

## Counting states

Phase space

$$Z(E, N, V)$$

Stirling formula

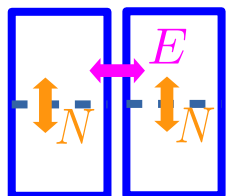
$$\ln N! \approx N \ln N - N$$

Equilibrium

$$\frac{\partial}{\partial x} S(x) \stackrel{!}{=} 0$$

$$\frac{\partial S_1}{\partial V_1} = \frac{\partial S_2}{\partial V_2} = \frac{p}{T}$$

$$\frac{\partial E}{\partial S} = T$$



$$\frac{\partial E}{\partial N} = \mu$$

$$E = \frac{d}{2} k_B T N$$

Quantum corrections  
Extensivity

$$S = k_B \ln Z$$

$$\frac{1}{T} = \left( \frac{\partial S(E, N, V)}{\partial E} \right)$$

## Microcanonical Ensemble

Thermodynamic potentials

$$dS \geq \frac{1}{T} dE - \frac{\mu}{T} dN + \frac{p}{T} DV$$

Legendre transform  
 $(E, N, V) \leftrightarrow (T, \mu, p)$

(Helmholtz) Free Energy  
Gibb's (Free) Energy

$$F(T, N, V) = U - TS$$

$$G(T, N, p) = U + pV - TS$$

**2<sup>nd</sup> Aim:**  
Derive ideal gas equation

Heat  $E$

Work  $V$

Mass  $N$

**1<sup>st</sup> Aim:**  
Proof the 3 laws of thermodynamics

## Canonical Ensemble

$$e^{-\beta H}$$

Saddle point approximation

$$\frac{\partial F}{\partial N} = \mu$$

$$\frac{\partial F}{\partial T} = -S$$

$$\frac{\partial F}{\partial V} = -p$$

## Quantum statistics

Fermi-Dirac statistics

Bose-Einstein condensation

Planck's law  
(Black body radiation)  
Ising model

## Grand Canonical Ensemble

$$z = e^{\beta \mu}$$

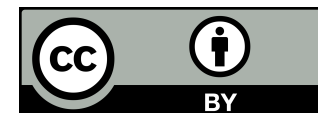
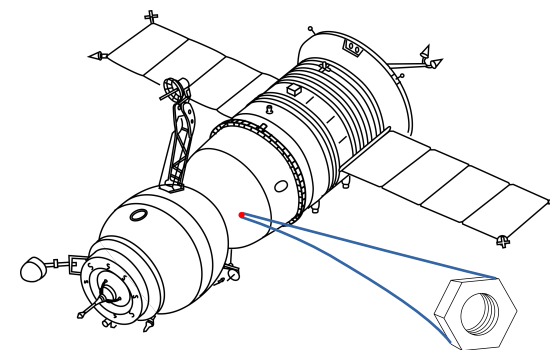
$$Z(T, \mu, V) = \sum_N z^N Z(T, N, V)$$

**3<sup>rd</sup> Aim:**  
Probability factors for (grand) canonical ensembles

Maxwell's velocity distribution

Ideal (classical) gas

Effusion



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