Entropy and probability:

\[ S = k_b \ln \Omega \]

where

\( S \) is entropy

\( \Omega \) is the number of micro states available for a state of a system (both energy and position states)

\( k_b \) is the Boltzmann constant: \( k_b = \frac{R}{N_a} \)

Entropy is:

- state function: change depend only on the final and initial states
- additive: \( S = S_1 + S_2 \)
  
  for \( N_a \) molecules \( S = N_a k_b \ln \Omega = R \ln \Omega \) (units of entropy: J/K)
- \( S(T=0) = 0 \), and is always positive and increases with \( T \)
2 Euro:
This coin depicts a scene from a mosaic in Sparta (third century AD), showing Europa being abducted by Zeus, who has taken the form of a bull. Europa is a figure from Greek mythology after whom Europe was named.
Microstates and macrostates

Total # of microstates: 8
Each microstate: equally probable
Macrostate "all heads": 1 microstate, P=1/8
Macrostate "2 heads, one tail": 3 microstates, P=3/8
Macrostate "all-tails or all-heads": 2 microstates, P=2/8=1/4
Macrostate "not all-tails and not all-heads": 6 microstates, P=6/8=3/4
A family has 2 children.

1. What is a probability that one of them is a boy?

Answer: 3/4:
Microstates:   BG, GB, BB, GG
Macrostate:   BG, GB, BB

2. What is a probability that the older one is a boy?

Answer: 1/2
Microstates:   BG, GB, BB, GG
Macrostate:   BG, BB
Energy and entropy

4 particles, each particle has average kinetic energy: \[ E = \frac{3}{2} RT \]

Total \( E_t \) of 4 particles: \[ E_t = 4 \cdot \frac{3}{2} RT = 6RT \]

Assume we have only quantized levels of energy for each particle:

\[ 45R, 30R, 15R, 0 \]

How many different arrangements yield total \( E_t \)?

Link to Entropy Model
Entropy and heat:

\[ \Delta S = \frac{Q}{T} \]

Exotermic: heat out, entropy decreases
Endothermic: heat in, entropy increases

\[ \Delta S = \int_{i}^{f} \frac{dQ_r}{T} \]
Second law of thermodynamics

In any spontaneous process the entropy of the universe must increase

Universe = system + surroundings

\[ \Delta S = \Delta S_{sys} + \Delta S_{sur} > 0 \]
Experimental basis for the second law of thermodynamics

Heat engines and Carnot cycle:

**The Carnot Cycle and the Efficiency of Engines**

Efficiency:

\[ e_{\text{max}} = 1 - \frac{T_{\text{env}}}{T_{\text{eng}}} \]

For \( T_{\text{eng}} = 600 \text{K} \) and \( T_{\text{env}} = 300 \text{K} \)

\[ e_{\text{max}} = 50\% ! \]
It is impossible to construct a device that will transfer heat from a cold reservoir to a hot reservoir in a continuous cycle with no net expenditure of work

Energy dissipation and 2nd law example: [The Second Law applet](#)
Entropy, macroscopic quantities, and the second law

\[ \Delta S = \int_{i}^{f} \frac{dQ_r}{T} \]

For \( T = \text{const} \):

\[ \Delta S = \int_{i}^{f} \frac{dQ_r}{T} = \frac{1}{T} \int_{i}^{f} dQ_r = \frac{\Delta Q_r}{T} \]

Chemical rxns at \( p, T = \text{const} \):

\( \Delta Q_r = \Delta H \)

\[ \Delta S = \frac{\Delta H}{T} \]
The Second Law

\[ \Delta S = \Delta S_{sys} + \Delta S_{sur} > 0 \]

Endotermic process: \( \Delta H > 0 \)

\[ \Delta S_{sys} = \frac{\Delta H}{T_{sys}} > 0 \]

\[ \Delta S_{sur} = -\frac{\Delta H}{T_{sur}} < 0 \]