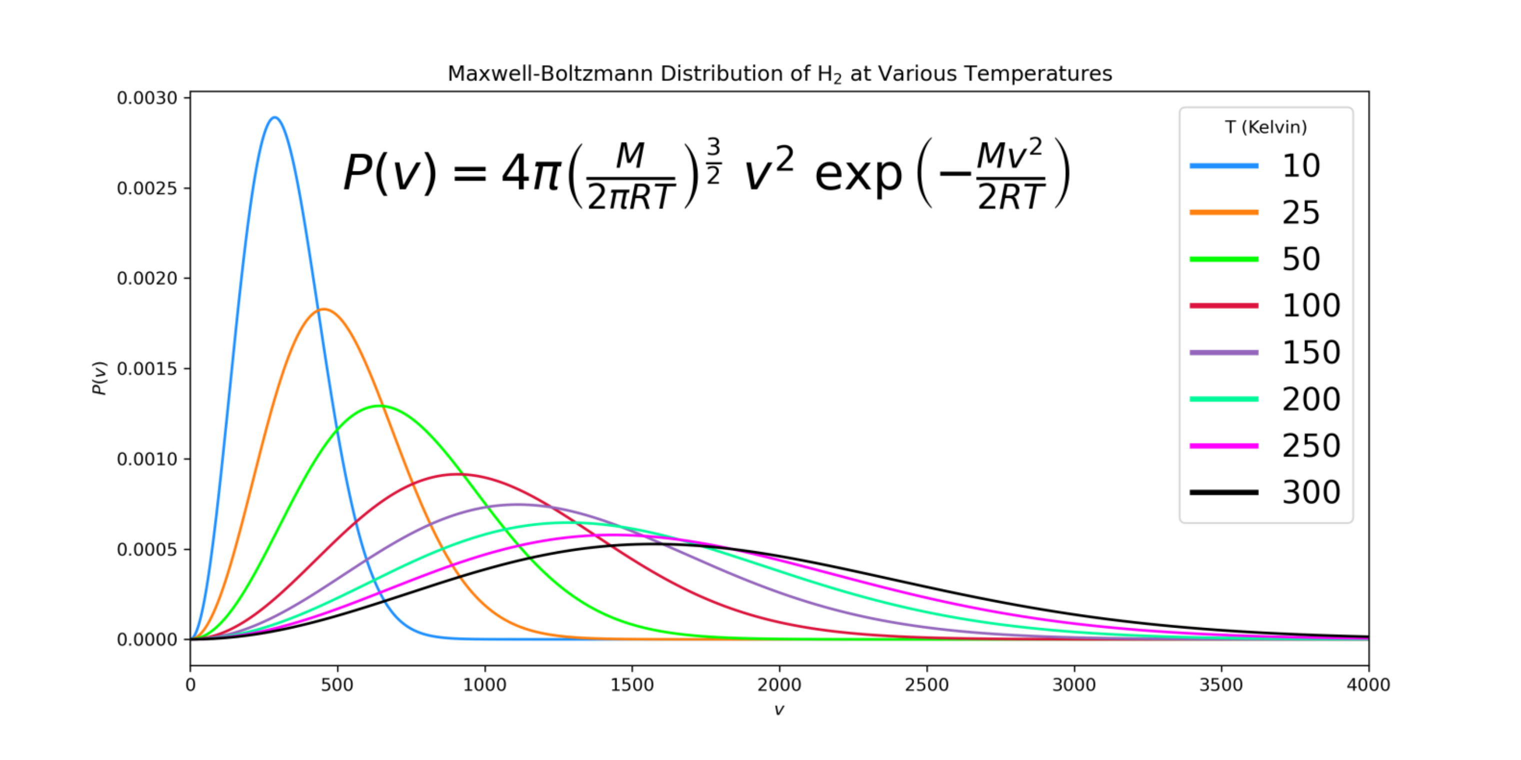
Recap from last time

What is temperature?

A statistical collection of energies for particles that make up the system for which we are measuring the temperature

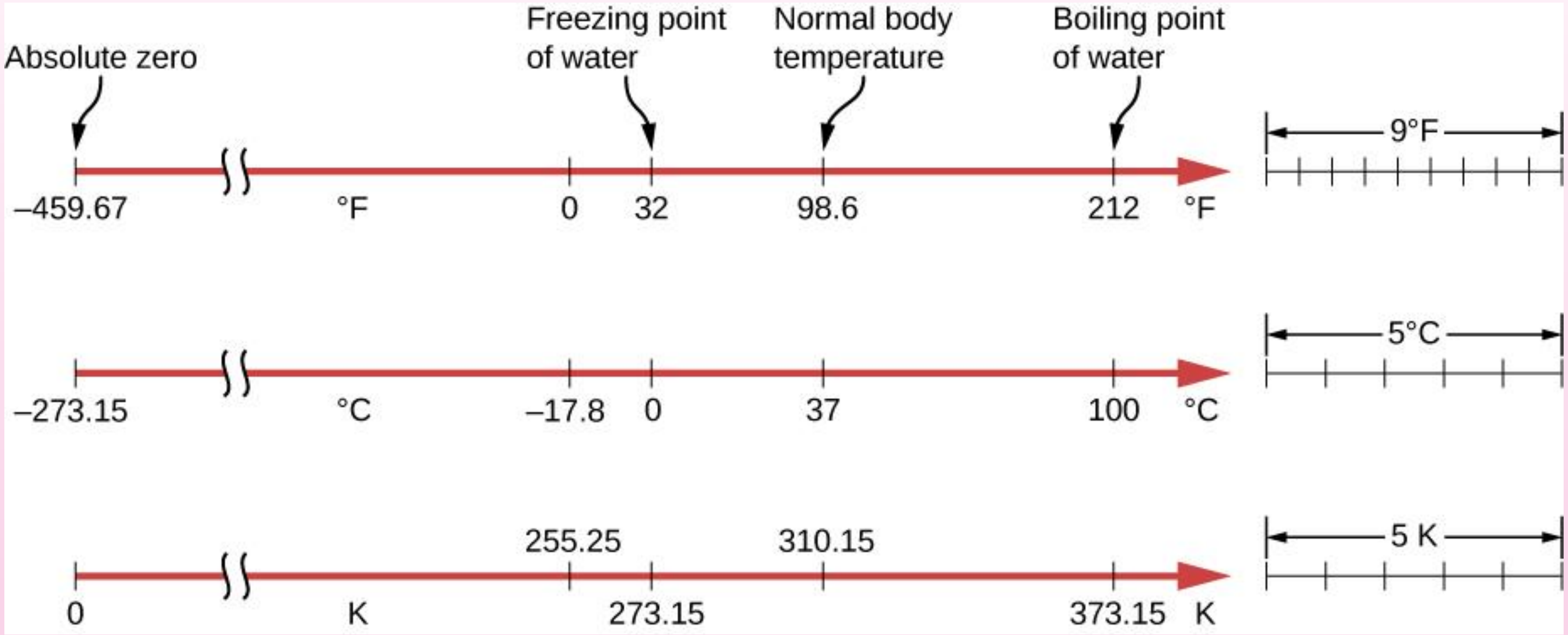


Recap from last time

Fahrenheit (°F, F-tier)

Celsius (°C, B-tier)

Kelvin (K, S-tier)



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Note the lack of a degrees sign

°F -> °C: $(x-32)\times\frac{5}{9}$

°C -> K: $(x+273.15)$

Defining a temperature scale

Need to find a quantity that depends on temperature in an obvious way (ideally linearly?) (x)

e.g. volume (as with liquid mercury)

Define a special temperature T_0 as our calibration point, at which our quantity has value x_0

$$T = T_0 + k\frac{x - x_0}{x_0}$$

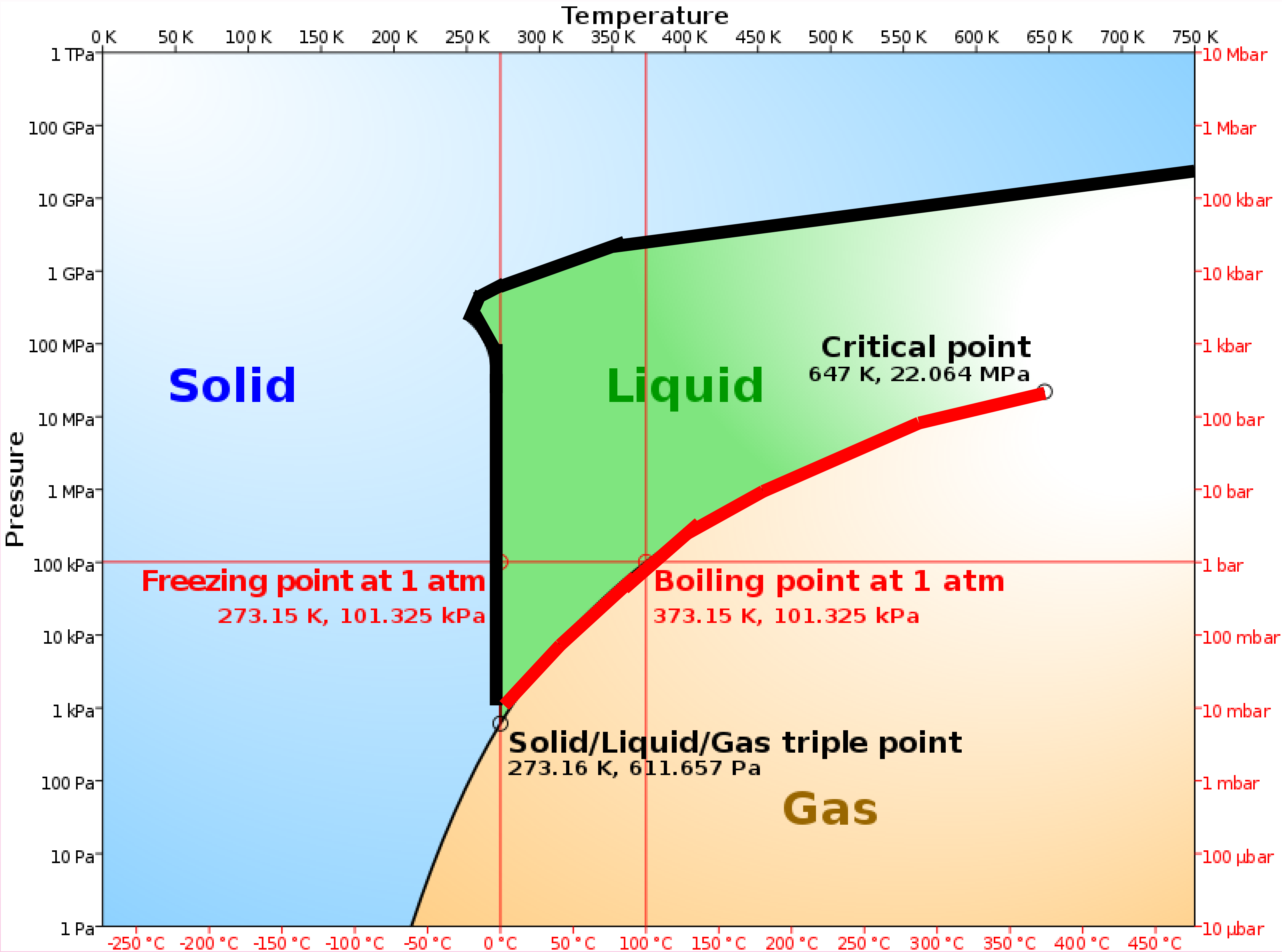
For degrees Celsius, $T_0 = 0$°C and we choose a value of k such that when water boils, $T = 100$°C

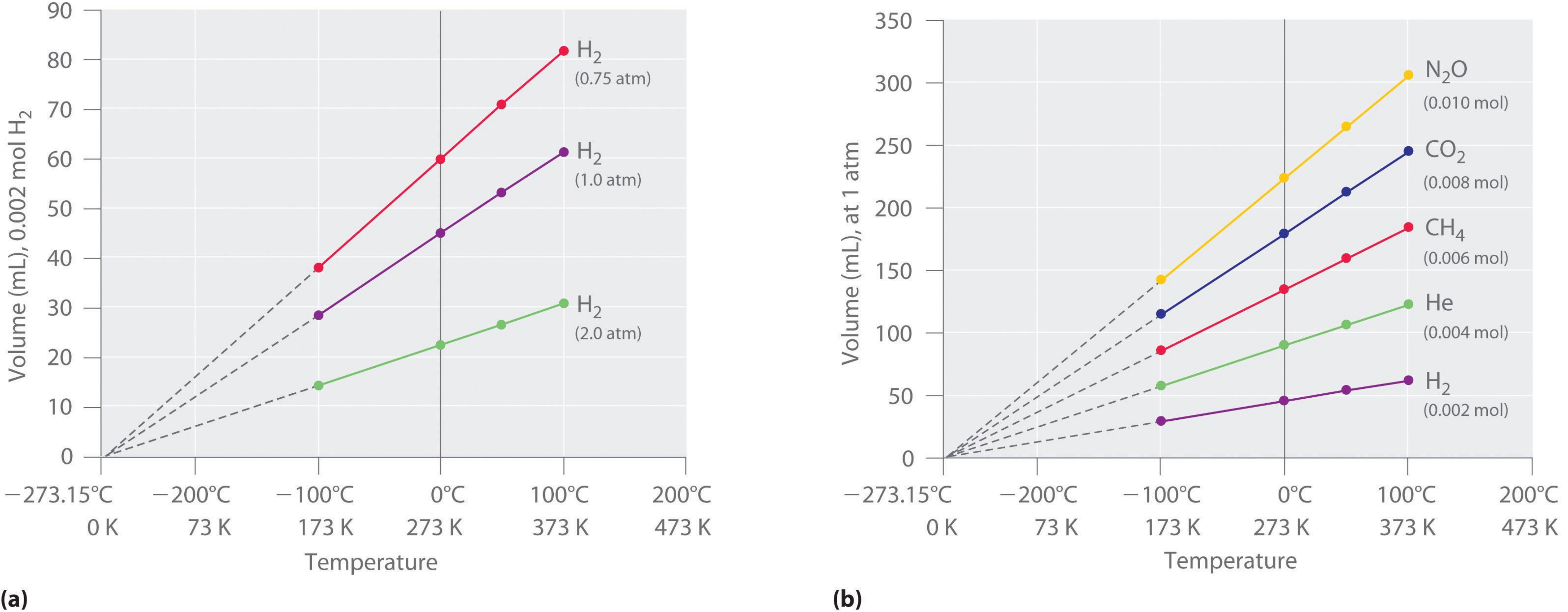
However, this depends on pressure… what other calibration point could we use?

Multiple freezing and boiling points for water…

Only one triple point!

Usually we would calibrate to this instead (very close to the freezing point at 1 atm)





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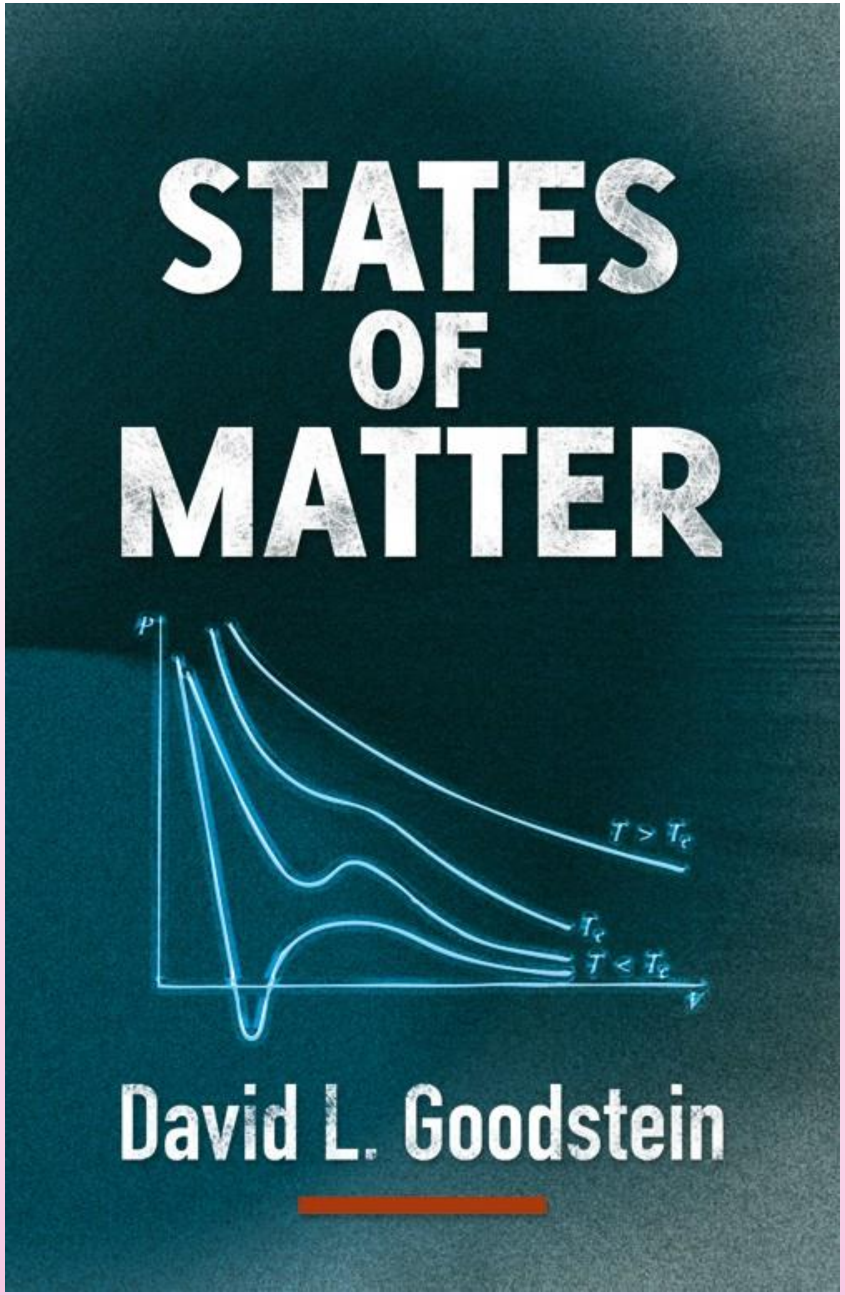
As we keep a gas at a constant pressure/volume, we find that all gases reach zero volume/pressure at the same theoretical temperature through extrapolation – absolute zero! This lets us calibrate the Kelvin (and Rankine…) scale(s)

Thermodynamics

Learning this subject has been very eloquently summarised by American physicist David Goodstein, in the intro to his book States of Matter (1975):

"Ludwig Boltzmann, who spent much of his life studying statistical mechanics, died in 1906, by his own hand. Paul Ehrenfest, carrying on the work, died similarly in 1933. Now it is our turn to study statistical mechanics. Perhaps it will be wise to approach the subject cautiously."



Thermodynamics

“**Thermodynamics** is the science of the relationship between heat, work, temperature, and energy. In broad terms, thermodynamics deals with the transfer of energy from one place to another and from one form to another. The key concept is that heat is a form of energy corresponding to a definite amount of mechanical work.”

From Ancient Greek θερμός (thermós, “warm, hot”).

δῠ́νᾰμῐς • (dúnamis) *f* (*genitive* **δῠνᾰ́μεως**); *third declension*

1. power, might, strength

(Greeks didn’t have calculus yet)

What is heat?

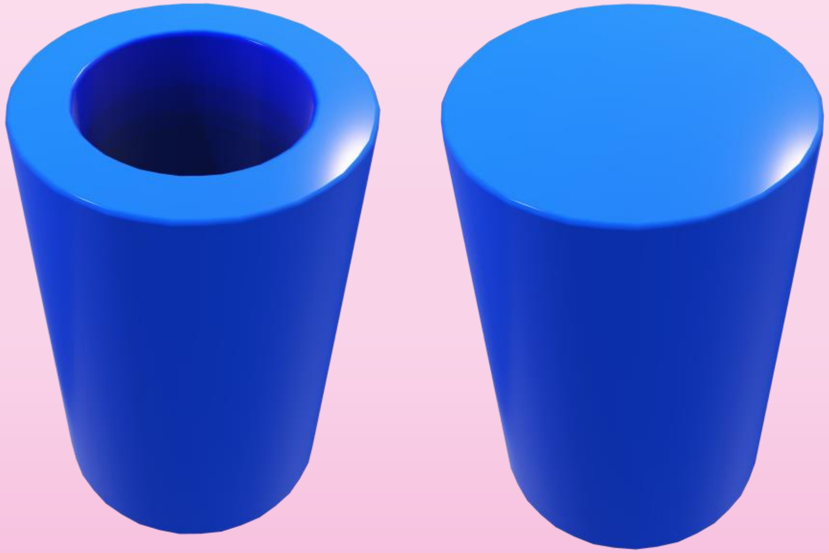
Heat is a measure of thermal energy transfer between two systems (?) in physics terms

Do not confuse this heat with the colloquial “being hot”

Systems

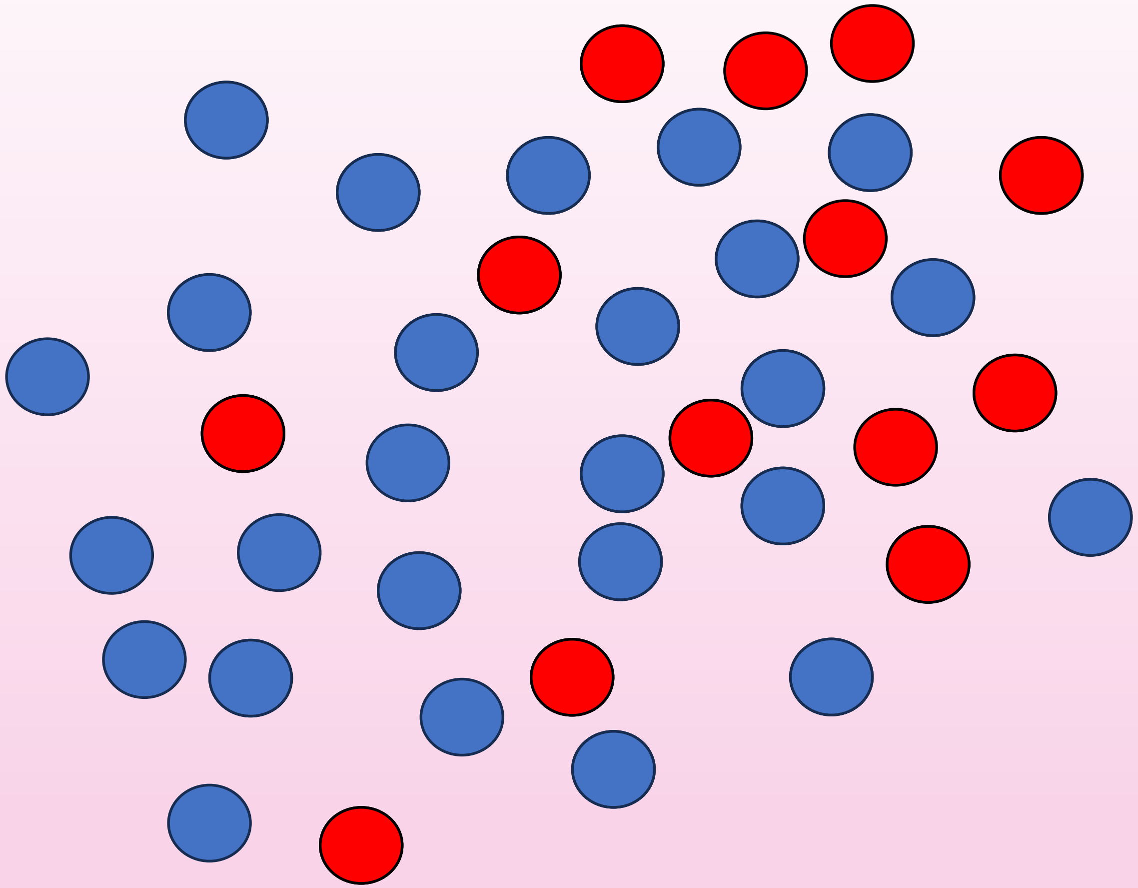
A system is a part of the universe we are investigating/discussing – e.g. a room, inside of a bottle, the entire Milky Way galaxy

Often we discuss systems comprised of a container containing some sort of fluid (liquid or gas), either open (no lid) or closed (lid)



Adiabatic walls – no heat transfer
Diathermal walls – heat transfer possible

Thermal equilibrium

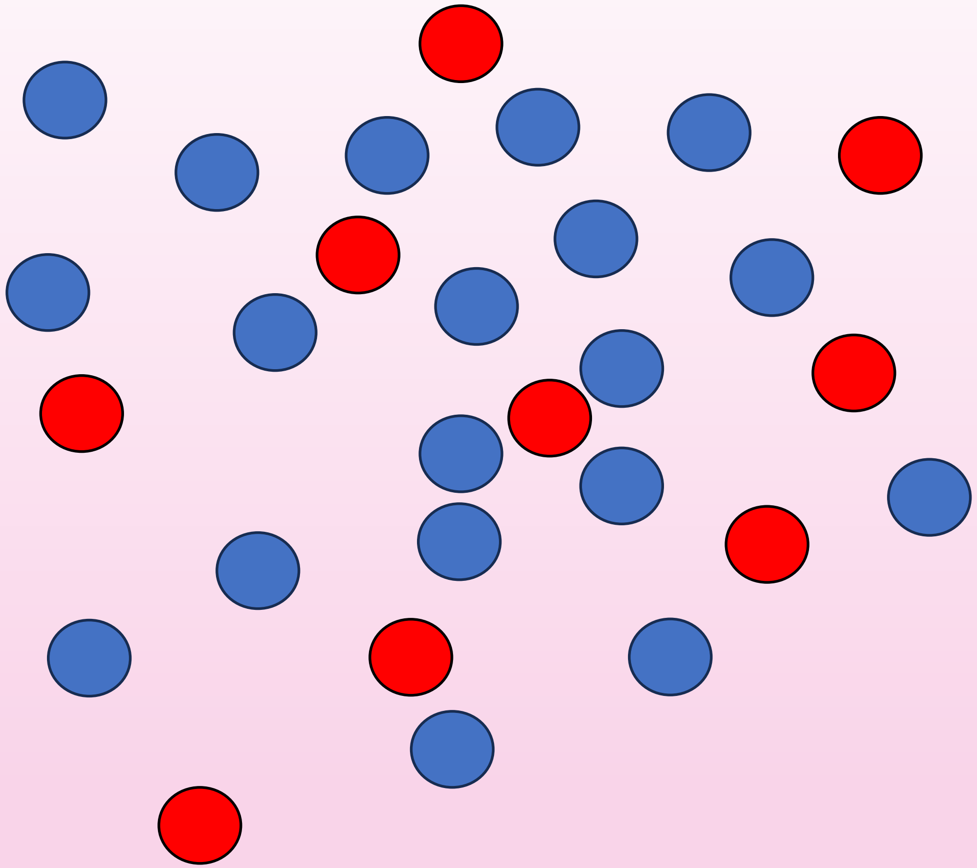


Consider the gas on the left: is this gas in thermal equilibrium?

Energy density not constant throughout -> gas is NOT in internal thermal equilibrium

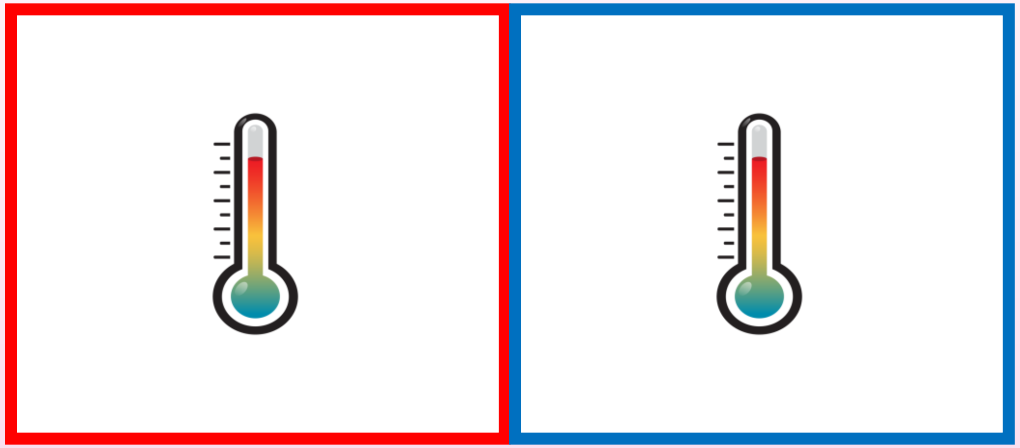
Temperature measured in one part of the gas significantly higher than in another part of the gas

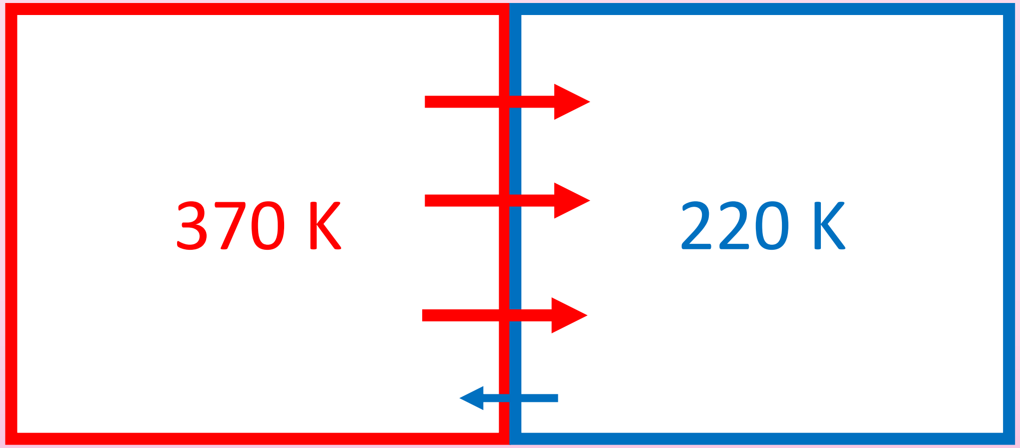
Thermal equilibrium



Energy density constant, so the system (gas) is in internal thermal equilibrium

Thermal equilibrium



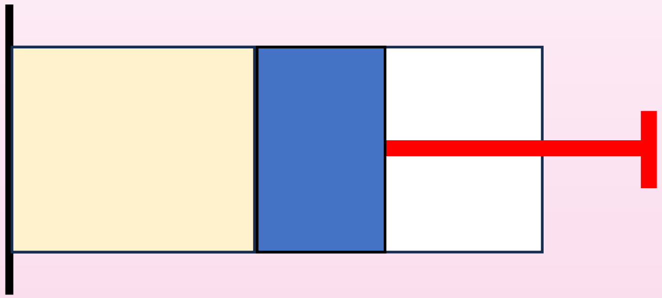


Energy density constant, so the system (gas) is in internal thermal equilibrium

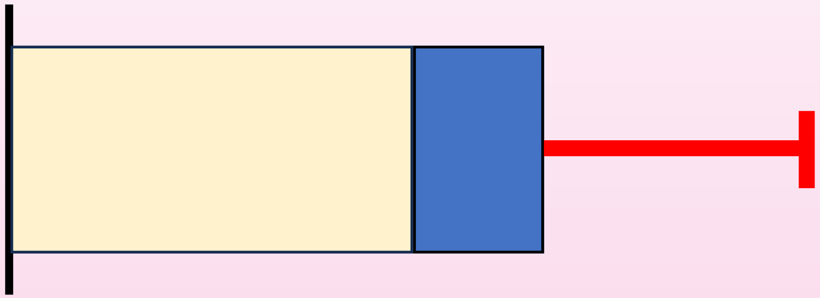
Two systems are in thermal equilibrium if there is no net transfer of heat energy between them

Thermal equilibrium

V_I, P_I, T_I



V_F, P_F, T_F



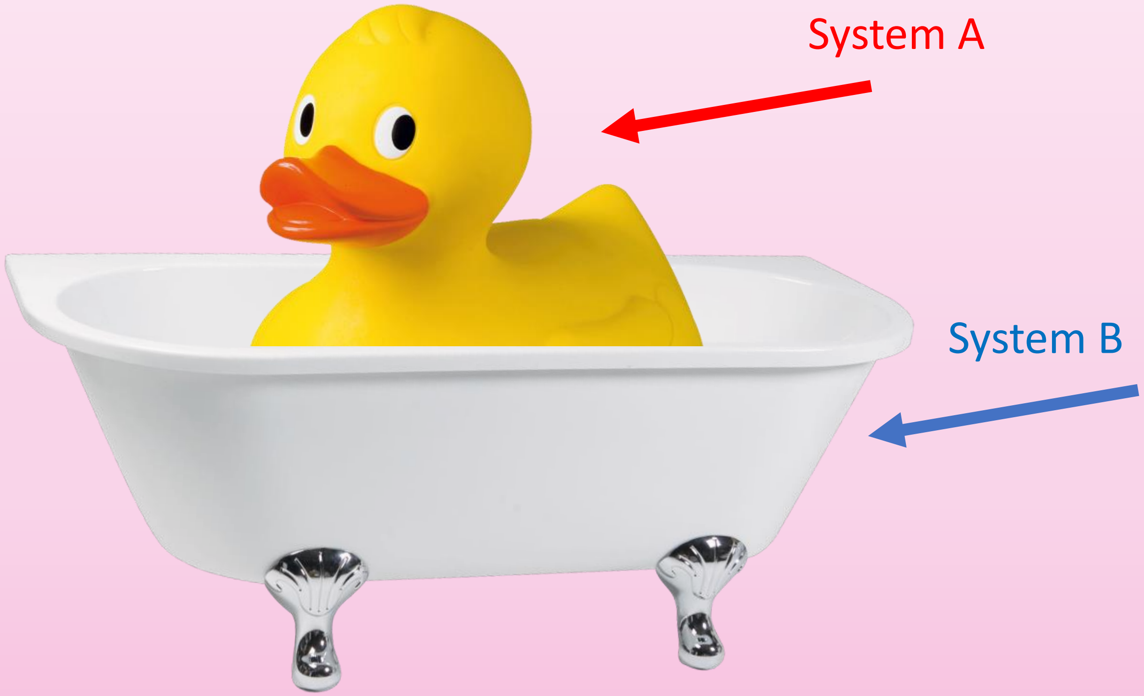
Volume of the gas changes as we pull out the piston, which in theory changes both the temperature and the pressure

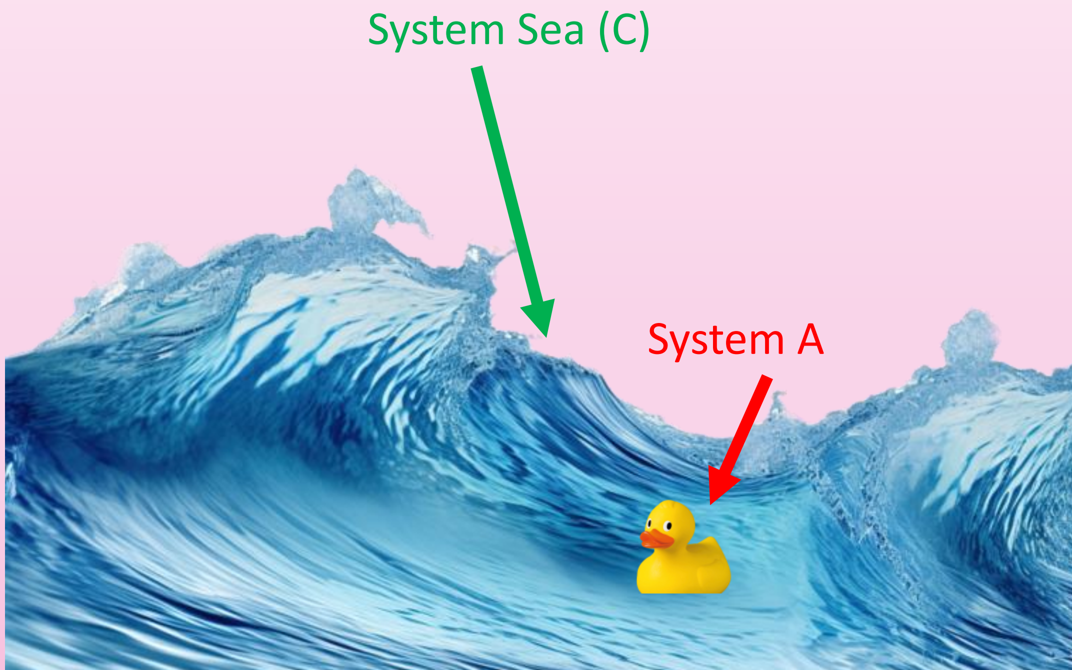
Gas has to reach thermal equilibrium again after the change (takes some amount of time to reach T_F

Systems

Systems can be brought into contact with one another – obvious example would be placing something in a bath of water

Which of these two system pairs will reach thermal equilibrium first?





Definitions

Isothermal – change to a system that takes place at a constant temperature (think thermal -> thermometer)

Isobaric – change to a system that takes place at a constant pressure (think bar -> pressure)

Isochoric – change to a system that takes place at a constant volume (remember the other two and that this one isn’t them)

Adiabatic – change to a system that takes place without transfer of heat (temperature can change, but heat cannot enter the system!)

Heat capacity

What is the relationship between heat energy, ΔQ, transferred to a system and its corresponding increase in temperature, ΔT?

Heat capacity of the system (J/K)

$$\Delta Q = C\Delta T \rightarrow C = \frac{\mathrm{d}Q}{\mathrm{d}t}$$

Varies depending on the amount of material, so can define

Specific heat capacity (J kg^{-1} K^{-1}) -> $C = mc$
Molar heat capacity (J mol^{-1} K^{-1}) -> $C = nc$

Higher heat capacity, smaller increase in temperature for a given heat

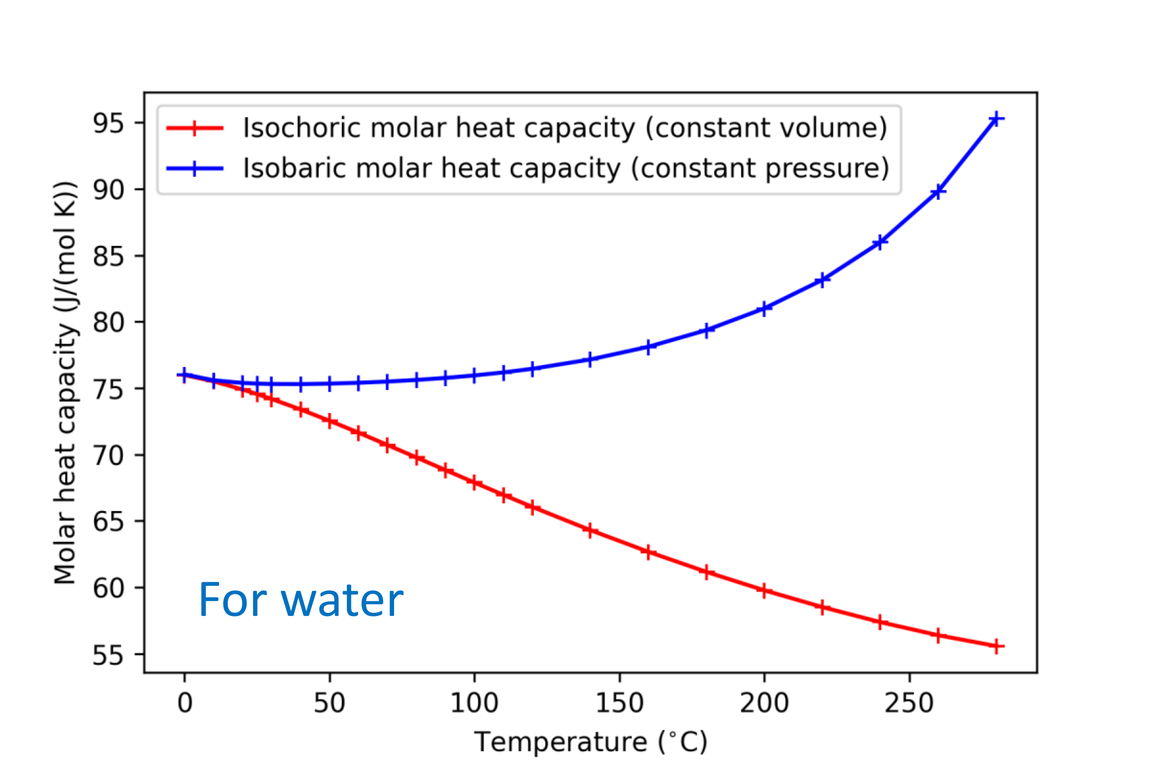
Heat capacity

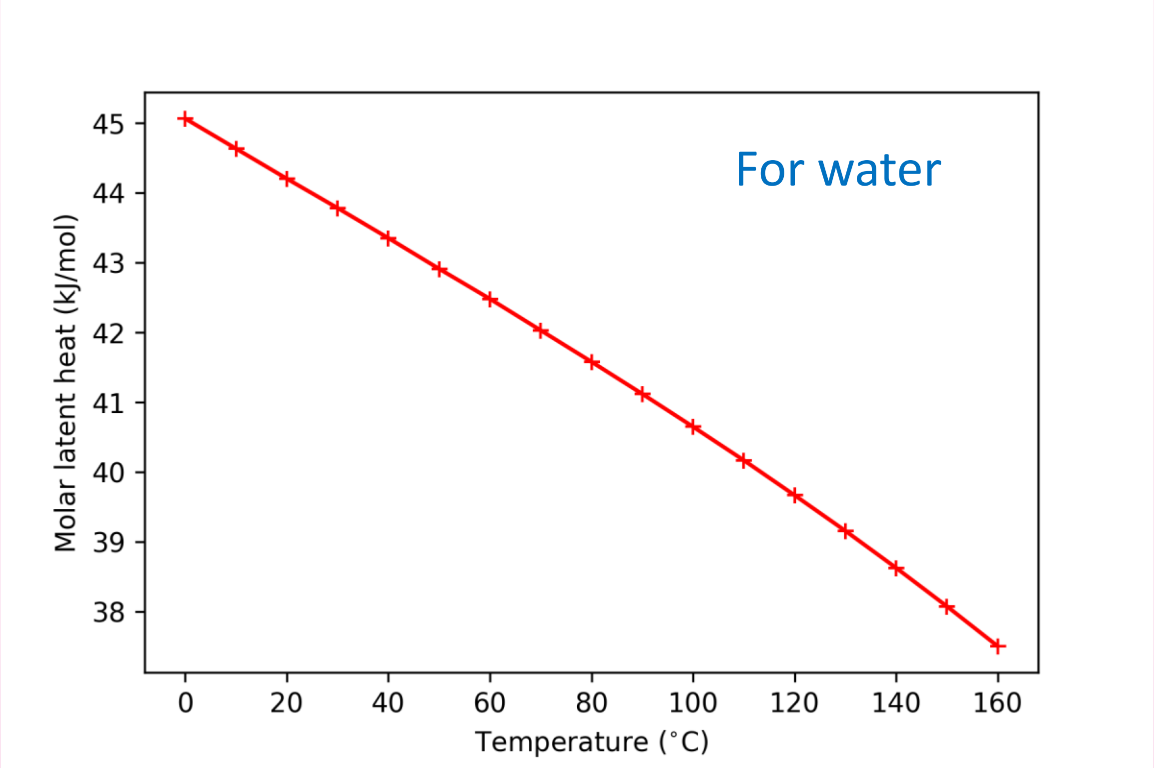
Material	Specific heat capacity (kJ kg^{-1} K^{-1})	Molar heat capacity (kJ mol^{-1} K^{-1})
Water	4.18	73.9
Iron	0.45	25.1
Mercury	0.14	28.0
Ethanol	2.40	111.5
Aluminium	0.90	24.3
Uranium	0.12	27.7
Hydrogen	14.30	28.8
Air (sea level, dry, 273.15 K)	1.00	29.1

Isobaric values at 298 K (with the exception of air)

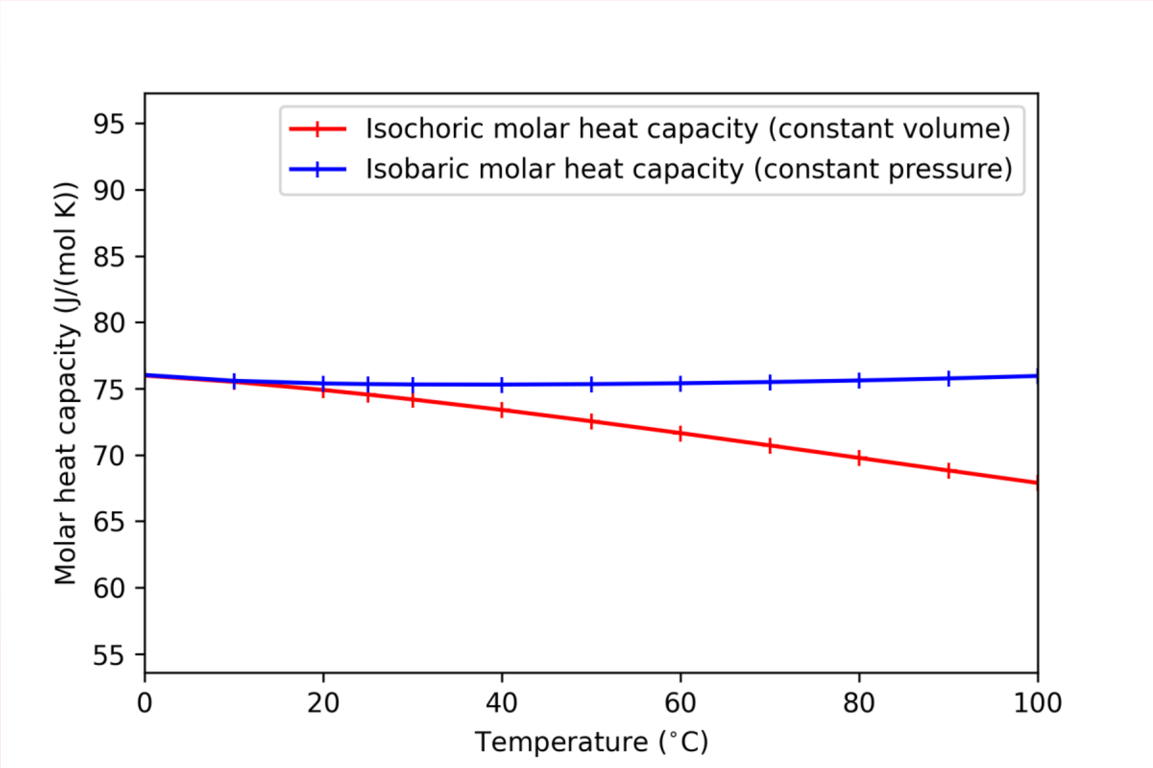
Heat capacity

Be careful that heat capacity varies with temperature, much like latent heat (lecture 4)



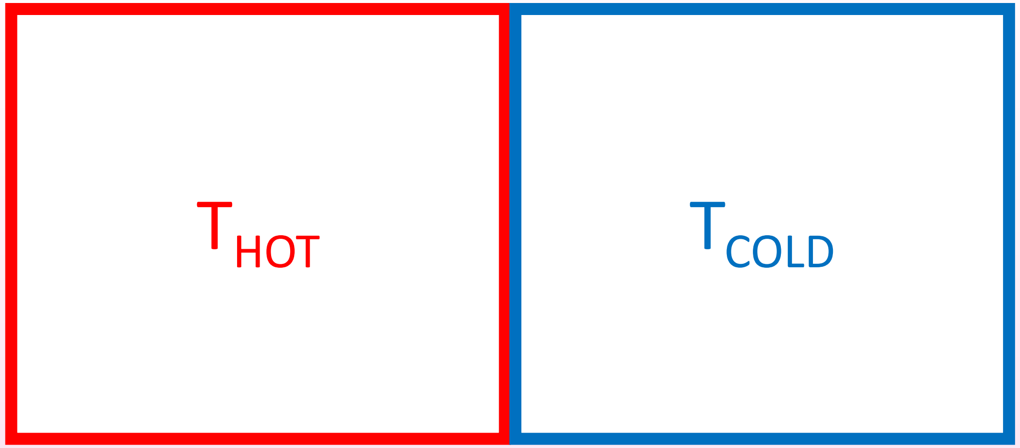


Heat capacity



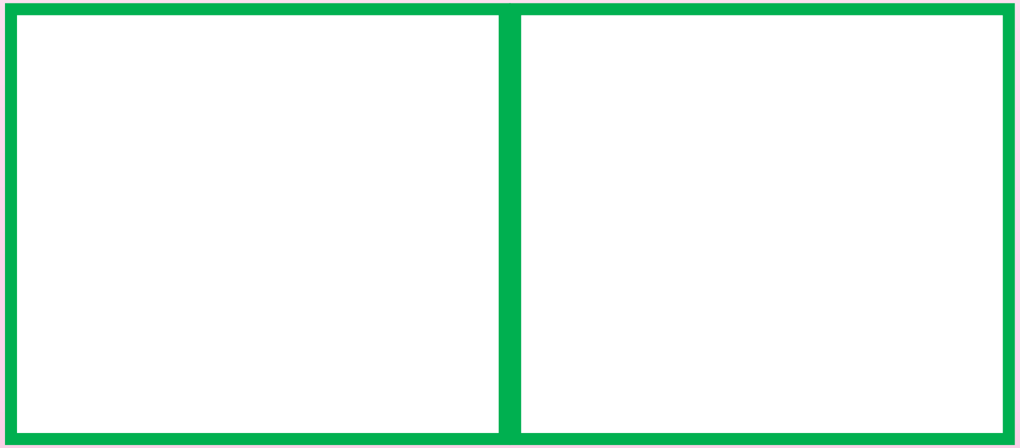
For the range of temperatures corresponding to liquid water at standard temperature, isobaric specific heat is approximately constant

-> Not unreasonable to treat C as a constant in some circumstances



$t = 0$

Two identical bodies are in thermal contact, with temperatures T_{HOT} and T_{COLD} respectively. What will the temperatures of the bodies be at thermal equilibrium?



t = later

$$T = (T_{HOT} + T_{COLD})/2$$

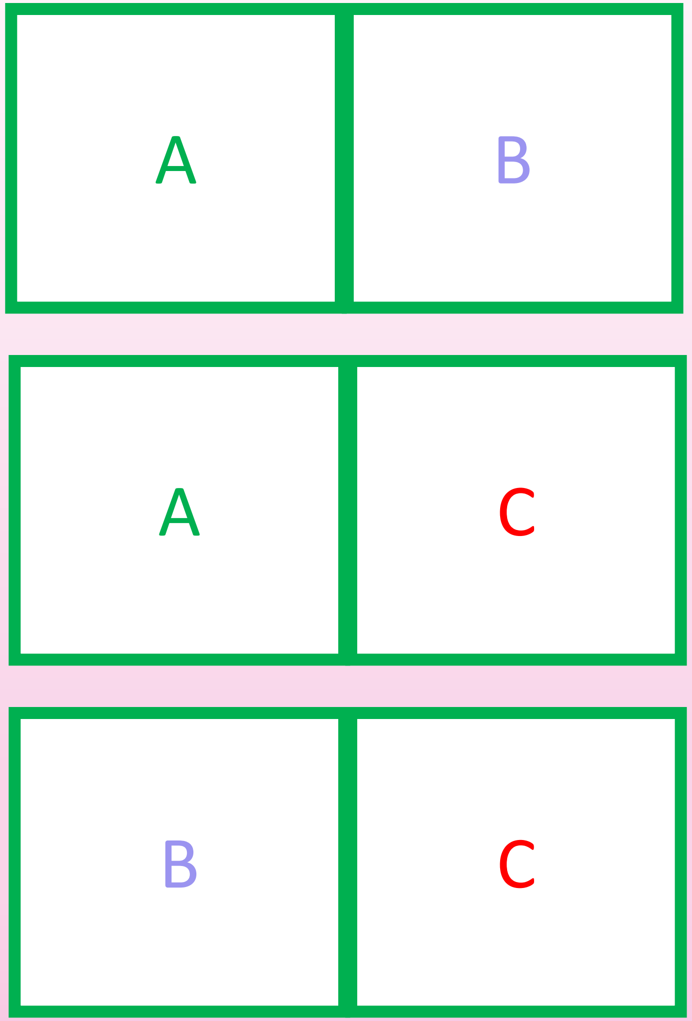
Heat flows until the bodies (systems) have the same energy density, and hence same temperature

Zeroth law of thermodynamics

Take any three systems, A, B and C

If A is in thermal equilibrium with B and is also in thermal equilibrium with C, then B and C must also be in thermal equilibrium

All systems in equilibrium with one another share a common temperature



Summary

Learnt about how temperature scales, heat, thermal equilibrium and systems are defined in thermodynamics

Defined a quantity, heat capacity, which determines how resistant a material is to a change in temperature for a given heat transfer

Defined the zeroth law of thermodynamics – For any three systems, A, B and C: If A is in thermal equilibrium with B and is also in thermal equilibrium with C, then B and C must also be in thermal equilibrium