

## 4.4 What drives entropy upwards?



The second law of thermodynamics tells us that entropy can never decrease, and will always increase for irreversible processes. But what drives entropy to increase? Is entropy the origin of the arrow of time? We will investigate that here.

### Contents:

1. Some interpretations of SMI for an ideal gas
2. Entropy and disorder
3. Macrostates and microstates
4. The driver of entropy
5. Philosophy extra: the arrow of entropic time

### Learning goals:

After taking this section you should be able to:

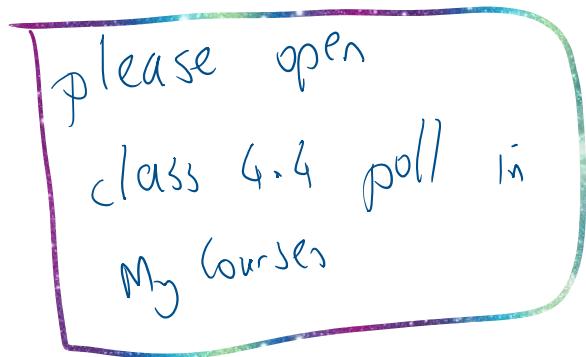
1. Define what is meant by an equilibrium state for a system
2. Explain why systems evolve towards equilibrium states
3. Calculate the probability of finding a system in an equilibrium state
4. Differentiate between microstates and macrostates for systems
5. Use the language of equilibrium states to explain why entropy increases

### References

Halliday and Resnick 'Fundamentals of Physics'

'A statistical view of entropy' (20-8 in the 7th ed., 20-4 in the 10th ed.)

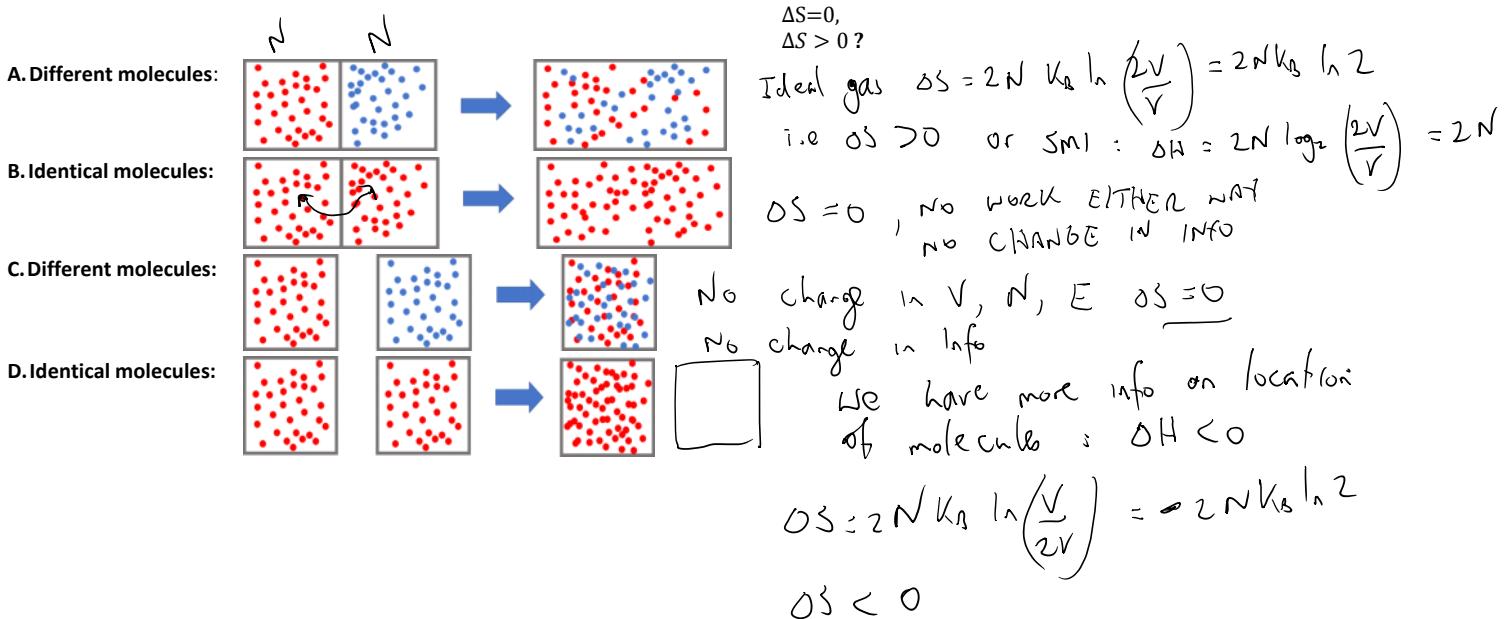
7th edition is available as an E-book: <https://mcgill.on.worldcat.org/oclc/700348118>



## Entropy and disorder

Are systems with higher entropy more disordered than systems with lower entropy?

- Assume that red and blue gas molecules are ideal and do not interact.
- Has entropy decreased, increased or remained unchanged?
- Do more 'disordered' situations have higher entropy?

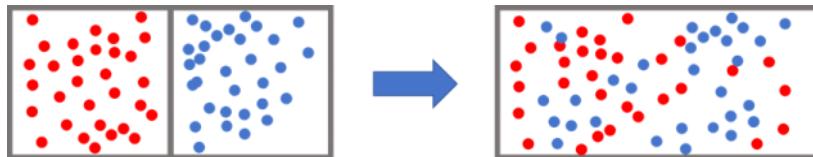


## 💎 Entropy and disorder (1/2)

**Are systems with higher entropy more disordered than systems with lower entropy?**

Assume that the red and blue gas molecules are ideal and do not interact

- A. Has entropy increased, decreased or stayed the same?

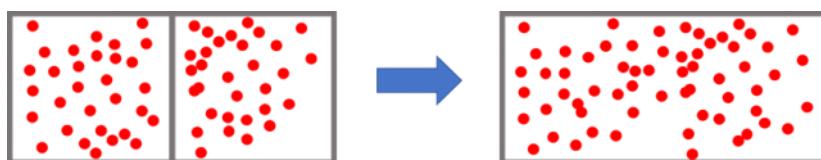


Each molecule has twice the volume to explore before as after, and so entropy (or SMI) will **increase**. I.e. We have less information about the location of the molecules.

$$\Delta S = 2Nk_B \ln\left(\frac{2V}{V}\right) = 2Nk_B \ln 2$$

Or  $\Delta H = 2N \log_2\left(\frac{2V}{V}\right) = 2N$

- B. Identical molecules: Has entropy increased, decreased or stayed the same?



$\Delta S = 0$  : The number of molecules has doubled, but so has the volume, so there is **no change**. Or alternatively, since the molecules are interchangeable, we have the same information about the location of each molecule as before.

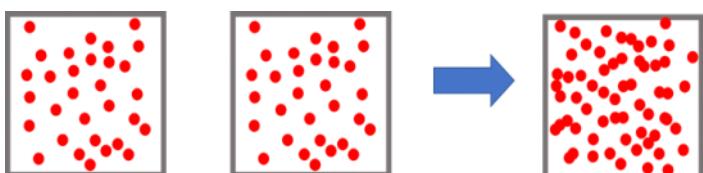
## ◆ Entropy and disorder (2/2)

C. Different molecules: Has entropy increased, decreased or stayed the same?



$\Delta S = 0$  : There is no change in the volume for each individual species, and they do not interact, so neither E,V nor N has changed. The gases have mixed and so it seems as though the system is more disordered, but **entropy has not changed**. It would take the same number of guesses for us to determine the location of the molecules after as before.

D. Identical molecules: Has entropy increased, decreased or stayed the same?



$$\Delta S = S_2 - S_1 = Nk_B \ln \left( \frac{V}{2V} \right) = -Nk_B \ln 2$$

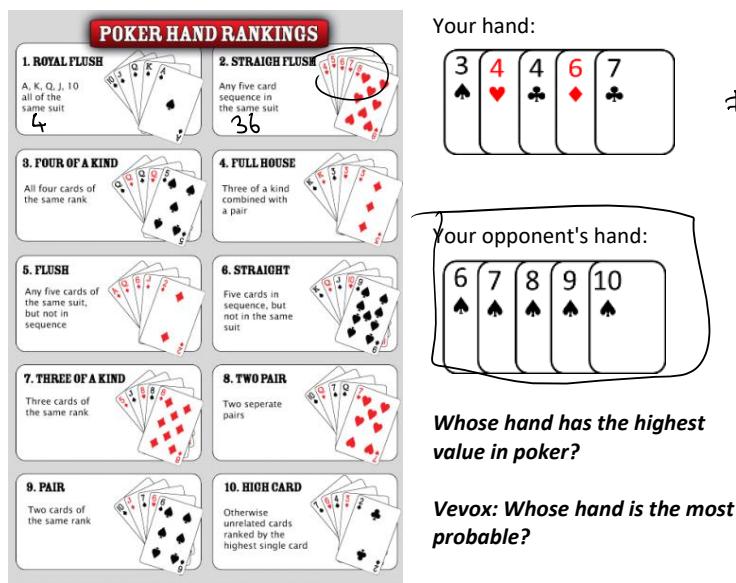
**Entropy has decreased.** This is equivalent to compressing  $2N$  molecules into half the volume.

We can conclude that entropy is not a measure of 'disorder' (which is not well defined) but of information (or lack of information).

So, what drives increases in entropy?

## Macrostates and microstates

Let's forget about gas molecules for a while and play poker:



Micro state = combination of cards

macrostate = type of hand  
(flush, pair, etc)

All microstates are equally likely

But macrostates have different probabilities

Macrostate is defined by having microstates with same equation of state (i.e. they are equivalent)

$$pV - NRT = 0$$

Deck has  $N = 52$  cards

we draw  $r = 5$  cards for a hand  
# of combinations (i.e. possible hands)

$$C(N, r) = \binom{N}{r} = \frac{N!}{r!(N-r)!}$$

(order doesn't matter)

$$\binom{52}{5} = \frac{52!}{5!(52-5)!} = 2,598,960$$

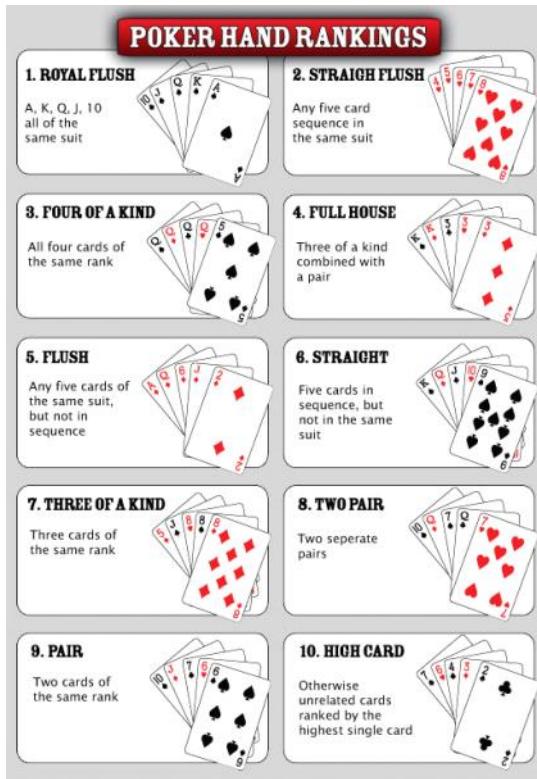
There are 36 straight flushes

$$p(\text{straight flush}) = \frac{36}{2,598,960} = \text{i.e. } 1 \text{ in } 72,000$$

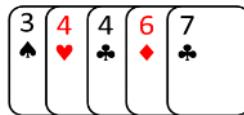
$$p(\text{pair}) = 42\%$$

# ◆ Macrostates and microstates (1/3)

Let's forget about gas molecules for a while and play poker:



You have this hand:



You are probably not very excited - it's a pair of 4's.

Your opponent however, has this hand:



She is probably quite excited indeed - she has one of the highest ranked hands - a straight flush

***However, whose hand is most probable - yours or your opponents?***

They are both equally probable

## ◆ Macrostates and microstates (2/3)

### Number of combinations for 5 cards

Number of different combinations when we select  $r$  items from  $N$  (and when the order does not matter) is

$$C(N, r) = \binom{N}{r} = \frac{N!}{r!(N-r)!}$$

The total number of distinct 5 card combinations is:  $\binom{52}{5} = \frac{52!}{5!(52-5)!} = 2,598,960$

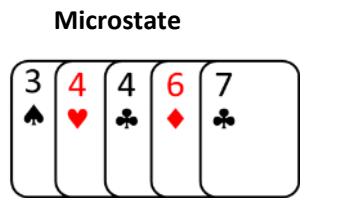
Each hand has a probability of  $1/2,598,960 = 3.85 \times 10^{-7}$

So, why is your opponent so excited? Because she has a hand that is one of a very rare group. There are only 36 straight flushes that can be drawn (excluding the royal flush of which there are 4). So, the chances of her drawing a straight flush are 36 in 2,598,960, or 1 in 72,193. I.e. it is extremely unlikely to have a straight flush.

On the other hand, the chances of drawing a pair (which is what you have) is 1 in 1.37 (42%) - i.e. it is extremely likely to get a pair.

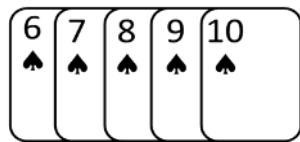
We can describe each type of hand (flush, pair etc) as a **macrostate**, and the individual hands as a **microstate**. Each microstate is equally likely, but some **macrostates** are much more likely than others because they contain many more **microstates**.

## ◆ Macrostates and microstates (3/3)



Macrostate

Pair



Straight flush

### SMI of a macrostate

The SMI for each **macrostate** is given by **log<sub>2</sub> of the number of microstates in that macrostate**. i.e. for  $i_{th}$  macrostate, with  $W_i$  microstates:  $H_i = \log_2 W_i$

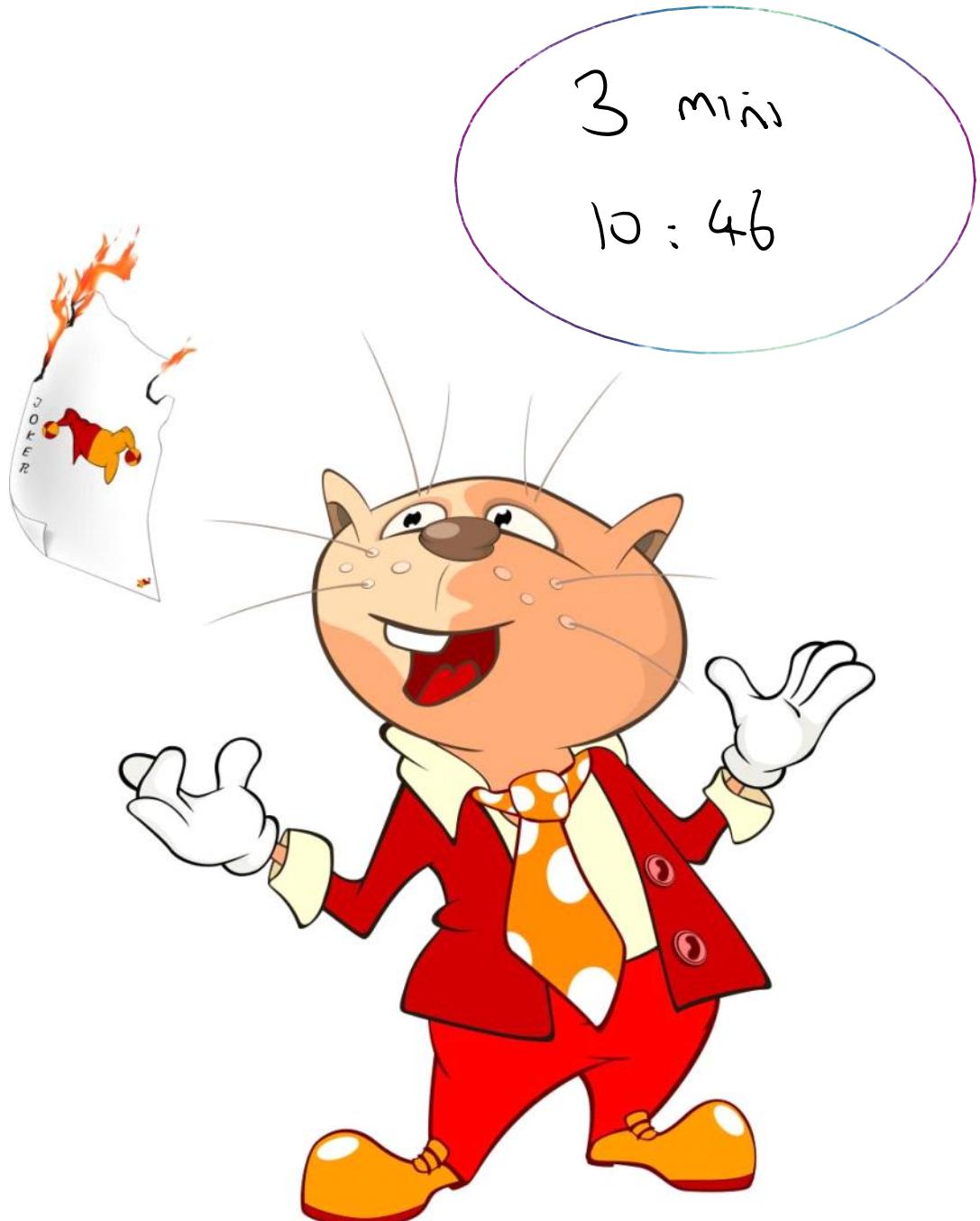
I.e. if someone tells you they have a royal flush, there are only 4 possible combinations (one for each suit) and so the SMI is  $\log_2(4)=2$  bits. So you could learn their hand with 2 questions.

However, the SMI for a pair is  $\log_2(1,098,240)=20.1$  bits. I.e. knowing that you hold a pair provides much less information about the state of your hand of cards.

### Requirement for a microstate

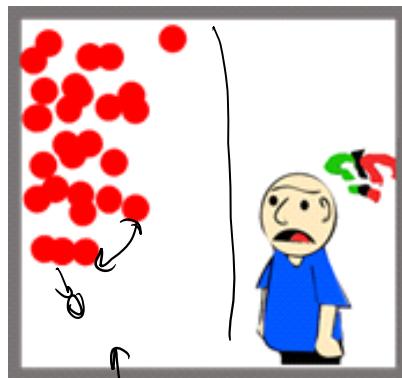
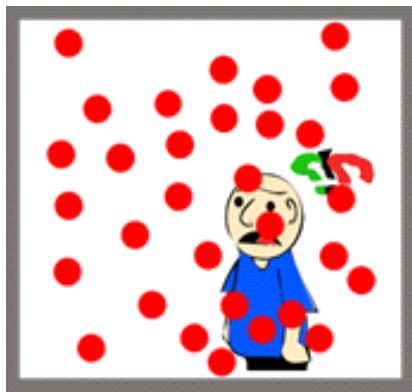
All **microstates within the same macrostate** have the **same value for their equation of state**, but **different configurations** of individual components. I.e. in poker the equation of state is the 'value' of a given hand. In an ideal gas the equation of state is pV-NRT (note that in Poker the analogy is not perfect since if two players both had a 'Straight flush' then the one with the higher card values would win).

## Take a break!



## So what does that have to do with gas molecules?

Do you ever worry when you walk into a room that all the air molecules might be in the other corner?



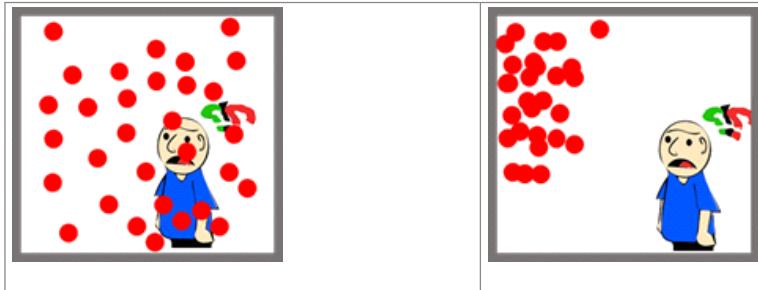
micro state = configuration of molecules

macrostate = half of room they are in

Swapping makes no difference to macrostate

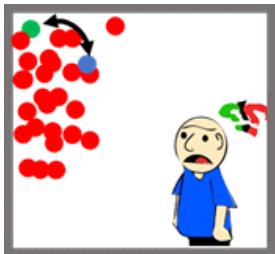
## So what does that have to do with air molecules?

Do you worry when you walk into a room that all the air molecules might be in the other corner?



Not really, because we expect that the air molecules will be spread around the room.

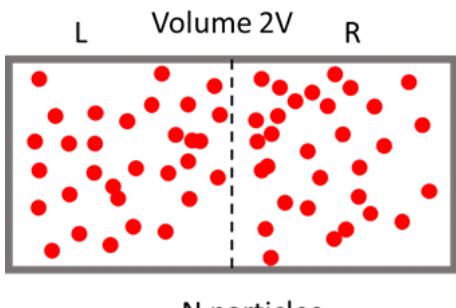
We could label the state where the air molecules are all in one corner of the room as a **macrostate**. We don't care what particular configuration they are in when they are in that corner, simply that they are there. Each configuration is a **microstate**.



Exchanging the two molecules represents two different microstates, but the same macrostate. I.e. it makes no difference to us if we just want air to breathe.

## Dividing the room into two halves

Imagine a box with volume  $2V$ , divided into a left and right half



$$w(n)$$

E.g. 4 identical particles: How many different ways can they be arranged into two boxes?

$(n, N-n)$	$W(n)$	$P_N(n)$	Microstates	Macrostate
(0,4)	1	$1/16$		1
(1,3)	4	$4/16$		2
(2,2)	6	$6/16$		3
(3,1)	4	$4/16$		4
(4,0)	$\frac{1}{16}$	$\frac{1}{16}$		5
Total		$w_T$		

$N$  total particles

$n$  on left,  $N-n$  on right

# of combinations

i.e. # microstates  
for  $n$

$$w(n) = \frac{N!}{n!(N-n)!}$$

Total # of microstates (i.e. configurations) :

$$w_T = \sum_{n=0}^N w(n) = \sum_{n=0}^N \frac{N!}{n!(N-n)!} = 2^N$$

$$p_n = \frac{w(n)}{w_T} = \frac{1}{2^N} \frac{N!}{n!(N-n)!}$$

$$P_n = \frac{W(n)}{W_T} = \frac{1}{2^n} \frac{N!}{n!(N-n)!}$$

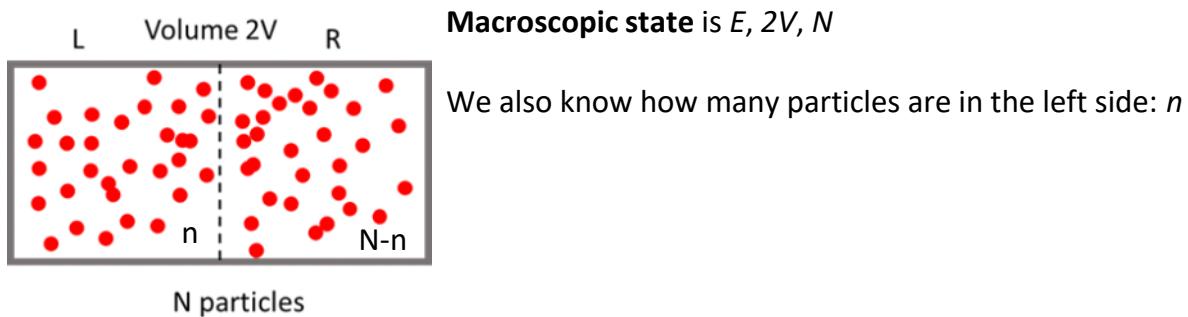
e.g.,  $N=4$ , we have  $W_T = 2^4 = 16$

$$W(2) = \frac{4!}{2!(4-2)!} = \frac{24}{2 \times 2} = 6$$

$$P_2(2) = \frac{6}{16} = \frac{3}{8}$$

## Dividing the room into two halves (1/2)

Imagine a box with volume  $2V$ , divided into a left and right half:



How many different ways  $W(n)$  can  $N$  particles be arranged to have  $n$  on one side and  $N-n$  on the other?

**E.g.  $N=4$  particles:**

$(n, N - n)$	$W(n)$	$P_N(n)$	Combinations ( <b>microstates</b> )	<b>Macrostate</b>
(0,4)	1	1/16		1
(1,3)	4	1/4		2
(2,2)	6	3/8		3
(3,1)	4	1/4		4
(4,0)	1	1/16		5
<b>Total</b>	<b>16</b>			

## ◆ Dividing the room into two halves (2/2)

Number of combinations of  $n$  particles on left and  $N-n$  on right

The expression for **number of combinations**  $W(n) = \frac{N!}{n!(N-n)!}$

Each configuration is a **microstate**, and each is equally probable. The total number of **specific configurations** is:

$$W_T = \sum_{n=0}^N W(n) = \sum_{n=0}^N \frac{N!}{n!(N-n)!} = 2^N$$

If we assume that all configurations are equally probable then the probability of finding  $n$  particles in one side and  $N-n$  in the other is given by

$$P_N(n) = \frac{W(n)}{W_T} = \left(\frac{1}{2}\right)^N \frac{N!}{n!(N-n)!}$$

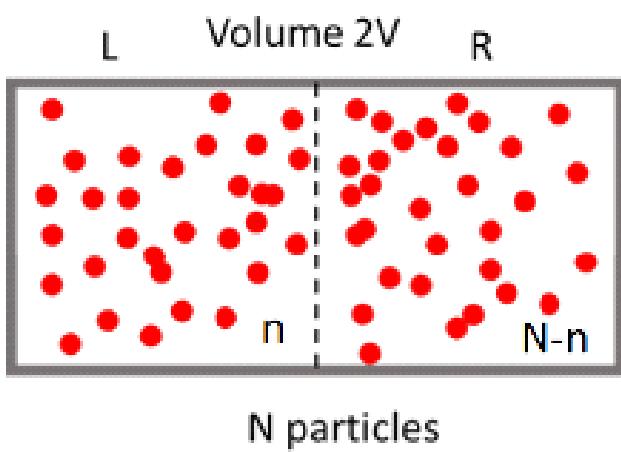
e.g.

for  $N=4$  we have:

$$W_T = 2^4 = 16$$

$$W(2) = \frac{4!}{2!(4-2)!} = \frac{24}{2 \times 2} = 6$$

## Most probable combination



**Recap:**

$n$  identical particles on left, and  $N-n$  on right

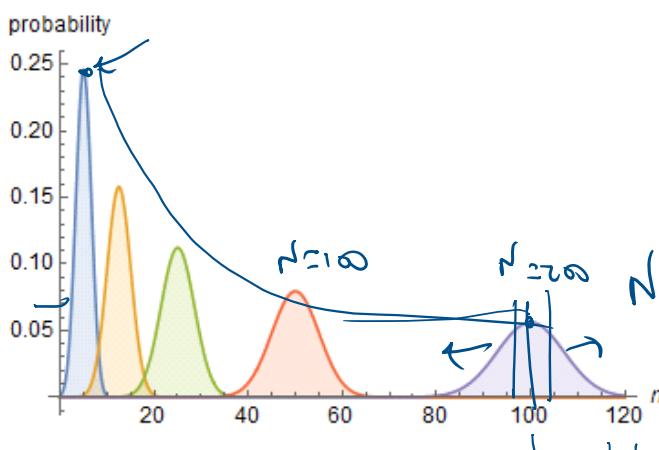
$$\text{Number of combinations } W(n) = \frac{N!}{n!(N-n)!}$$

Total number of specific configurations:

$$W_T = \sum_{n=0}^N W(n) = \sum_{n=0}^N \frac{N!}{n!(N-n)!} = 2^N$$

Probability of finding  $n$  molecules on left:

$$P_N(n) = \frac{W(n)}{W_T} = \left(\frac{1}{2}\right)^N \frac{N!}{n!(N-n)!}$$



Plot of  $P_N(n)$  for various values of  $N$

**Vevox:** From plot, what is the most probable value of  $n$  as a function of  $N$ ?

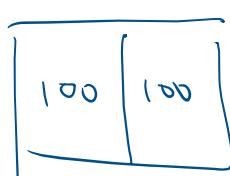
**Vevox:** Does the probability of finding the system in exactly that state increase or decrease with  $N$ ?

Most probable macrostate  $n^* = \frac{N}{2}$

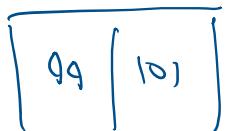
# of configurations (i.e. microstates) of this macrostate

$$\text{is } w(n^*) = \frac{N!}{\left[\left(\frac{N}{2}\right)!\right]^2}$$

probability of system being in most probable state:



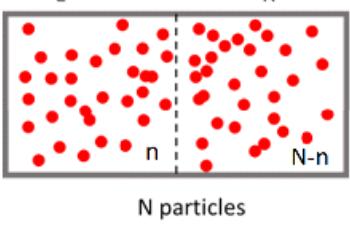
$$P_N(n^*) = \frac{w(n^*)}{2^N} = \frac{N!}{2^N \left[\left(\frac{N}{2}\right)!\right]^2}$$

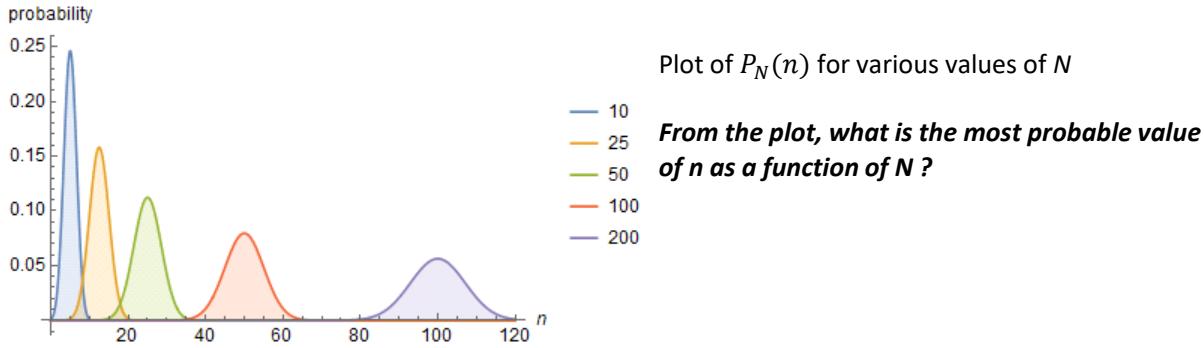


99 | 101

102 | 98

## 💎 Most probable combination

 <p>N particles</p>	<b>Recap:</b> $n$ particles on left, and $N-n$ on right <b>Number of combinations</b> $W(n) = \frac{N!}{n!(N-n)!}$ <b>Total number of specific configurations:</b> $W_T = \sum_{n=0}^N W(n) = \sum_{n=0}^N \frac{N!}{n!(N-n)!} = 2^N$ <b>Probability of finding <math>n</math> molecules on left:</b> $P_N(n) = \frac{W(n)}{W_T} = \left(\frac{1}{2}\right)^N \frac{N!}{n!(N-n)!}$
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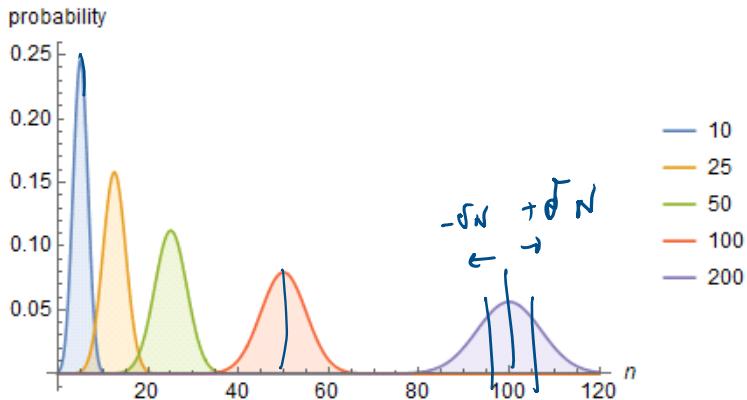
i.e. the **most probable** macrostate is to have one half the molecules in one side and one half in the other, i.e.  $n^* = N/2$

The number of configurations in this macrostate is :  $W(n^*) = \frac{N!}{\frac{N}{2}!(\frac{N}{2})!} = \frac{N!}{\left[\left(\frac{N}{2}\right)!\right]^2}$

And the probability of this macrostate is:  $P_N(n^*) = \frac{W(n^*)}{2^N} = \frac{N!}{2^N \left[\left(\frac{N}{2}\right)!\right]^2}$

As  $N$  increases, the probability of the system being **specifically in state  $n^*$**  actually **decreases**, but the probability that it is in a state **close to  $n^*$**  becomes almost 100%.

## Departures from the mean



Plot of  $P_N(n)$  for various values of  $N$

$P_N(n)$  has a **maximum** at  $n^*=N/2$   
What is the probability of finding the system  
with a value of  $n$  that is very far from  $n^*$ ?

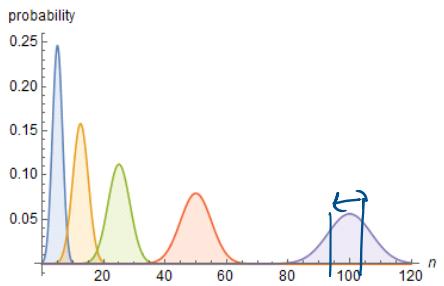
Probability that the system is in a state that is  $\pm \delta N$  from  $n^*$  :

$$P_N(n^* - \delta N \leq n^* \leq n^* + \delta N) = \sum_{n=n^*-\delta N}^{n^*+\delta N} P_N(n)$$

$$\approx \int_{n^*-\delta N}^{n^*+\delta N} \frac{1}{\sqrt{\pi N/2}} \exp\left(-\frac{\left(n - \frac{N}{2}\right)^2}{N/2}\right) dn = \text{erf}(\delta\sqrt{2N})$$

(this makes use of fact when probability is close to 50%, and for large  $N$ , the binomial distribution approaches the normal distribution [7.4: Normal Approximation of the Binomial Distribution - K12 LibreTexts](#))

## Side bar: error function



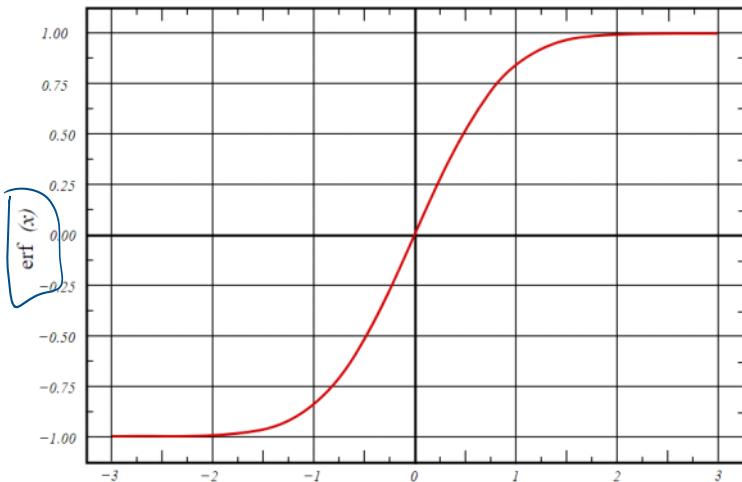
Error function

$$\operatorname{erf} x = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

$\operatorname{erf}(x)$

Probability that the system is in a state that is  $\pm \delta N$  from  $n^*$ :

$$= \operatorname{erf}(\delta \sqrt{2N})$$



For a normally distributed random variable  $Y$ , with zero mean and standard deviation  $\frac{1}{\sqrt{2}}$ ,  $\operatorname{erf}(x)$  is probability that  $Y$  lies between  $\pm x$

## Probability gas is in state close to the mean

Plot of  $P_N(n^* - \delta N \leq n^* \leq n^* + \delta N)$

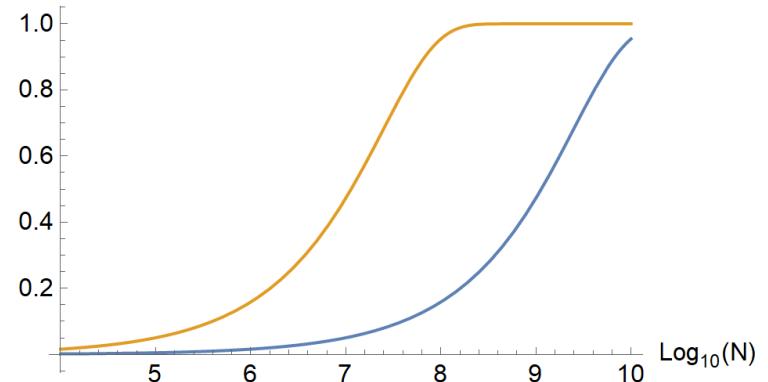
$\delta = 10^{-4}$



$\delta = 10^{-5}$



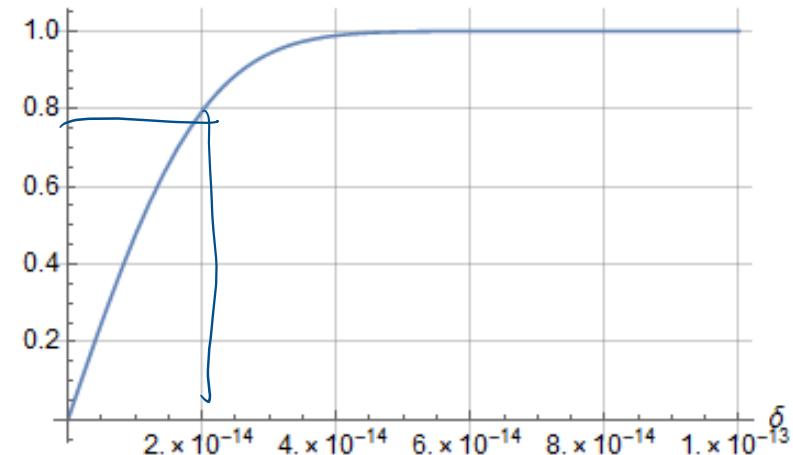
probability



- 1 mole occupies  $0.024 \text{ m}^3$
- A room of  $5 \times 5 \times 3 \text{ m}^3$  contains 3125 moles, or  $N = 1.8 \times 10^{27}$  molecules.
- Fluctuations  $\delta > 4 \times 10^{-14}$  are very unlikely

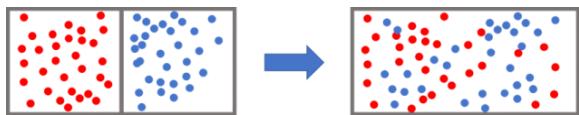
The probability that **all**  $10^{27}$  molecules are in one side of the room is 1 in  $2^{10^{27}}$

probability



## Statistical entropy

Molecules expanding into 2X their volume (assume N in total):



- Each molecule has twice the volume to explore before.

- Entropy change:

$$\Delta S = Nk_B \ln\left(\frac{2V}{V}\right) = Nk_B \ln 2$$

- Number of combinations with  $n$  in left and  $n - 1$  in right:

$$W(n) = \frac{N!}{n!(N-n)!}$$

- Number of states:

$$W_T = \sum_{n=0}^N W(n) = \sum_{n=0}^N \frac{N!}{n!(N-n)!} = 2^N$$

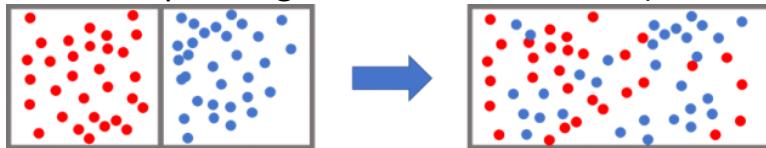
$$K_B \ln(W_T) = K_B \ln 2^N = N K_B \ln 2$$

Statistical entropy:  $S = k \ln(\Omega)$ , where  $\Omega$  is  
# of states available to system

more states  $\rightarrow$  higher entropy

## ◆ Statistical entropy

Molecules expanding into 2X their volume (assume N in total):



Each molecule has twice the volume to explore before as after, and so entropy (or SMI) will increase. I.e. We have less information about the location of the molecules.

$$\Delta S = Nk_B \ln \left( \frac{2V}{V} \right) = Nk_B \ln 2$$

Number of combinations with  $n$  in left and  $n - 1$  in right:

$$W(n) = \frac{N!}{n! (N-n)!}$$

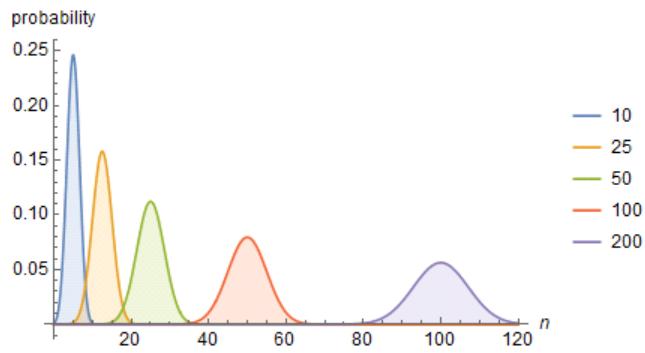
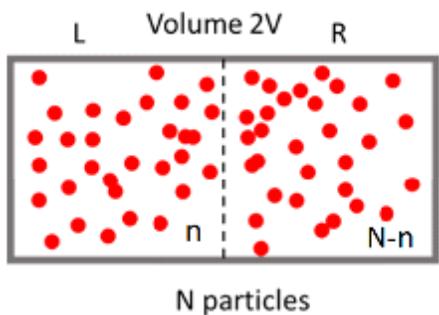
Number of states:

$$W_T = \sum_{n=0}^N W(n) = \sum_{n=0}^N \frac{N!}{n! (N-n)!} = 2^N$$

We can see that  $k_B \ln W_T = k_B \ln 2^N = Nk_B \ln 2$

We can define statistical entropy as  $S = k \ln W$  where  $W$  is the number of states available to a system. More states --> higher entropy

## Why entropy increases with time



systems will spend more time in Macrostates that have most microstates

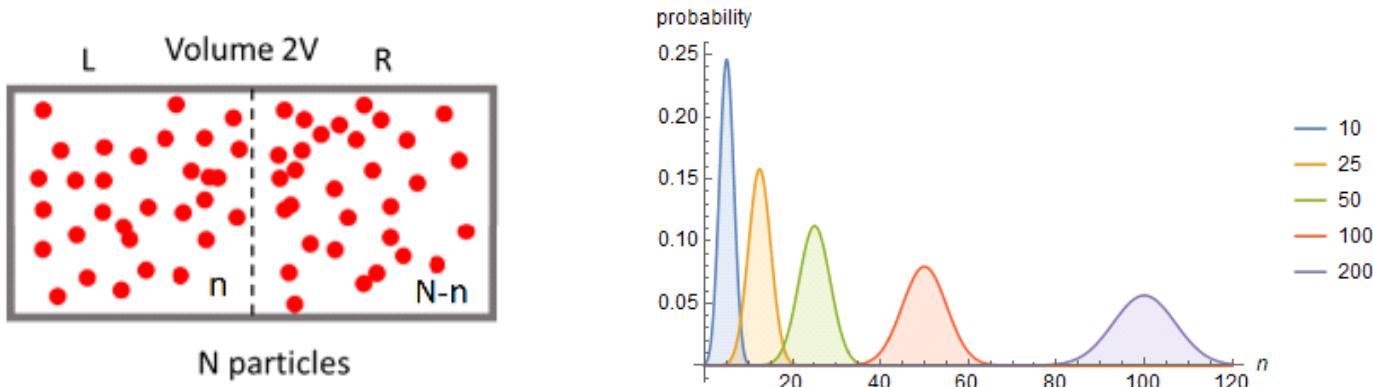
$$S = k \ln W$$

$$\boxed{A} \quad \boxed{B} \quad p(A \cap B) = p(A) \times p(B)$$

$$\begin{aligned} S &= S_A + S_B = k \ln W_A + k \ln W_B \\ &= k \ln (W_A \times W_B) = k \ln (W_T) \end{aligned}$$

## ◆ Why entropy increases with time

All microstates are equally probable, but as a system evolves, it will tend towards **macrostates that have the most microstates**. When a system contains many components (such as air molecules) those macrostates will be almost inevitable. This is called the **equilibrium state** of the system. Fluctuations about the equilibrium state can certainly occur, but they will be small and the system will return to its equilibrium state.



These states are also the states with the highest entropy (because they contain the most microstates). So, it is **probability** that drives entropy to increase.

This is what led Ludwig Boltzmann to write down his famous equation:  
 $S = k \ln W$

*Entropy S* of a macrostate is proportional to the logarithm of the number of microstates *W* in that macrostate.  
The logic of this relationship is based on the fact that entropies of individual systems sum, but probabilities multiply.  
I.e. if we have two individual systems A and B with a number of states  $W_A$  and  $W_B$  and entropies  $S_A$  and  $S_B$  then total entropy:

$$S = S_A + S_B = k \ln W_A + k \ln W_B = k \ln(W_A W_B) = k \ln W$$

## Philosophy extra: The arrow of entropic time

[Entropic Time \(Backwards Billy Joel Parody\) | A Capella Science](#)



(if you want more, the 'making of video' is also worth watching: [The Making Of "Entropic Time" | A Capella Science 2](#))

### **What is time?**

Nobody really knows. Newton assumed that there was a universal clock that ticked the same way everywhere. Einstein showed that cannot be true, but we still tend to feel that time is something that exists outside of us.

However, one of our best theories is that time is our measure of the direction of the increase in entropy. Time is a measurement of rate of change, and things will always change to increase entropy. Even our memories, which we use to record time, go from a low entropy state to a high entropy state as they fill with data.

## What is entropy?

We have now seen three different definitions of entropy:

### 1. Thermodynamic

$$dS = dQ/T$$

Relates heat and work,  
increases for irreversible  
processes

$$\Delta E = TdS - pdV$$

### 2. Information

$$H = -K \sum_1^N p_i \log_2 p_i$$

A measure of our uncertainty  
or lack of knowledge of a  
situation

$$H(X) = - \int_S f(x) \log_2 f(x) dx$$

### 3. Statistical

$$S = k \ln W$$

Entropy is a measure of the  
number of microstates  
 $W$  available to a given  
macrostate

## Sample problem 1

Eight people occupy four offices in a company. Due to a pandemic they are told that they should try to maintain two people per office. Assuming that they ignore these instructions and wander around completely at random, and assuming that it doesn't matter which people are in which office (i.e. people are interchangeable) calculate:

- a) How many different ways are there to distribute the people among the offices?
- b) What is the most probable distribution of people
- c) What is the chance that at any one moment there are exactly two people in each office?

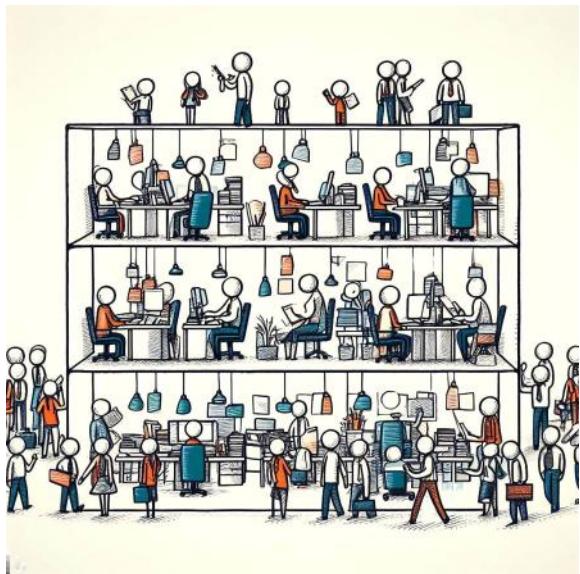


Image created (but not according to the prompt I gave it) by DALL-E....

## Sample problem 1 solution

Eight people occupy four offices in a company. Due to a pandemic they are told that they should try to maintain two people per office. Assuming that they ignore these instructions and wander around completely at random, and assuming that it doesn't matter which people are in which office (i.e. people are interchangeable) calculate:

- How many different ways are there to distribute the people among the offices?
- What is the most probable distribution of people?
- What is the chance that at any one moment there are exactly two people in each office?

Solution:

- The number of possible ways that we can distribute  $r$  identical objects into  $N$  groups is given by the multinomial  $\binom{r+N-1}{N-1}$   
For 8 people in 4 offices there are therefore 165 different ways to distribute them
- Each microstate (i.e. distribution pattern) is equally probable
- Of those 165 states, there is only one configuration where there are exactly two people in each office, so the probability is 1/165

 Sample problem 2

A micro-chamber contains  $10^{12}$  air molecules at a temperature of 293K and a pressure of 103.2 kPa. What is the probability that at any one instant there is a difference of more than 0.1 Pascals (*not kPa*) in pressure between two halves of the chamber? What is the probability that the difference is greater than 0.01 Pa? Please explain your calculations.

## Sample problem 2 solution

We know that number of molecules  $N = 10^{12}$ ,  $T = 293$  K and  $p = 103.2$  kPa. In order to calculate the probability of finding a particular pressure difference between two sides of the chamber, we need to calculate the number of molecules that would represent, and then use the error function expression from class 4.4.

First, we need to calculate the volume of the chamber  $V$ .

Since  $V = Nk_B T/p$  we find

$$V = 10^{12} \times 1.38 \times 10^{-23} \times 293 / 103,200 = 3.92 \times 10^{-14} \text{ m}^3$$

(or  $39,198 \mu\text{m}^3$ )

If we divide the chamber into two, then each has a volume of  $V_{1/2} = 19,599 \mu\text{m}^3$

If some molecules  $\Delta N$  move from right side to the left, that will increase the pressure on the left side and reduce it on the right.

Pressure on the left will be  $p_L = \left(\frac{N}{2} + \Delta N\right) k_B T / V_{1/2} = 2 \left(\frac{N}{2} + \Delta N\right) k_B T / V$

Pressure on the right will be  $p_R = 2 \left(\frac{N}{2} - \Delta N\right) k_B T / V$

So pressure difference  $\Delta p = p_L - p_R = \frac{4\Delta N k_B T}{V}$

From this we find  $\Delta N = \frac{V\Delta p}{4k_B T}$ . So we can put in the numbers to obtain  $\Delta N = 242,186$  molecules

This is a fraction  $\delta = \Delta N / N = 242,186 / 10^{12} = 2.422 \times 10^{-7}$

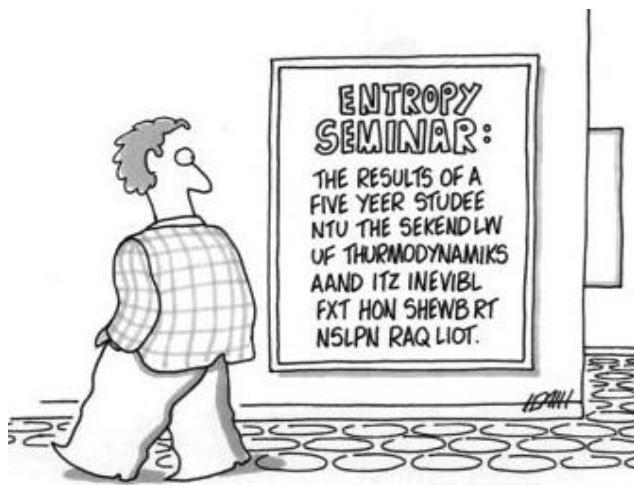
The probability that the system is in a state of  $\pm \delta N$  from the equilibrium distribution (i.e. where an equal number of molecules are on each side) is  $\text{erf}(\delta \sqrt{2N})$

Using an erf function from Mathematica, we find  $\text{erf}\left(2.422 \times 10^{-7} \sqrt{2 \times 10^{12}}\right) = 0.372$

The probability that the pressure difference is greater than this is  $1 - 0.372 = 0.628$

I.e. there is a better than even chance that the two halves of the microchamber will have a pressure difference of less than 0.1 Pa. For a pressure difference of 0.01 Pa, the is only a 0.039 probability that the two sides are within this, and 96% chance that they are not.

## Summary questions



Systems remain in an equilibrium state because:

- a. It has the lowest energy
- b. It is the most probable
- c. It has the lowest entropy

1. What is meant by an *equilibrium state* for a system?
2. Why do systems evolve towards equilibrium states?
3. How do we calculate the *probability* of finding a system in an equilibrium state?
4. What is the difference between *microstates* and *macrostates* for systems?
5. Why entropy increase?

# Key take-aways

Systems remain in an equilibrium state because:

- b. It is the most probable\*

## 1. Define what is meant by an equilibrium state for a system

An equilibrium state is the macrostate that contains the most microstates. It is therefore the most probable.

## 2. Explain why systems evolve towards equilibrium states

Due to random changes, any time we observe the system we are most likely to see it in the most probable state, which is the one with greatest number of microstates.

## 3. Calculate the probability of finding a system in an equilibrium state

The probability that a system of  $N$  components is within  $\delta$  of an equilibrium states is given by  $\text{erf}(\delta\sqrt{2N})$

## 4. Differentiate between microstates and macrostates for systems

A microstate of a system refers to its microscopic configuration, i.e. the positions (or values) of all constituents. All microstates are equally probable. A macrostate refers to the macroscopic properties of the system (such as temperature and pressure for a gas, or the 'rank' of a hand of cards in poker). Many microstates may have the same macroscopic properties and so are part of the same macrostate.

## 5. Use the language of equilibrium states to explain why entropy increases

Imagine that a system starts in a macrostate where we have all the information possible about the constituents. Since we have nothing to learn about it, the entropy would be zero. It is now allowed to evolve at random, and will tend to evolve to the equilibrium state that has the highest probability. We now have the least possible information about the constituents and so entropy is at a maximum for those conditions.

**Next class: Module 5: The Ultimate Limits to Computing**