FYS2160

Fall, 2018

OVERVIEW ON THERMAL AND STATISTICAL PHYSICS

20.08.2018

Thermodynamics

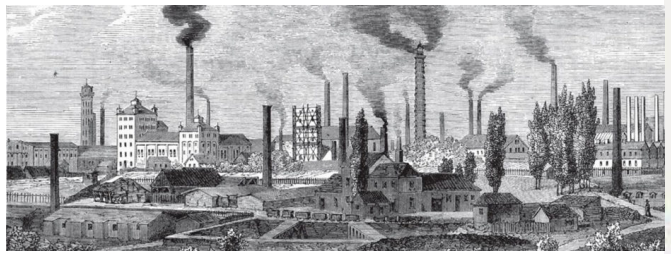
«A theory is more impressive, the greater the simplicity of its premises is, the more different kinds of things it relates and the more extended is its area of applicability. Therefore the deep impression that classical thermodynamics made upon me. It is the only theory of universal content concering which I am conviced that, within the framework of applicability of its basic concepts, it will never be overthrown.»

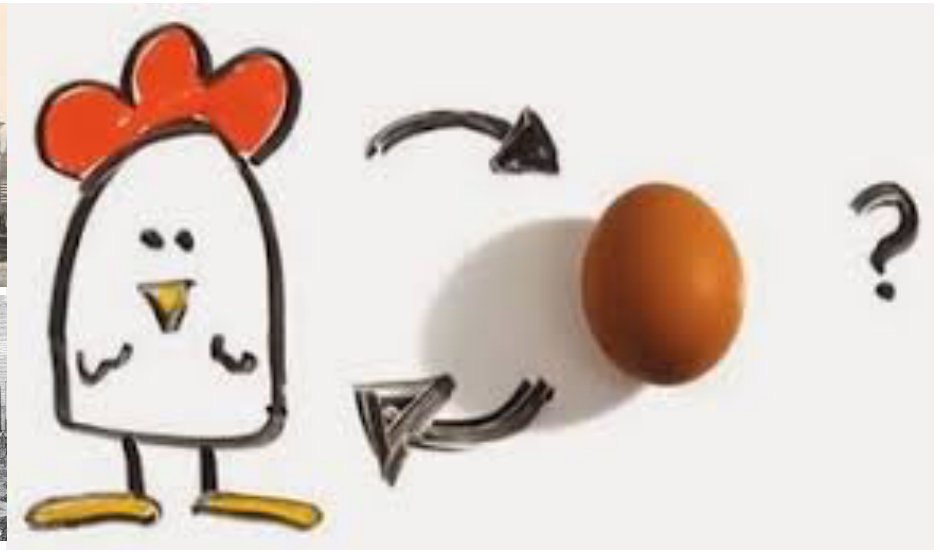
Einstein (taken from Martin J. Klein «Thermodynamics in Einstein's thought», Science , 1967, Vol.157(3788), p.509)

Thermodynamics—Theory of principle

The science that deals with heat Q and work W and properties of matter that relate to Q and W

- *invention* and *trigger* of the Industrial Revolution (1800→..)





$$\Delta U = Q + W$$

$$\mathrm{T}\Delta S \geq \Delta U + P\Delta V$$

$$PV = nRT$$

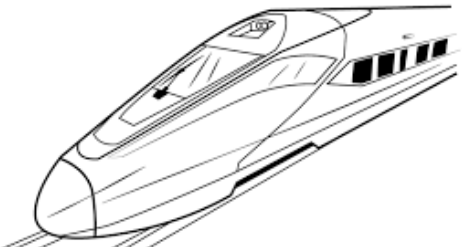
Thermodynamics—Theory of principle

- Based on few empirically observed general properties elevated as thermodynamic principles

  - ❖ 0^{th} law → defines temperature (T)
  - ❖ 1^{th} law → defines energy (U) and energy transformation
  - ❖ 2^{th} law → defines **ENTROPY** (S)
  - ❖ 3^{rd} law → fixes the value of ENTROPY at $T = 0$ Kelvin

- These laws are UNIVERSALLY VALID

Thermodynamic systems—Everywhere



What is a thermodynamic system?

- **Systems**: *the part of the Universe that we choose to study*
- **Surrounding or environment:** *the rest of the Universe*
- **Boundary:** *the surface separating the System from the Surrounding*

A System relative to its surroundings can be:

- **Open**: System can exchange both mass and energy with the Surroundings
- **Closed**: System can exchange only energy with the Surroundings, but NOT mass
- **Isolated**: Neither Mass nor Energy can transfer between the System and the Surroundings

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How do we describe the system:

- A few macroscopic properties:
  pressure, temperature, volume, molar volume, ...

- Homogeneous or Heterogeneous

- State of the system:
  equilibrium or non-equilibrium

- Number of components:
  pure system or composite system

Statistical mechanics – Constructive theory

Invented to *explain* the principles of thermodynamics based on the **atomistic** description of matter – kinetic theory of gases (1870→)

Thermodynamics:

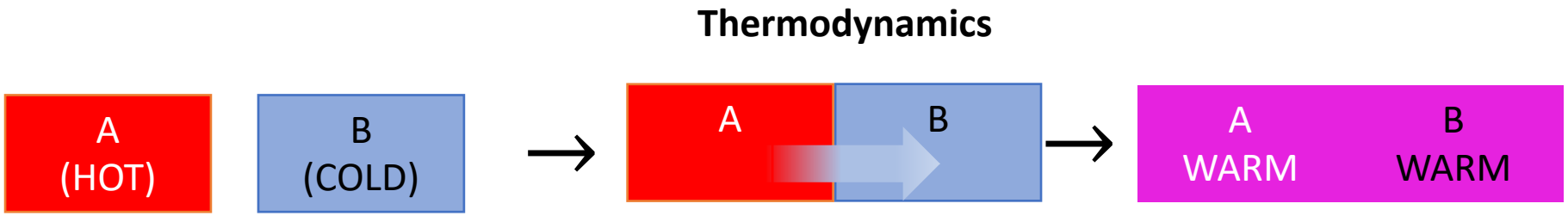
Heat *always* flows *spontaneously* from hot to cold until the same *temperature* is reached

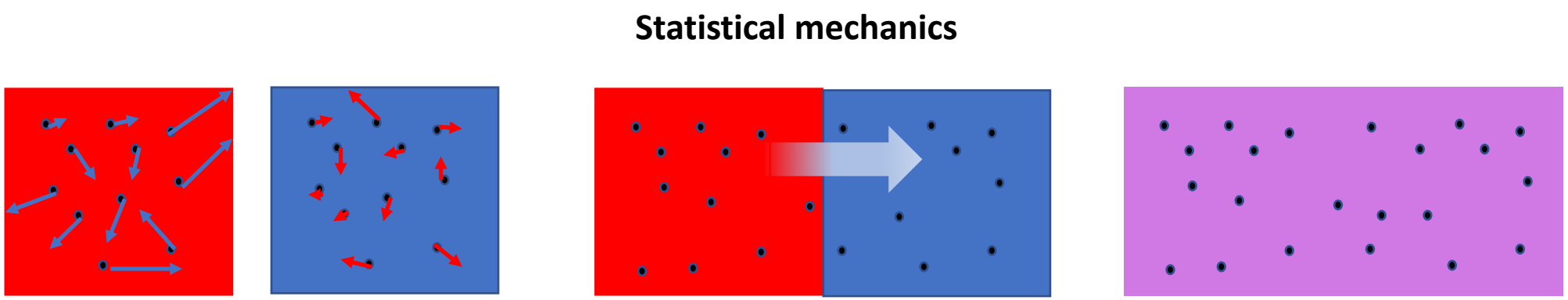
Statistical mechanics:

Most likely, heat flows spontaneously from hot to cold because the atoms of the hot system have more kinetic energy. Therefore there is a natural tendency that, by mutual collisions, «hot» atoms loose some of their energy while «cold» atoms gain some kinetic energy until everyone has *the same kinetic energy,* **on average**

Statistical mechanics – Constructive theory

Invented to *explain* the principles of thermodynamics based on the atomistic description of matter

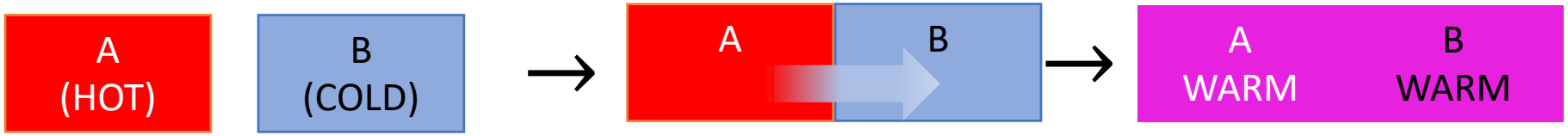




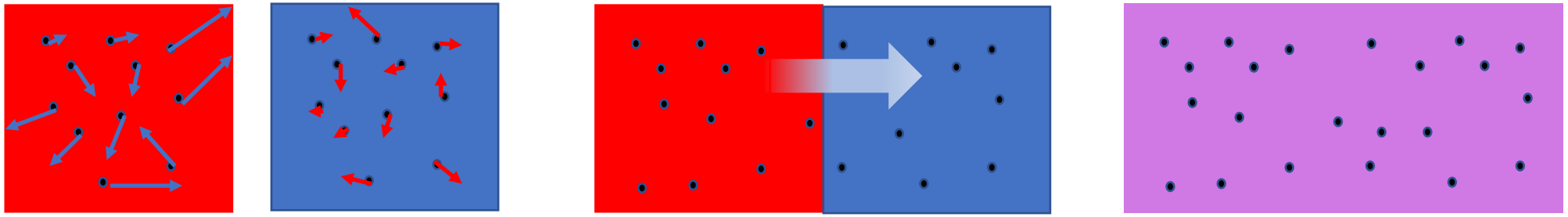
Statistical mechanics – Constructive theory

Invented to *explain* the principles of thermodynamics based on the atomistic description of matter

***Thermodynamic process*: Sponteneous relaxation to thermal equilibrium**



Sponteneous *heat diffusion* until they reach the equipartition of energy



Statistical mechanics – Constructive theory

- Frames the validity of the thermodynamic principles

  Importance of statistical fluctuations

- New discoveries:

  exotic new states of matter Bose-Einstein condensation, superconductors...

- Based on particle *modelling*

  Statistial Models of matter: Ideal gas model, molecular dynamics, Ising model..

Thermodynamics--Statistical mechanics: Correspondence

- «Atoms» = microscopic particles, neutral atoms, electrons, photons, phonons, M&Ms ...so *particles* in general

Thermodynamic system (T,P,V,N..)	**Ensemble of particle configurations at (T,P,V,N...)**
Equilibrium state (macrostate)	Number of configurations (multiplicity of microstates)
Free energies	Partition functions: weighted sum over the number of microstates

Prototype Models in statistical mechanics

Gases: Ideal gas

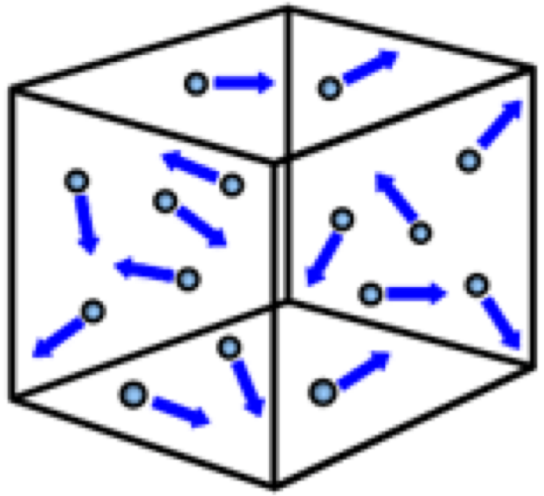
Solid crystals: Einstein model

Magnetism: Ising spin model

Cosmic radiation: Black body radiation model

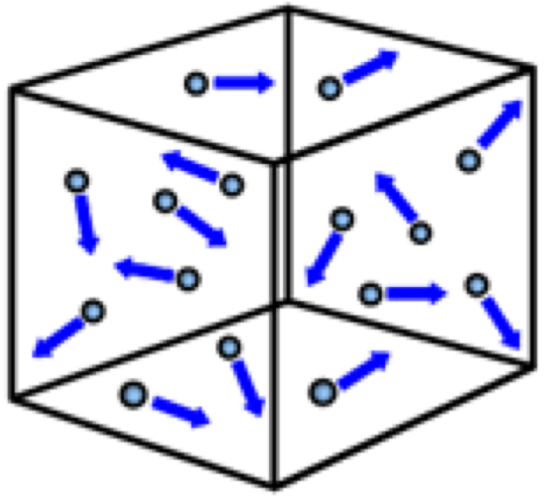
Dilute gases in a box: Ideal gas model

- Low density of particles
- Newtonian particles
- No interaction forces
- Perfect collisions



Dilute gases in a box: Ideal gas model

Predictions from the model

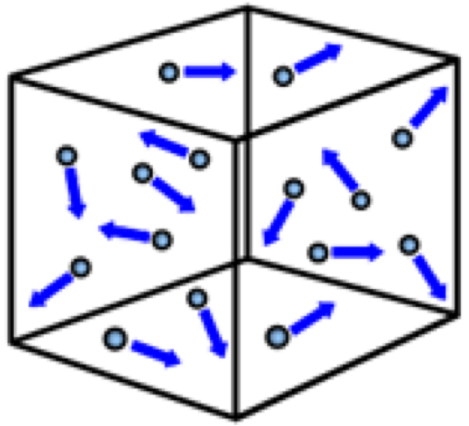


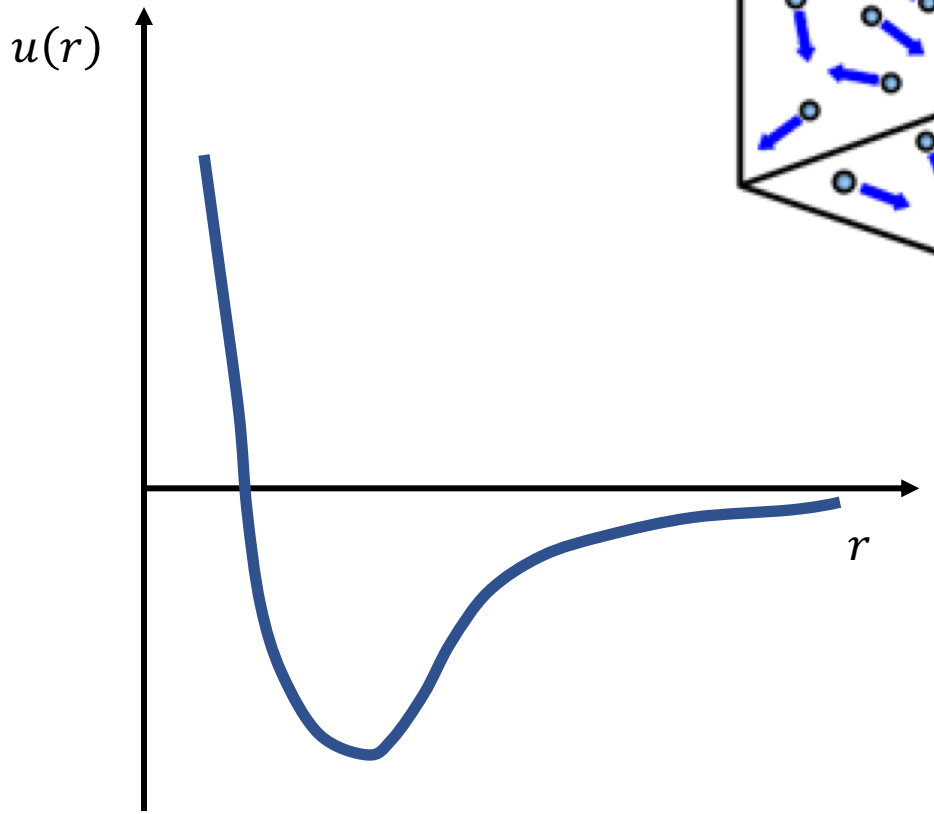
- Pressure, Temperature and the equation of state
- What is the **entropy** of the gas
- How does the gas reponds to external forces?

Real gases in a box: Van der Waal gas model

- Newtonian particles
- Weak interaction
- Lenard Jones potential (1924)

$$u(r) = 4\epsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right]$$

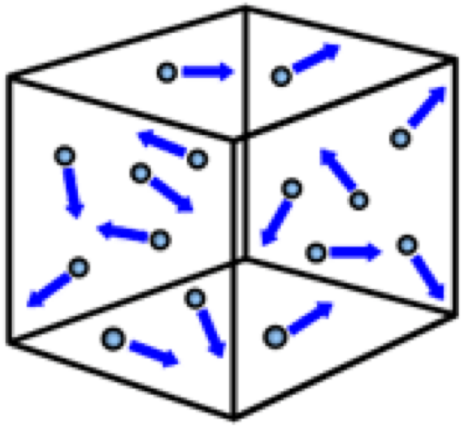


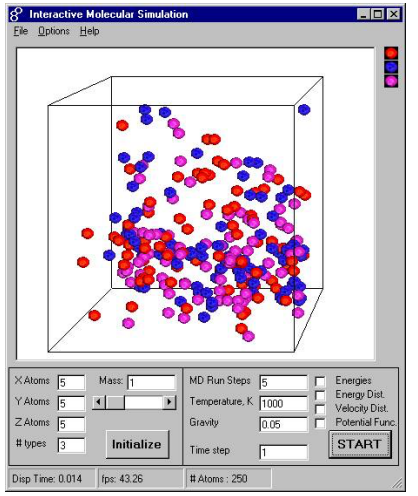


Real gases in a box: Molecular dynamics

- Newtonian particles
- Weakly interaction
- Lenard Jones potential (1924)

$$u(r) = 4\epsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right]$$

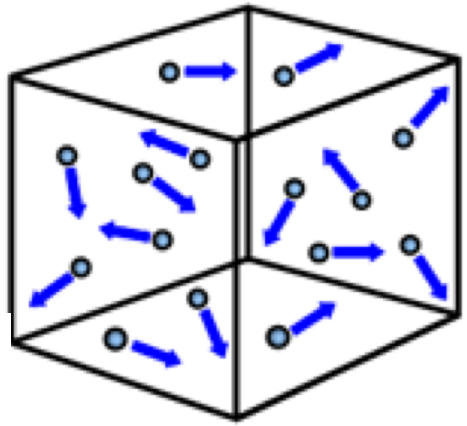




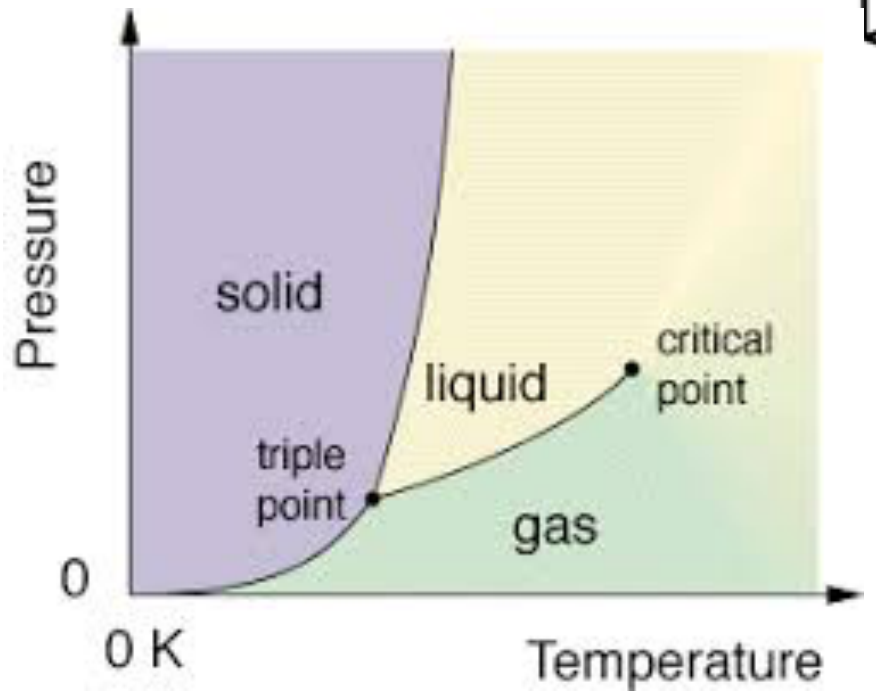
http://physics.weber.edu/schroeder/md/InteractiveMD.html

Real gases in a box: Van der Waal gas model

Model Predictions

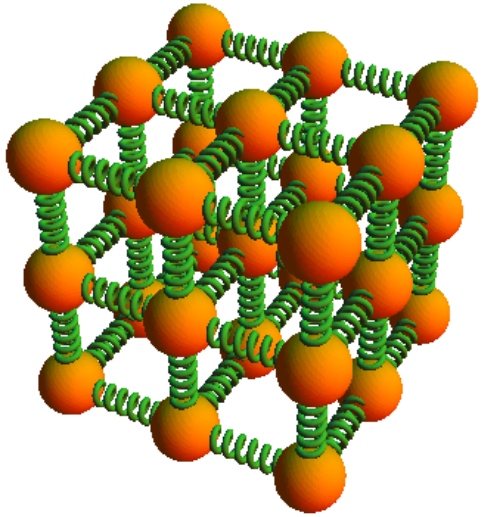


Liquid-gas phase transition



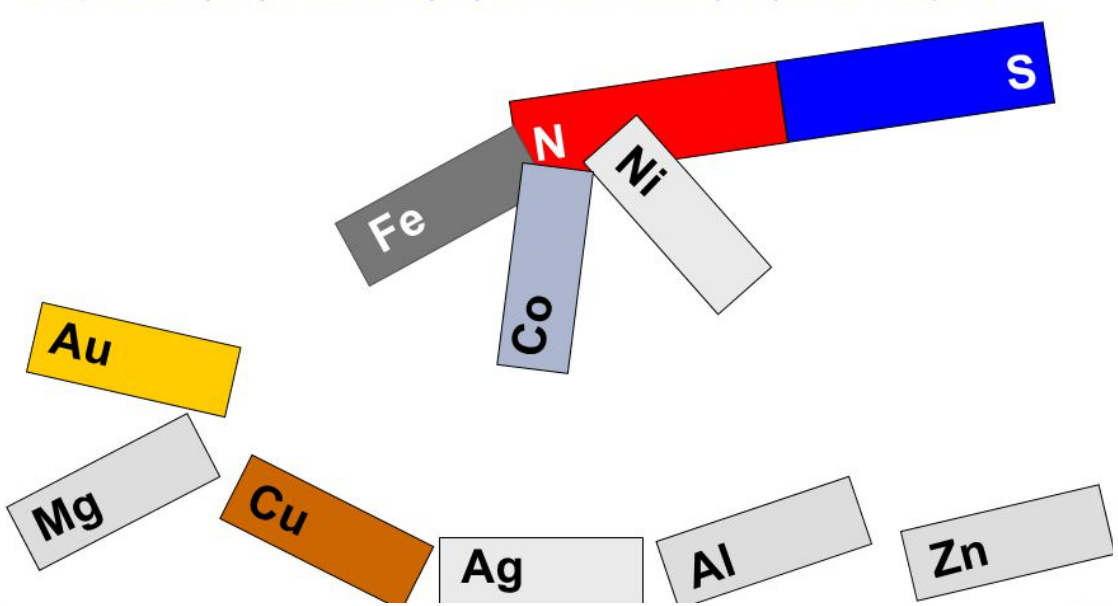
Solids: Einstein model

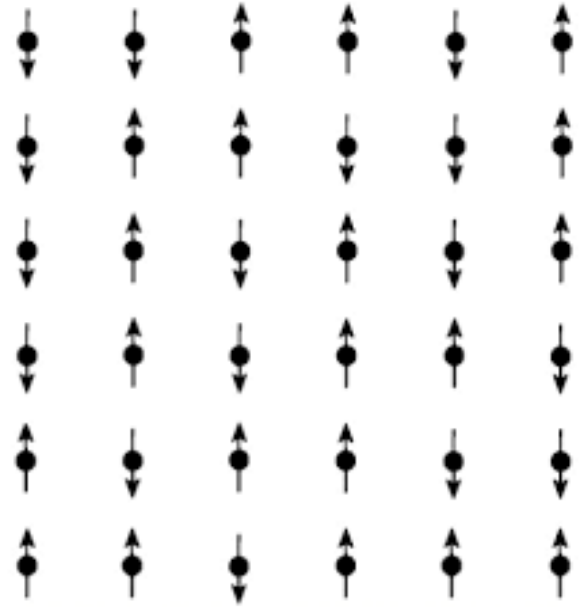
- Particles can oscillate indendently along each lattice direction

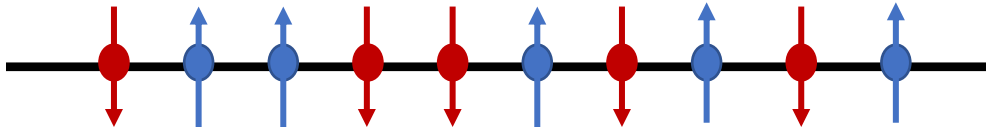


- Harmonic oscillators

Magnetism: Ising Spin Model



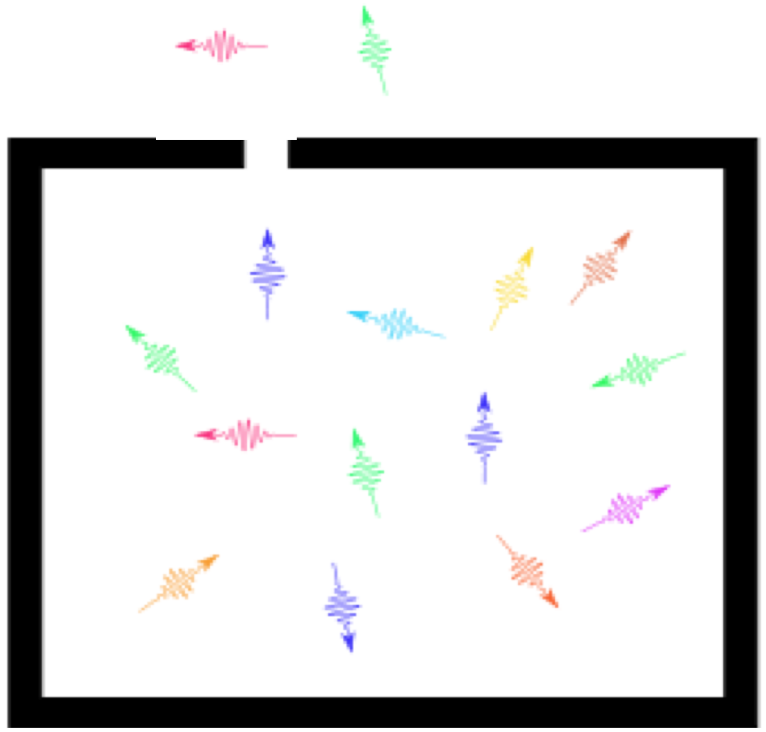




Cosmic radiation: Black-body radiation

- Quantum ideal gas of photons

- Quantum harmonic oscillator



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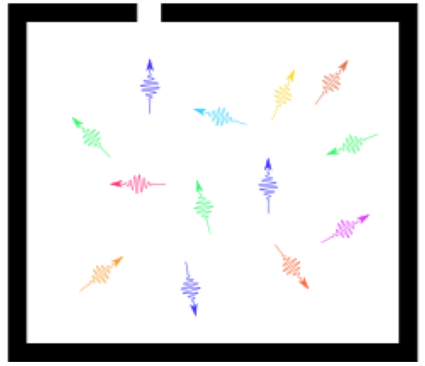

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