General principles of modern physics. Energy minimum. Absolute speed (speed of light). Linear and angular momentum. Spin of the particle. Pauli exclusion principle. Entropy.

11.09.2020

Topics

- Speed of light and its importance

- Energy of a system
- Energy minimum principle
- Energy barriers and metastability
- Spin of a particle
- Pauli exclusion principle and how matter is formed
- Entropy

Speed of light

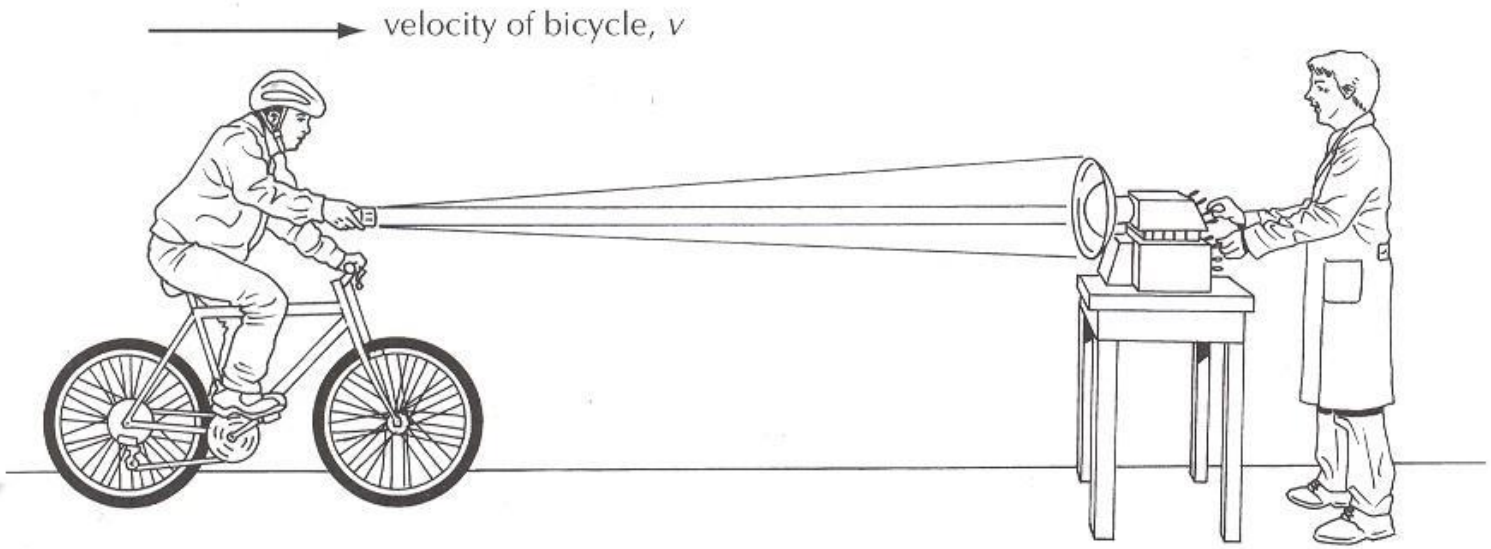
Speed of light – important facts

1. Speed of light is $3*10^8$ m/s
2. Nothing (even information) can travel faster than the speed of light
3. Speed of light is independent from the frame of reference
4. Time is relative

1. Speed of light

- 300 000 km/s equals to:
- 300 000 / 40 000 = 7,5 roundtrips around the earth in 1 s.
- ~130 ms response (ping) time over internet when visiting a page in New-Zealand ;)
- Sun -> Earth distance at light speed is 8 minutes
- Nearest star is at distance of 4.3 light years (distance travelled by light in one year). How many km-s is it ?
- Most distant visible place in the universe is ~13 billion light years away

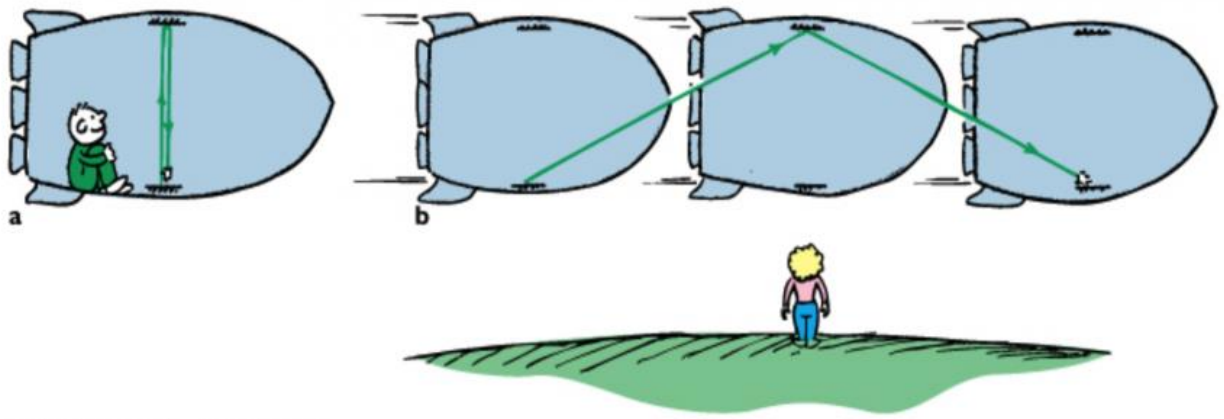
Nothing can go faster



Light leaves the torch at velocity *c* with respect to the person on the bicycle.

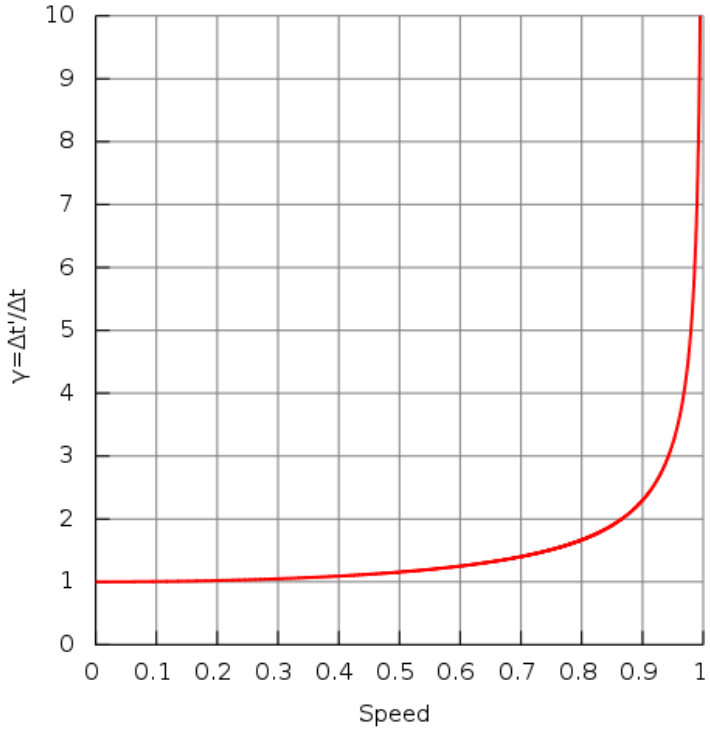
Light arrives at the observer *at velocity c* (not *v* + *c*).

Time is relative – speed changes the preceived time

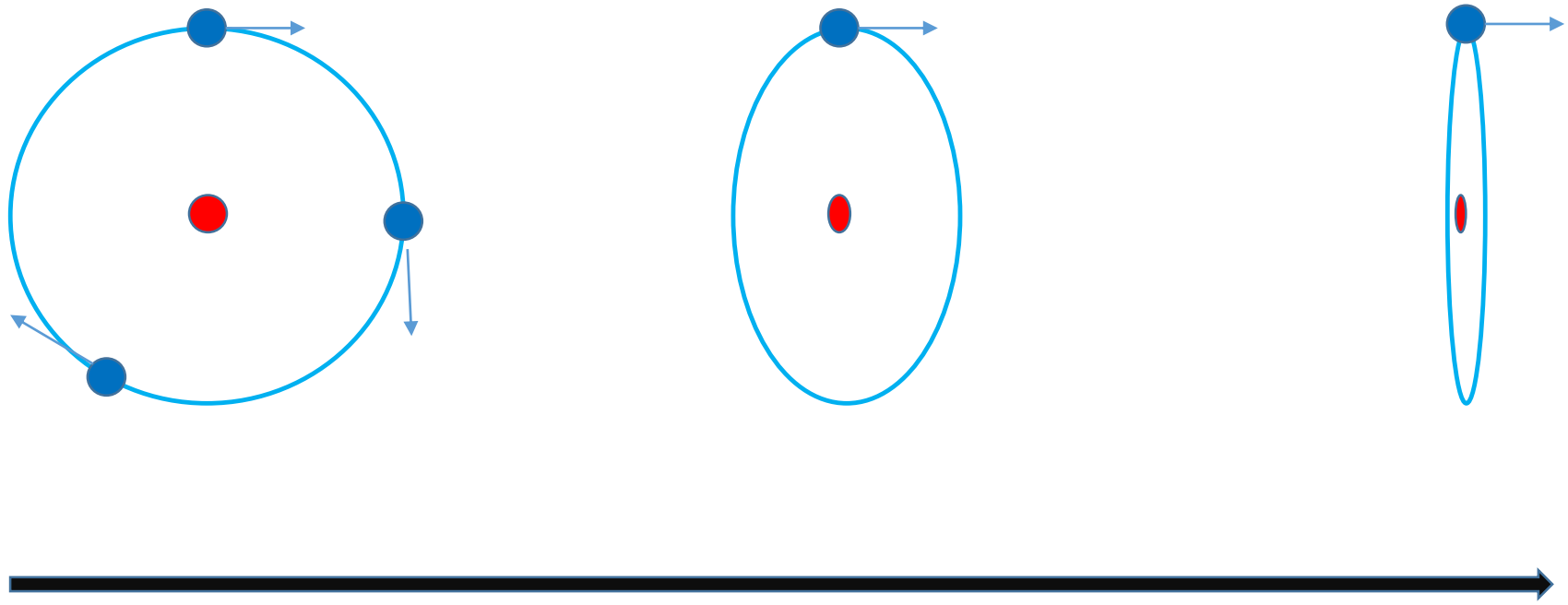


$$t = \frac{t_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

$$\gamma \equiv \frac{1}{\sqrt{1 - v^2/c^2}}$$



Time and space distortions



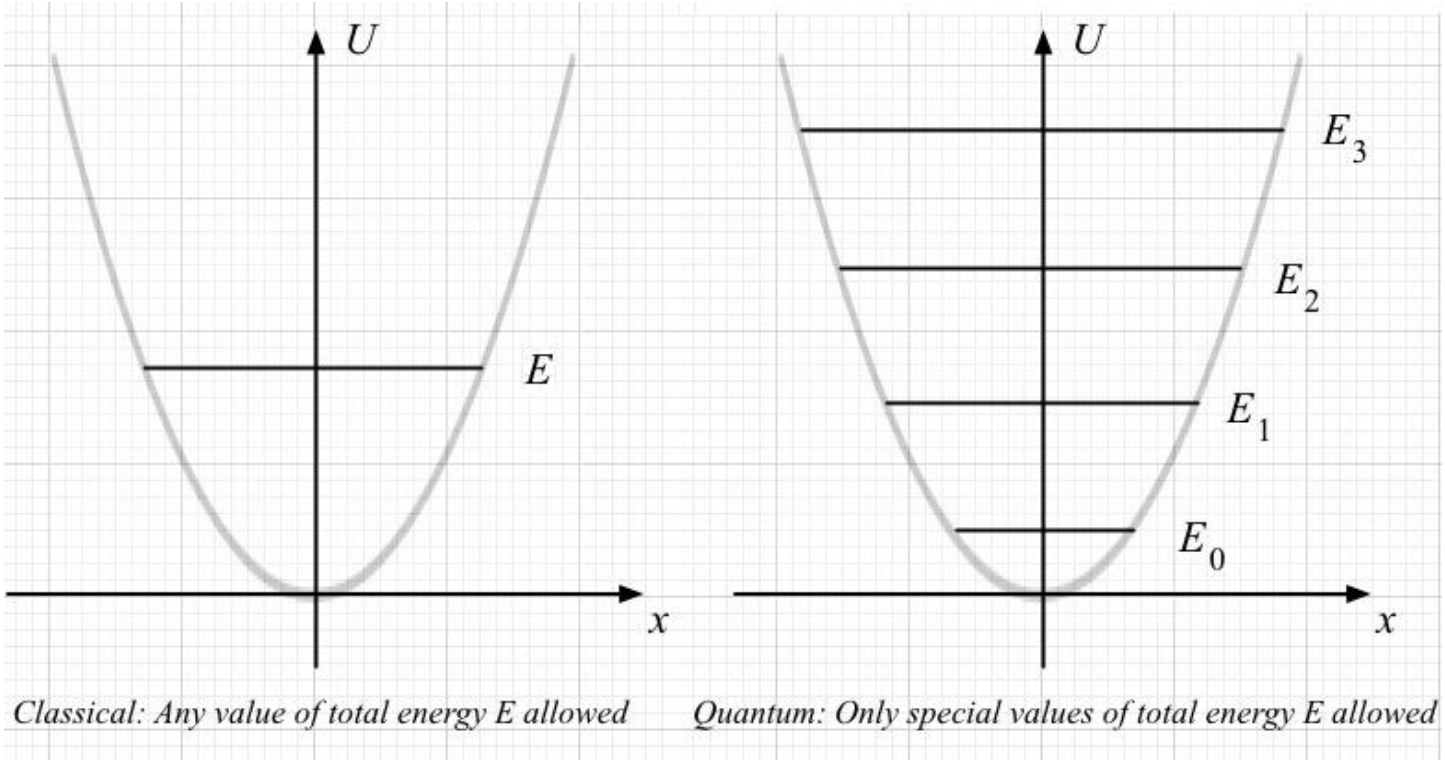
0 m/s

speed

300 000 m/s

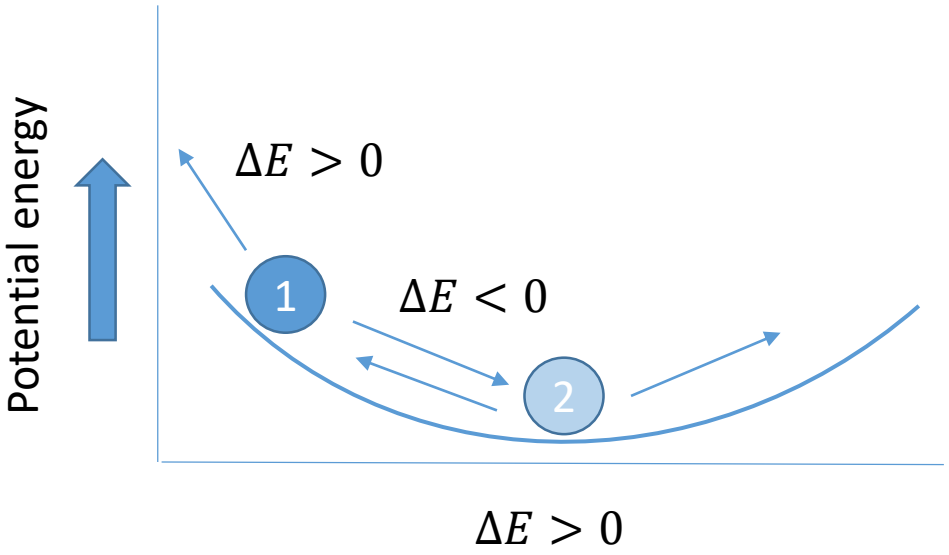
Energy levels

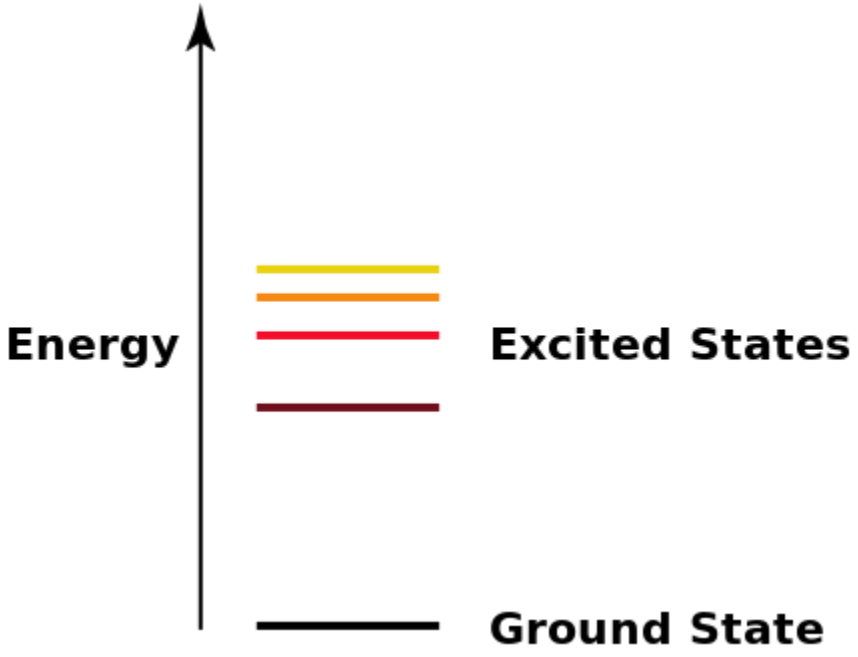
System energy levels: classical and quantum



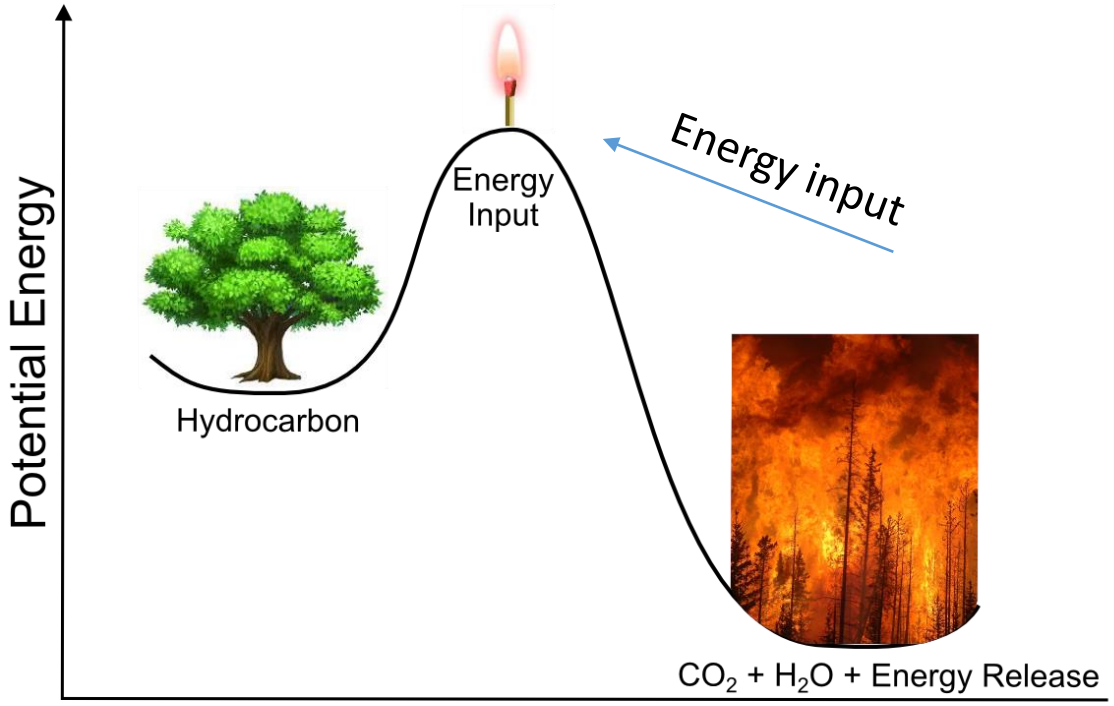
Energy minimum

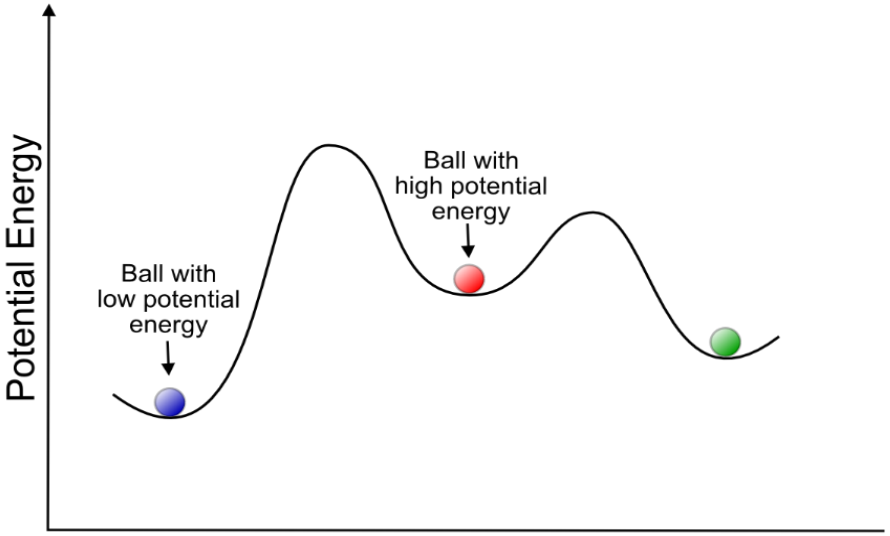
- for a closed system, with constant external parameters and entropy, the internal energy will decrease and approach a minimum value at equilibrium.

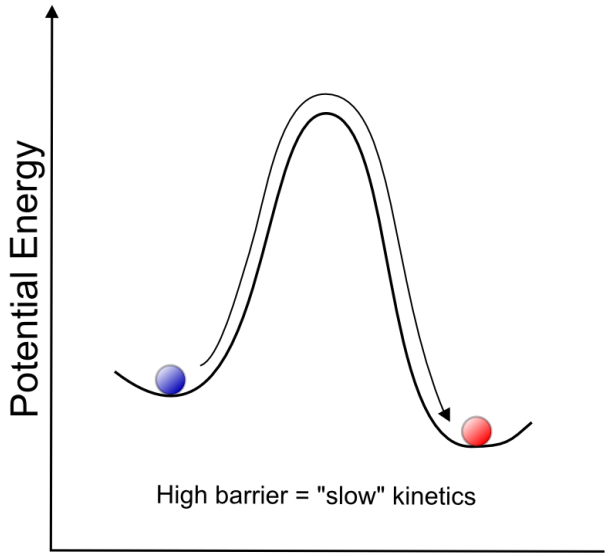


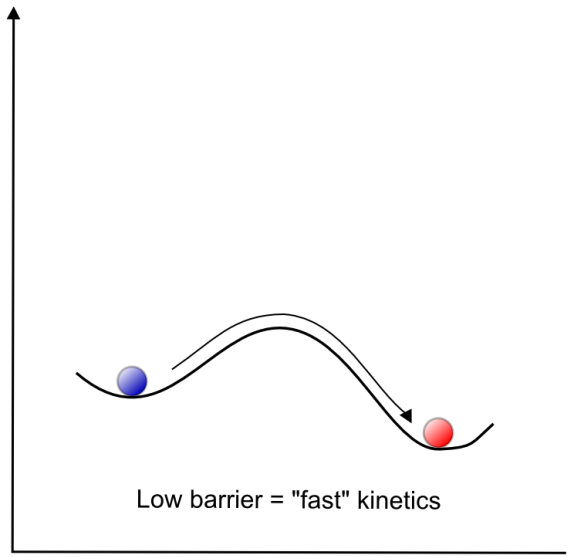


Energy barriers



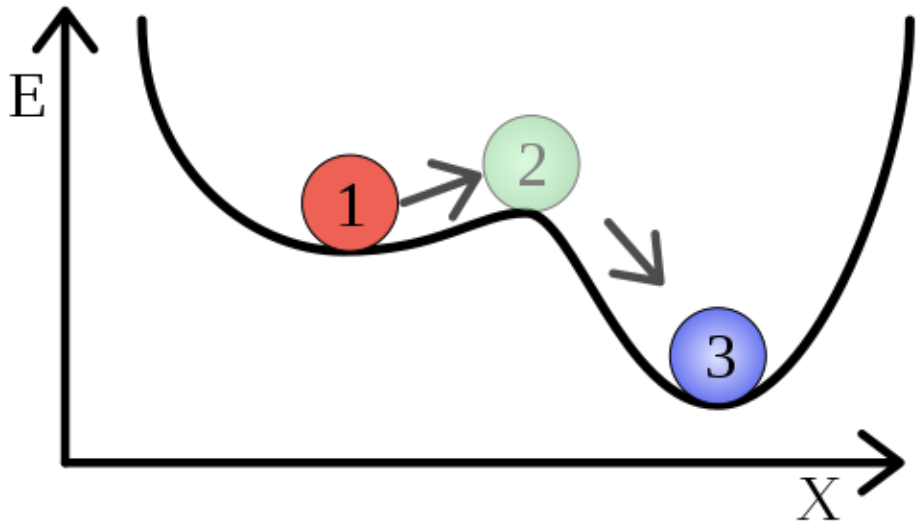




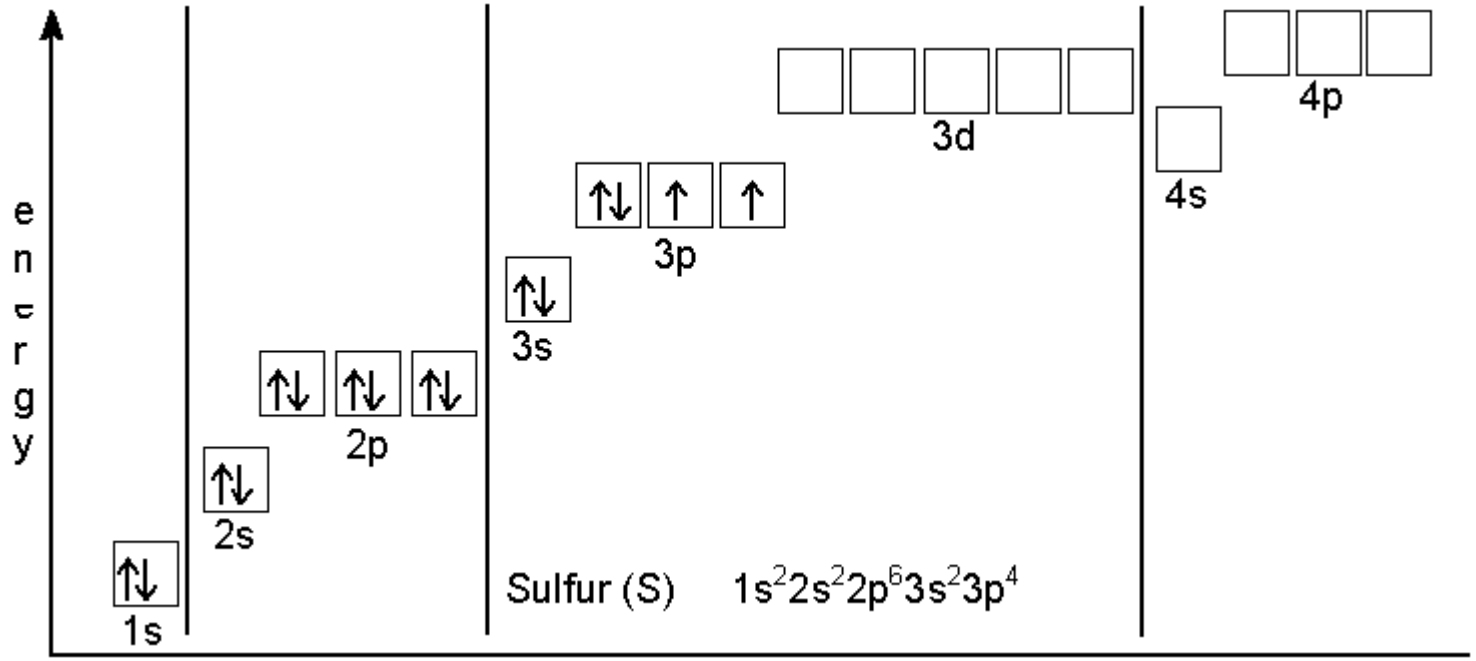


Meta-stabiliy

Very small disturbances can cause state to transition into stable state.



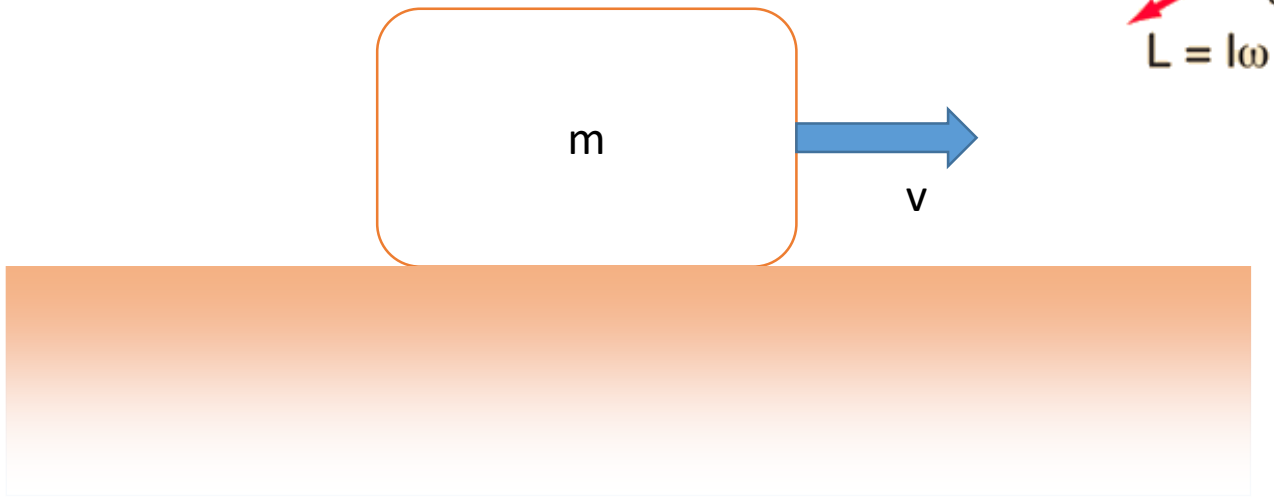
Energy levels of an atom – not a classical case

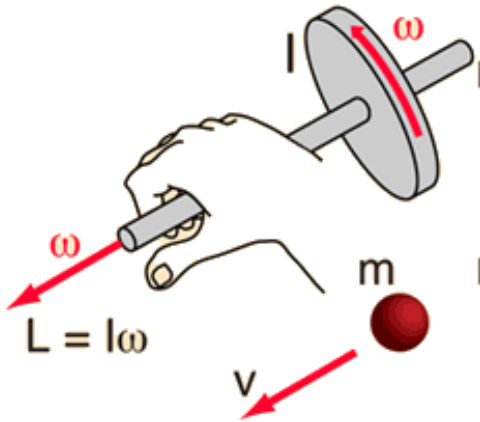


Pauli exclusion principle

Linear momentum <--> Angular momentum

$$p = m \cdot v \left[\frac{kg \cdot m}{s}\right]$$

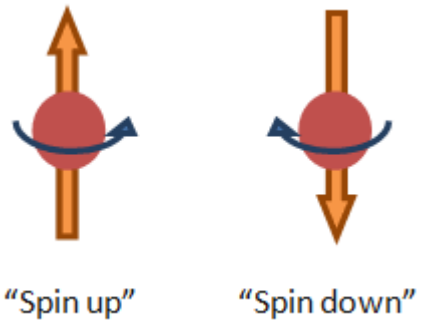




Angular Momentum	=	Moment of Inertia	x	Angular Velocity
L	=	I	x	ω
Linear Momentum	=	Mass	x	Velocity
p	=	m	x	v

The x implies simple multiplication here.

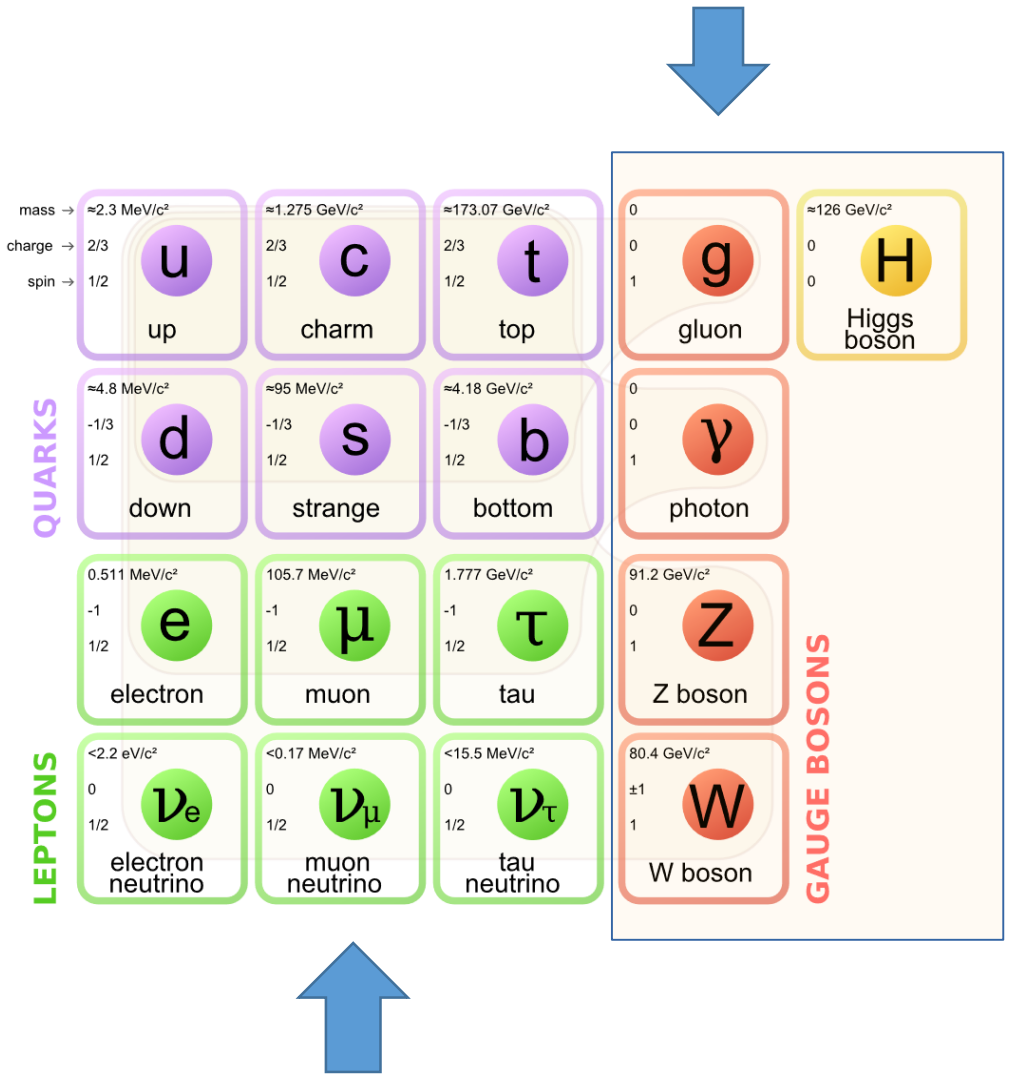
Spin of a particle



- Gives rise to magnetic moment, bigger than possible by approximation with a spinning object

- Can only take discrete values and orientations.
- Every fermion(electron) has a spinn of 1/2 !
- Gives rise to Pauli explusion principle

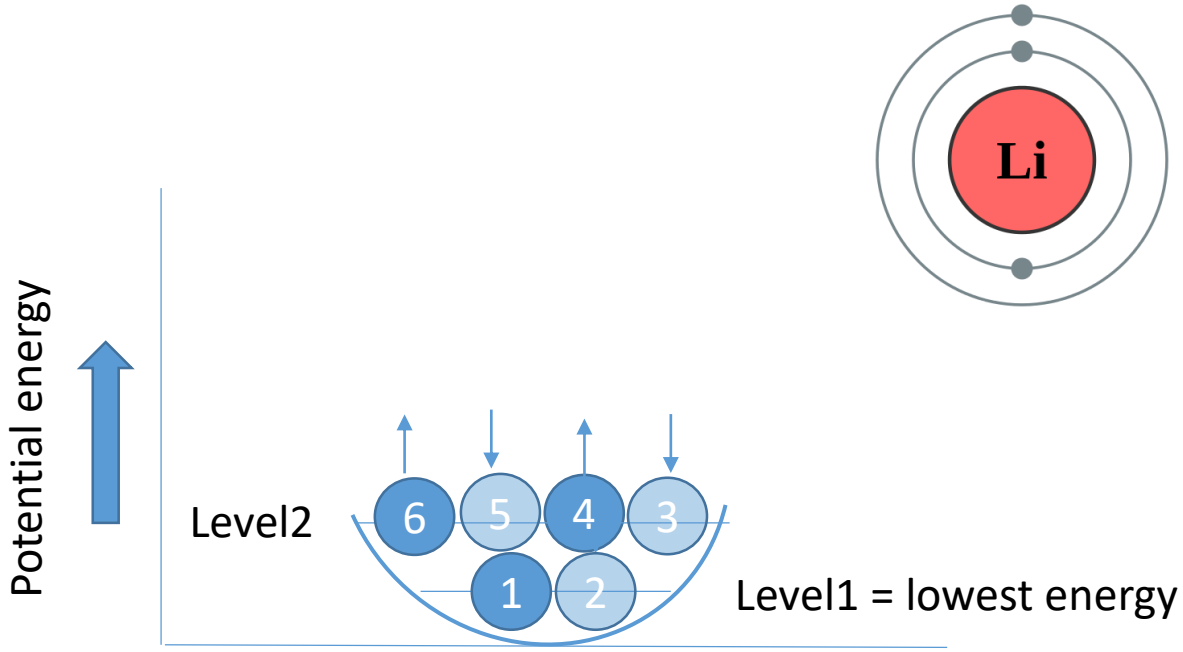
Spin 1

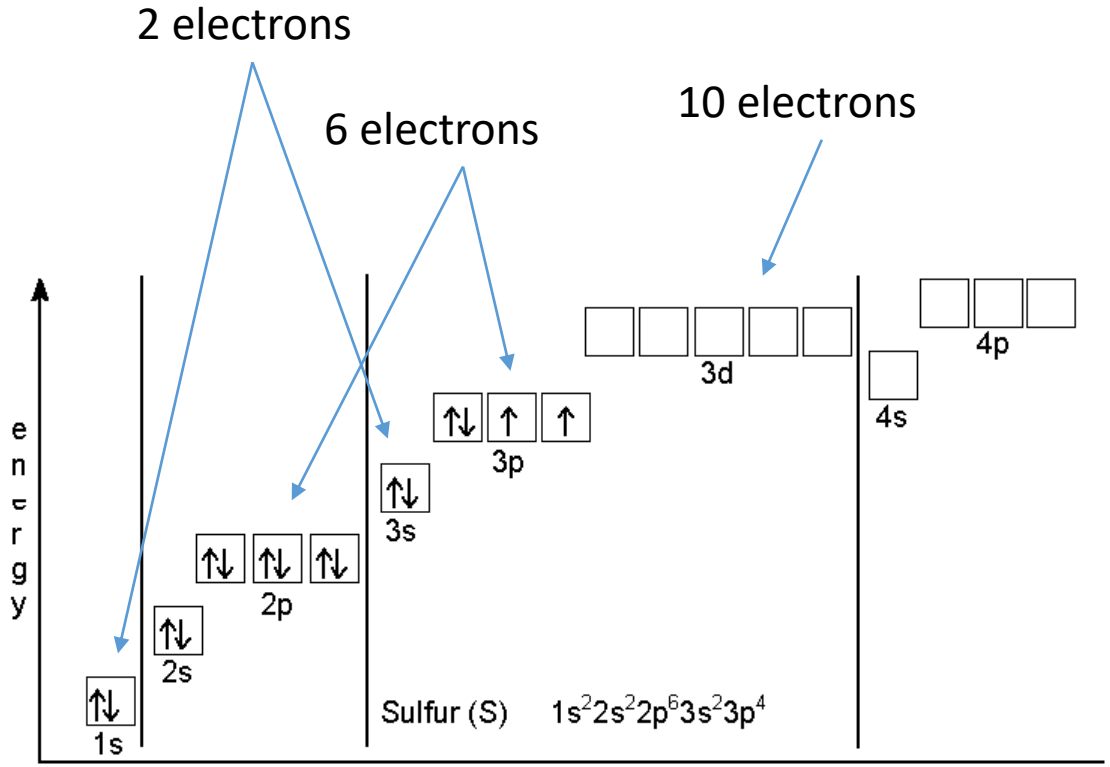

mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
QUARKS
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
LEPTONS
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
GAUGE BOSONS

Spin ½

Pauli exclusion principle

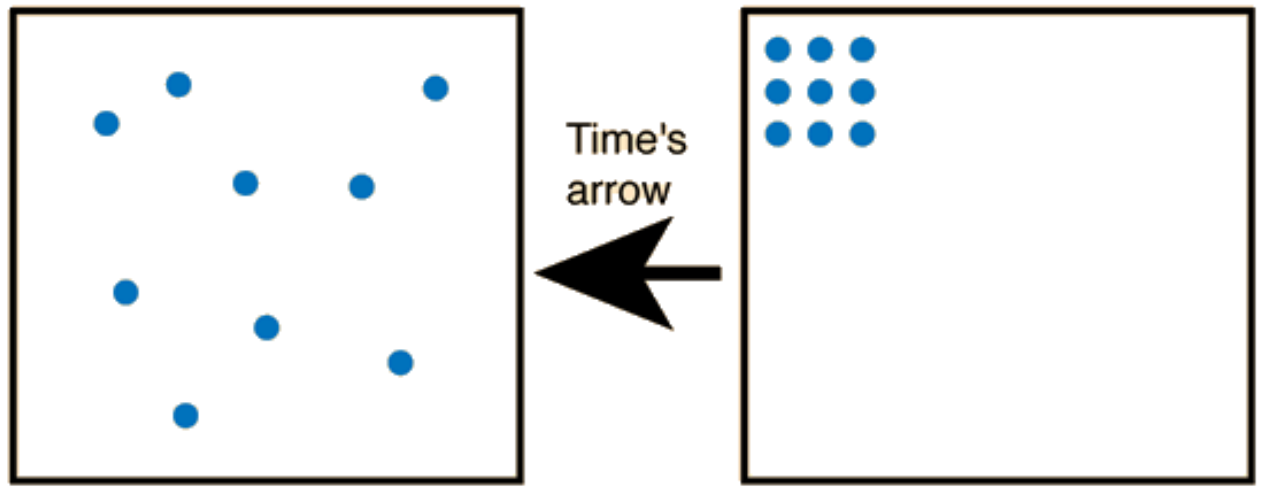
- Only maximum of two fermions with opposite spin states can occupy one energy state



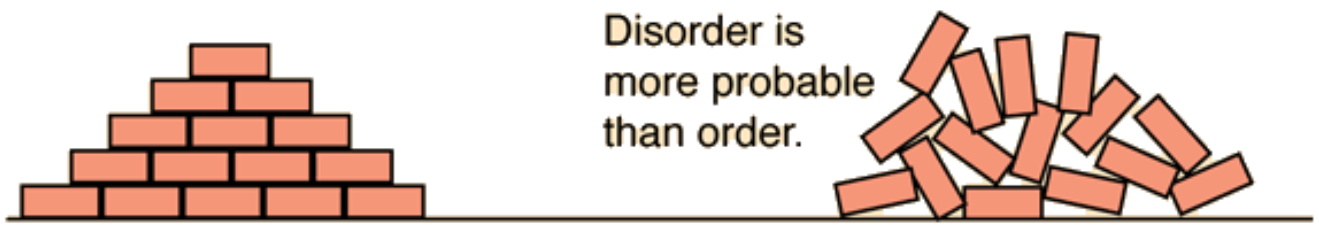


What if this principle didnt work ?

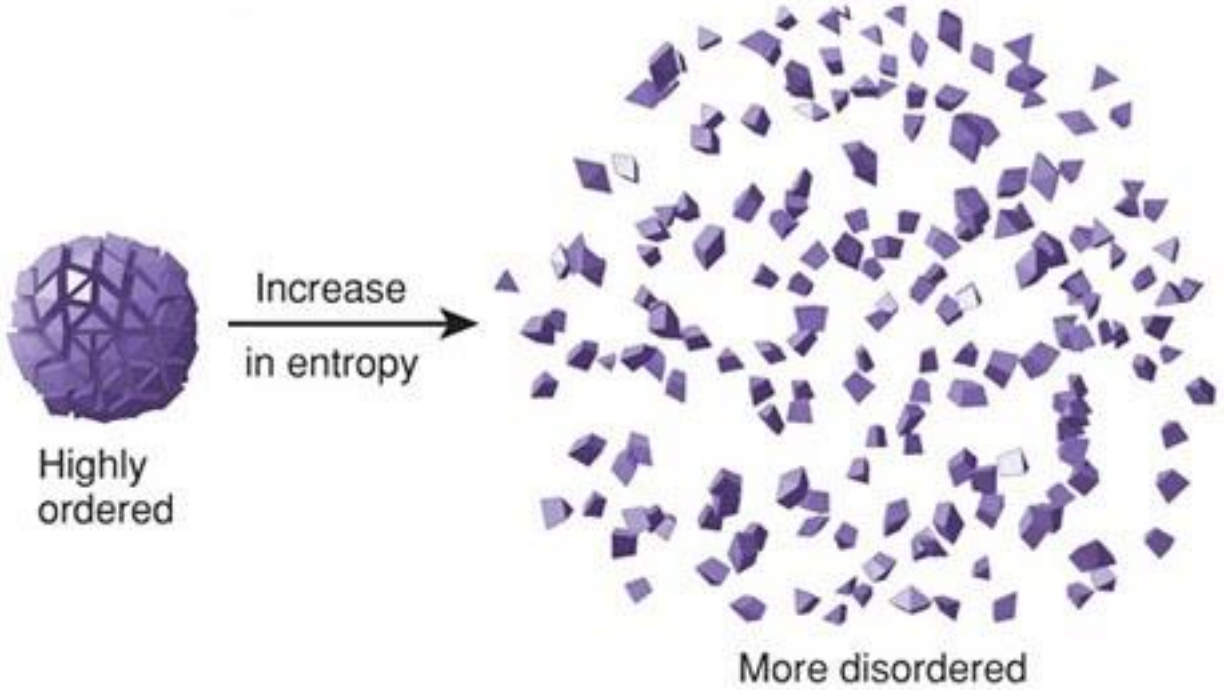
If the particles represent gas molecules at normal temperatures inside a closed container, which of the illustrated configurations came first?

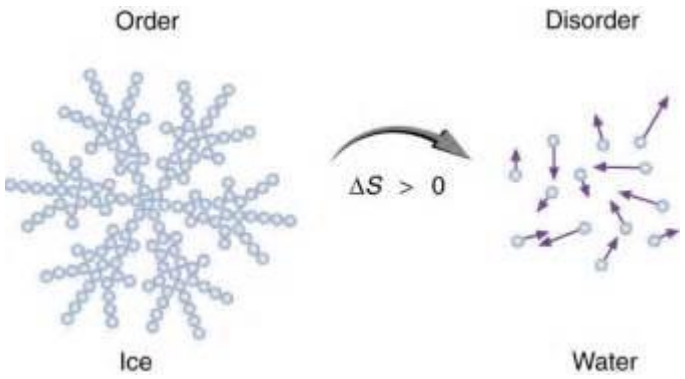


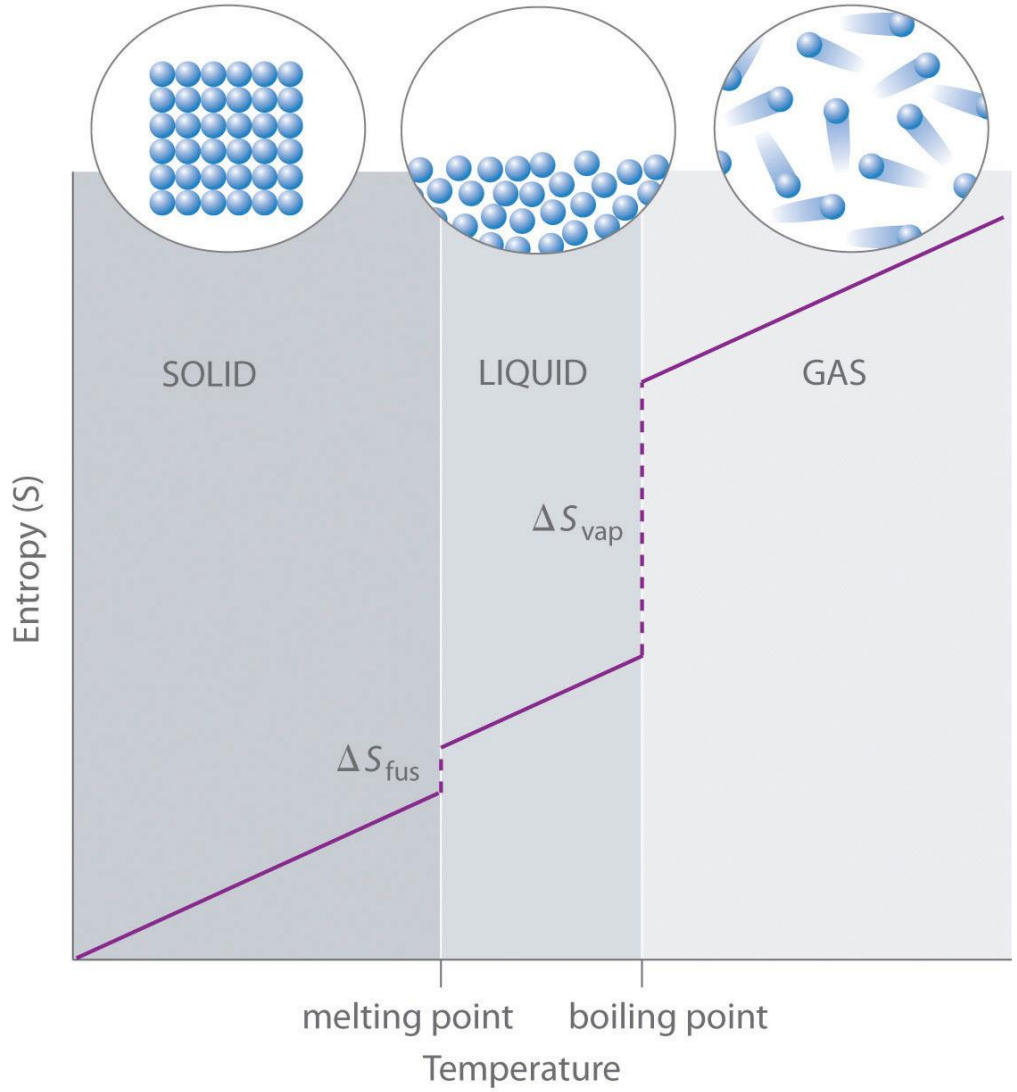
If you tossed bricks off a truck, which kind of pile of bricks would you more likely produce?



Entropy


Increase
in entropy
Highly
ordered
More disordered

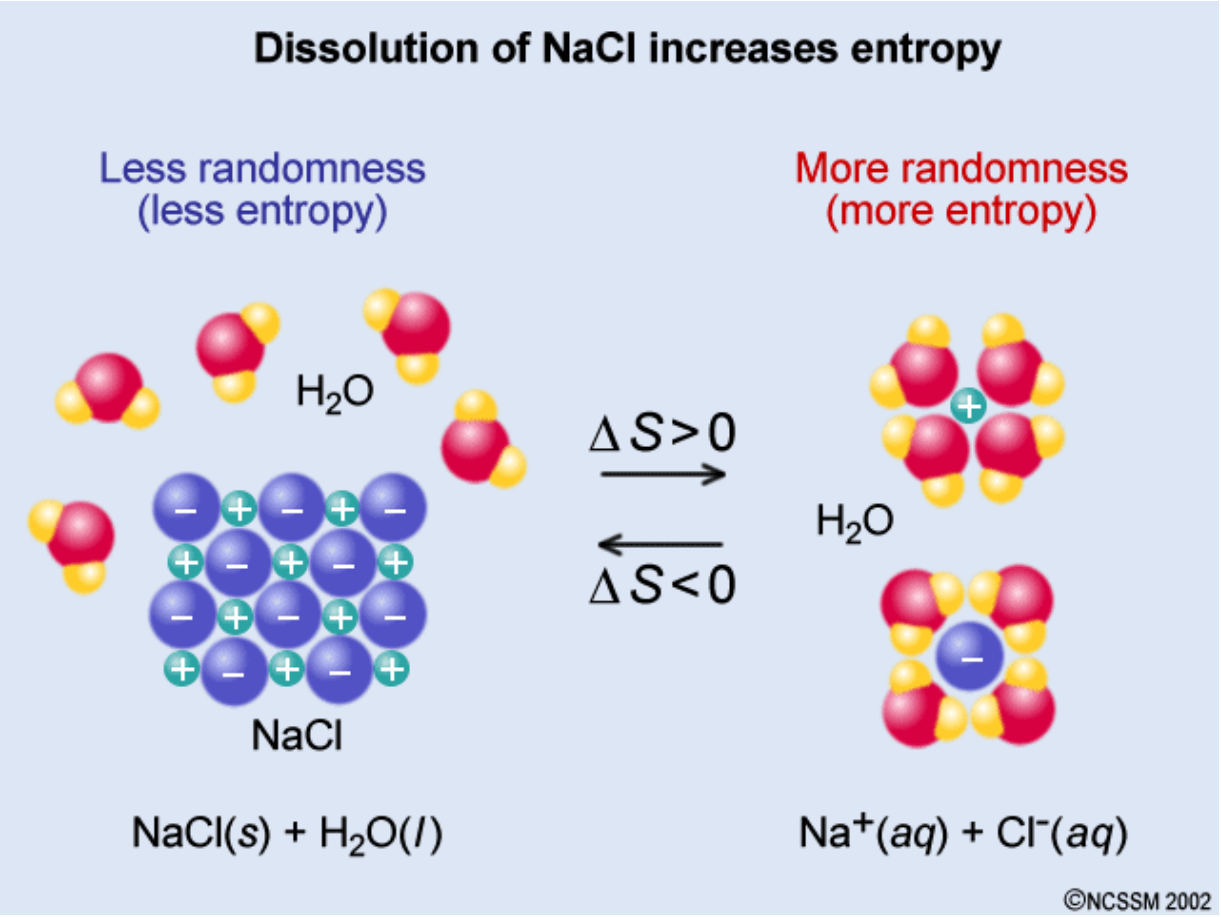

Order
Disorder
ΔS > 0
Ice
Water


SOLID
LIQUID
GAS
Entropy (S)
ΔS vap
ΔS fus
melting point
boiling point
Temperature

Entropy increase by mixing substances

$$S = k \cdot \ln(W)$$

- Bolzmann constant k=1.38065 × 10^{-23} J/K.
- W = number of possible microstates
- Natural processes move in the direction of entropy increase.
- System tries to find Macrostate with most number of Microstates



Why your room never turns to order spontaneously ?