The microclimate in packages, showcases, microclimate vitrines and backing board protected paintings

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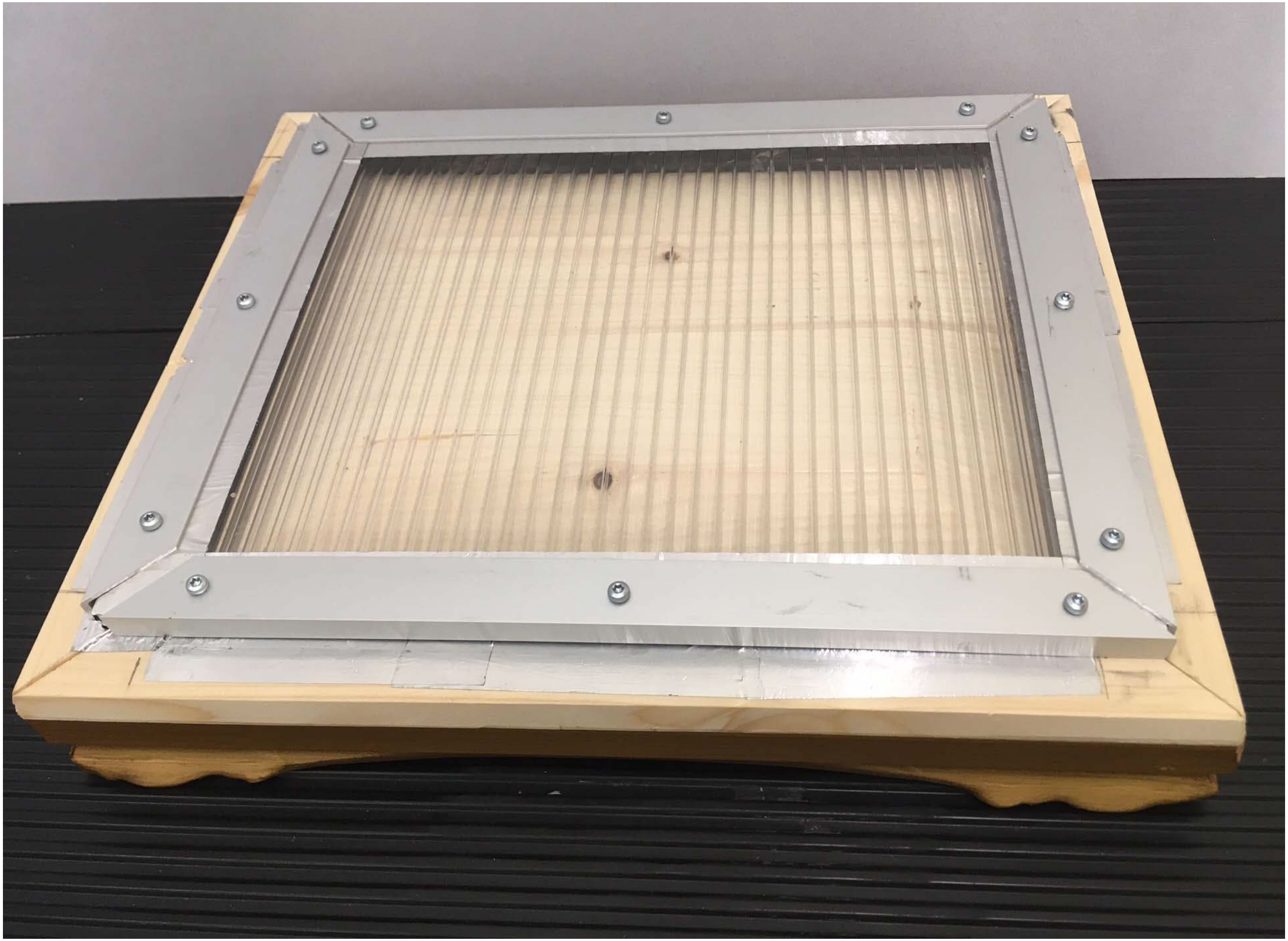
Introduction

examples of closed and semi-closed systems that contain hygroscopic materials

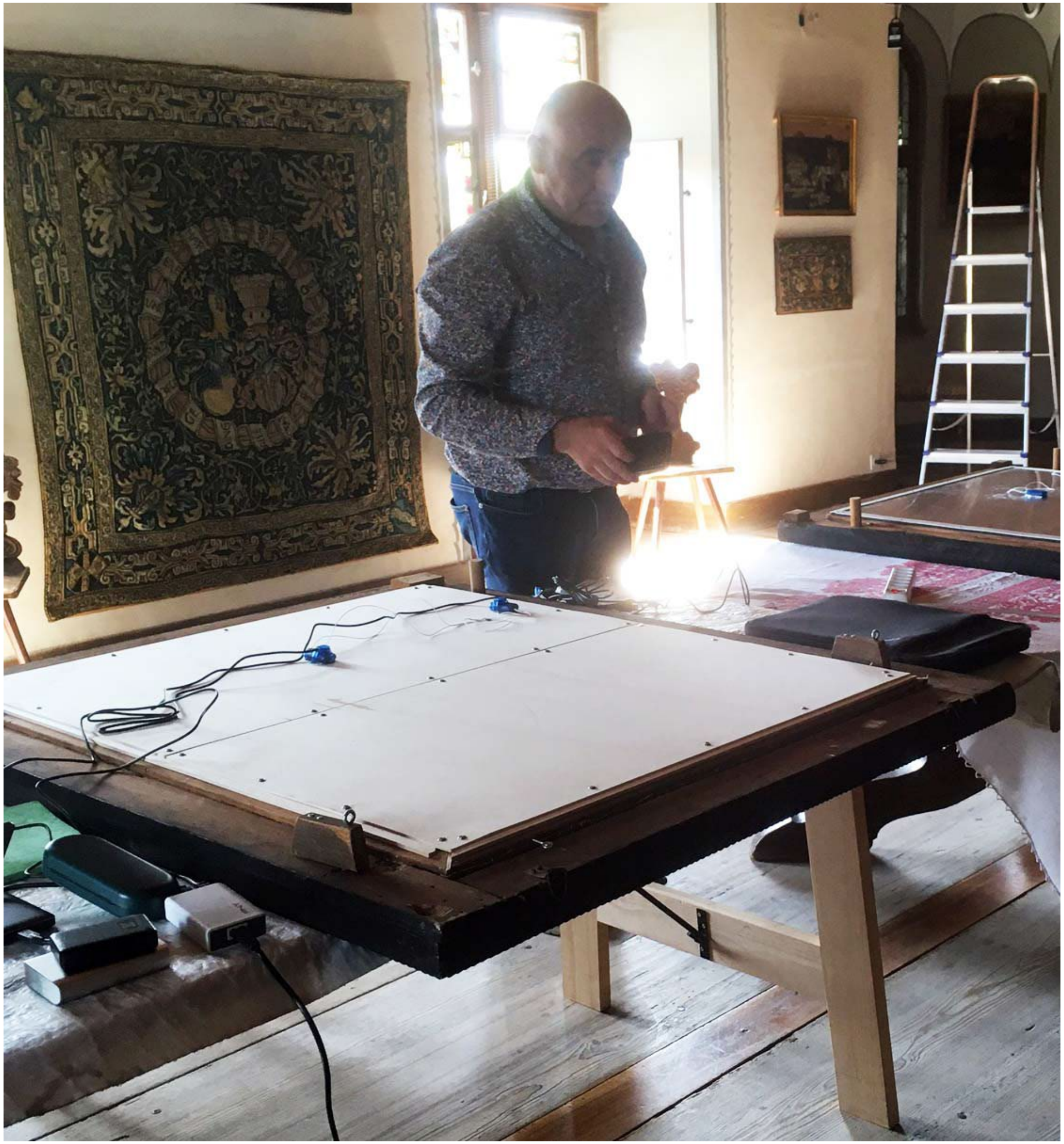


Microclimate vitrine, design Laurent Sozzani
closed system= (almost) no air exchange

artworks stored packed in plastic foils

A museum cabinet (Museum für Gestaltung, Zürich
closed system= (almost) no air exchange

Graphic art (Museum Spittel, Büren an der Aare)
semi-closed system: moderate air exchange



painting with a backing board (Schloss Altenklinge)
semi-closed system: moderate air exchange

Aim of these lessons is to be able to understand the role of the hygroscopic materials in these systems and be able to establish grounded hypothesis about their climate response

Fundamentals

- **Lesson 1**
  - definition of saturation humidity as equilibrium between the water liquid and gas phase in a closed system
  - definition of absolute and relative humidity

- **Lesson 2**
  - the water vapour concentration diagram. Definition and possible uses

- **Lesson 3**
  - the sorption isotherm

- **Lesson 4**
  - the RH response of closed systems subjected to temperature changes. Case study: a microclimate vitrine

- **Lesson 5**
  - the RH response of closed system after the insertion of hygroscopic materials
  - the RH response of semi-closed system subjected to surrounding RH variations

Advanced

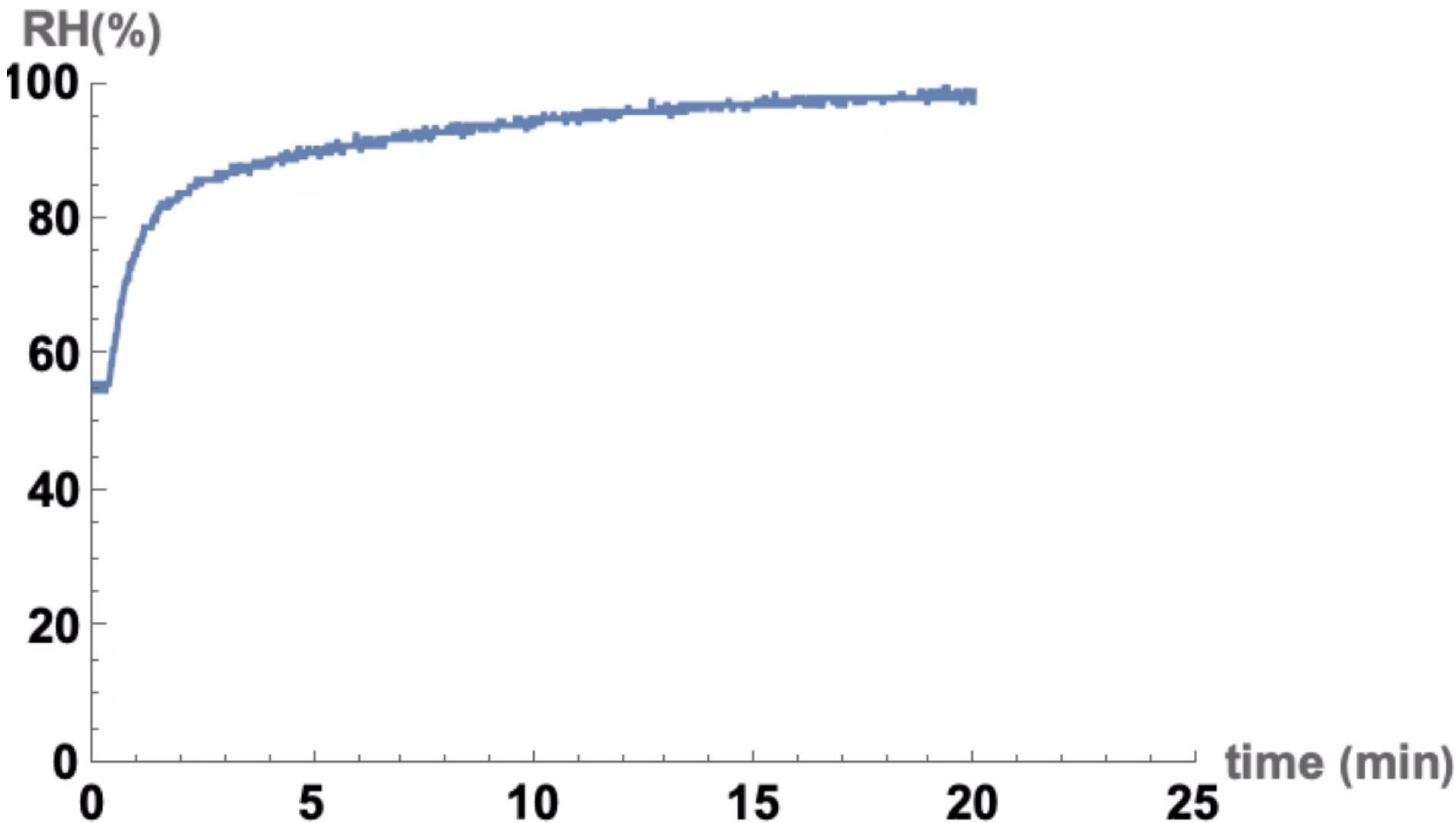
- **Lesson 6**
  - backing board protected paintings subjected to RH changes

- **Lesson 7**
  - backing board protected paintings subjected to T gradients

Lesson 1
The definition of relative humidity

We look at the value of the Relative Humidity in the bottle

RH in the bottle with water container



Animation 1. RH increase in a bottle once a beaker with water is inserted (please see "Animation" on Pressbooks for video).

1. The RH increases till (almost) 100%
2. The level of water is not visibly lower

Formulate:

1. an hypothesis for the increase of RH = a description of the mechanism leading to the increase of RH
2. a test experiment for your hypothesis
3. a prediction for the outcome of your test hypothesis

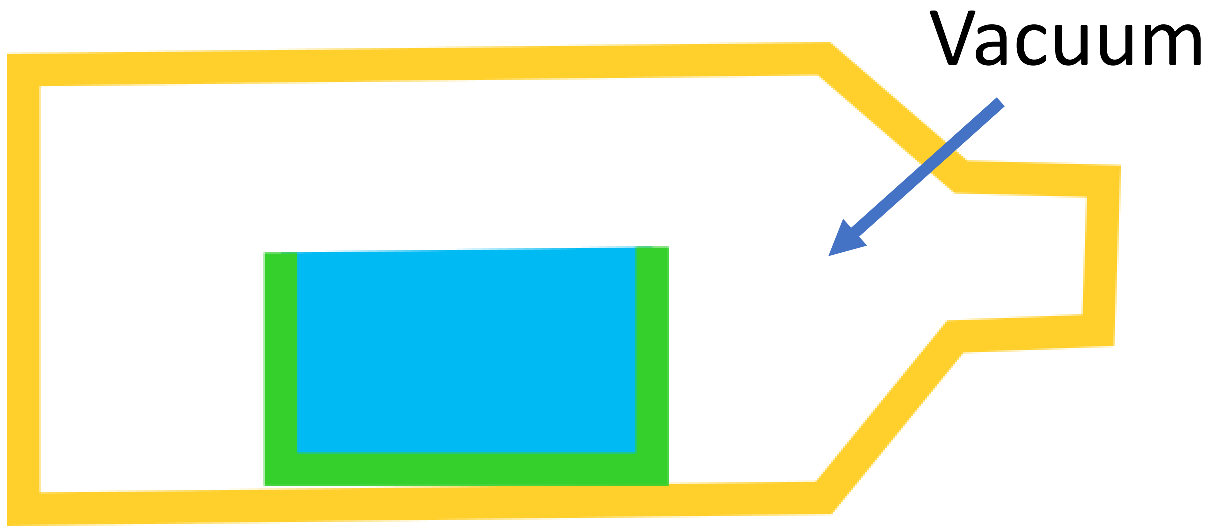
Previous years students have formulated 2 different hypotheses for the transport of water from the liquid to the air:

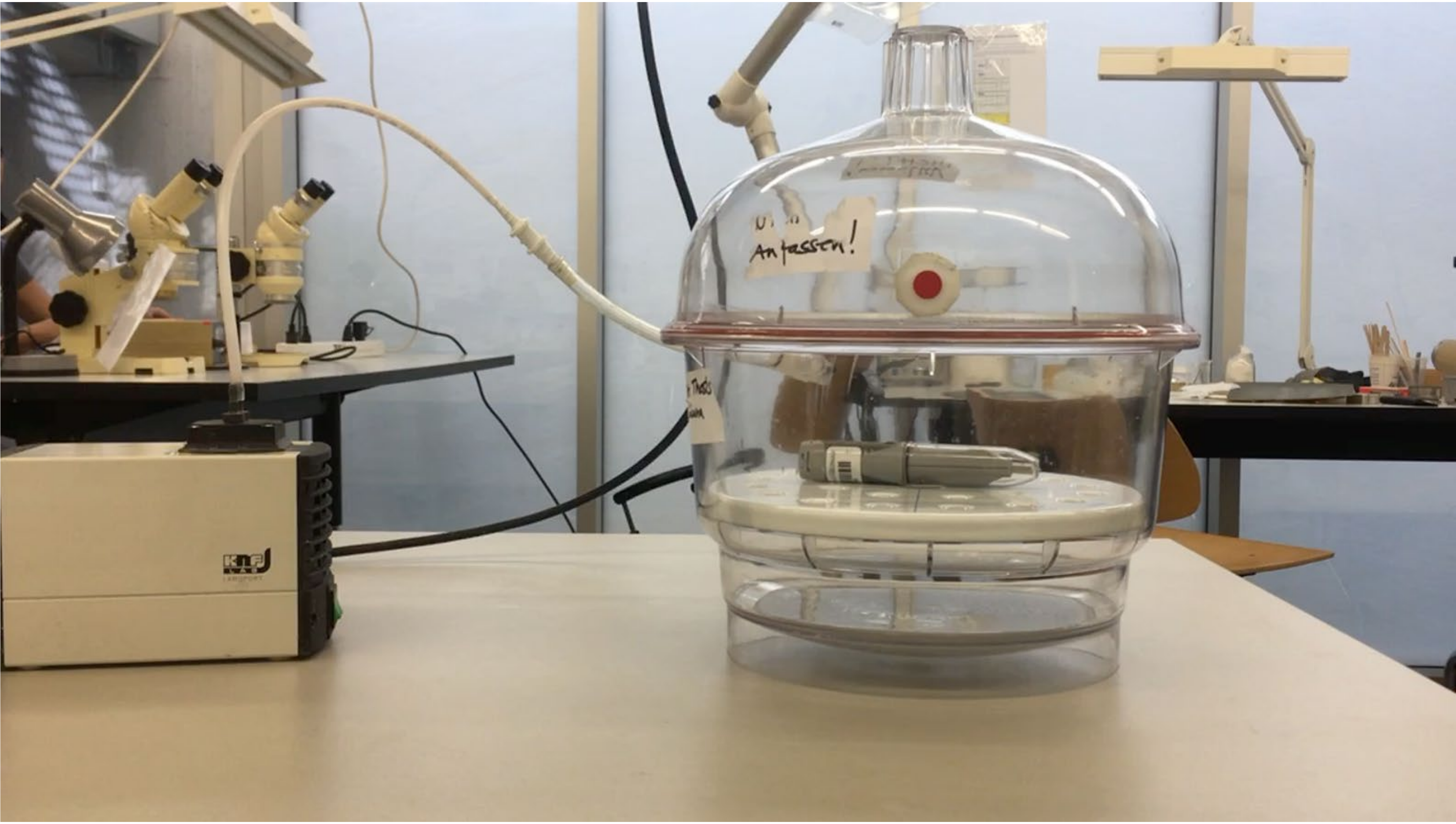
Reaction hypothesis: water molecules (H2O) react with air molecules (N2,O2) and are stripped away from the liquid

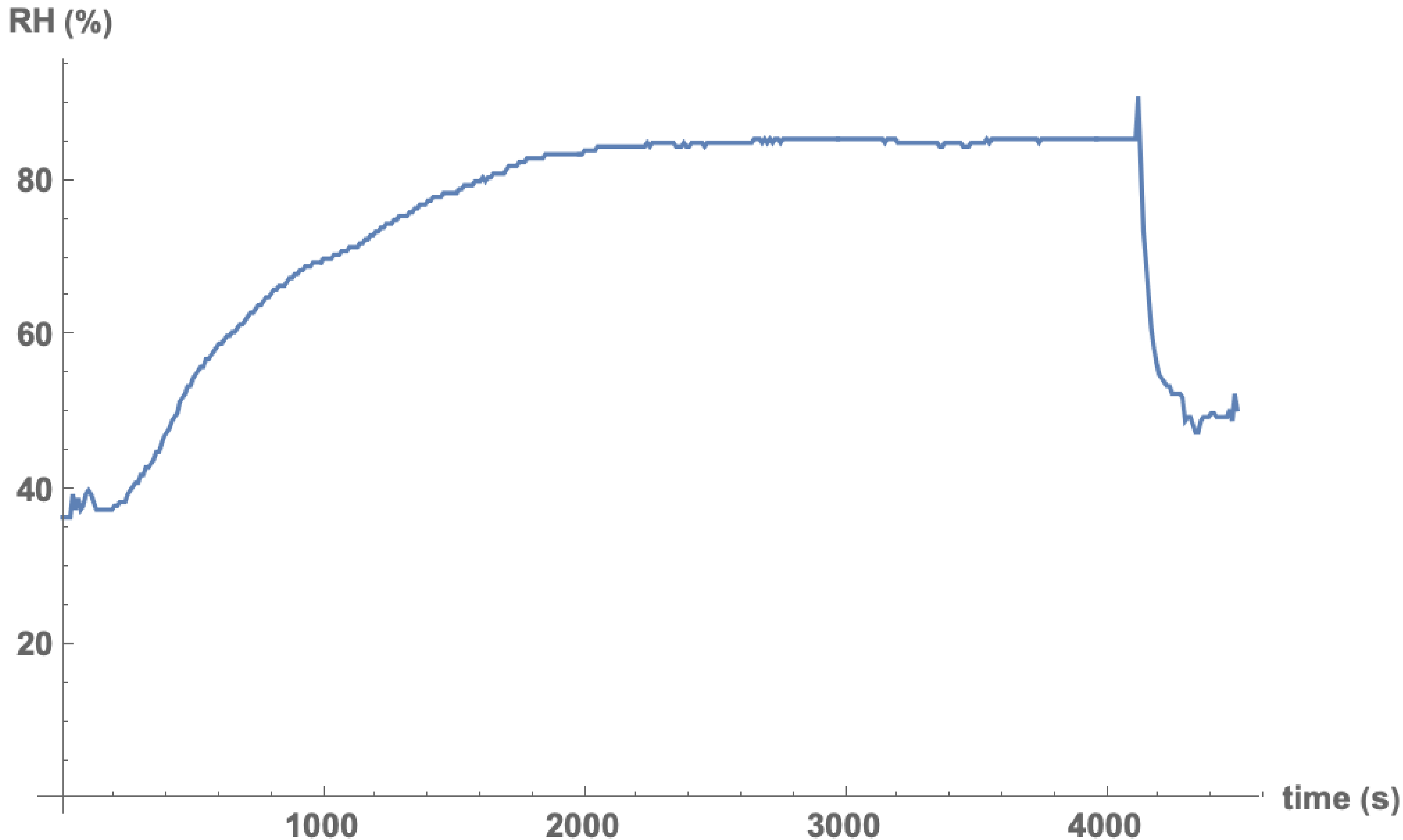
Bond breaking hypothesis: the hydrogen bonds among liquid water molecules get broken and the water molecules detach from the liquid

Test experiment for the reaction hypothesis: remove the air from the bottle (or dessicator) and measure the relative humidty

prediction: according to the „reaction hypothesis“ the relative humidity should not increase if air is removed from the bottle as there are no air molecules (N2, O2) with whom water can react




Anfassen!



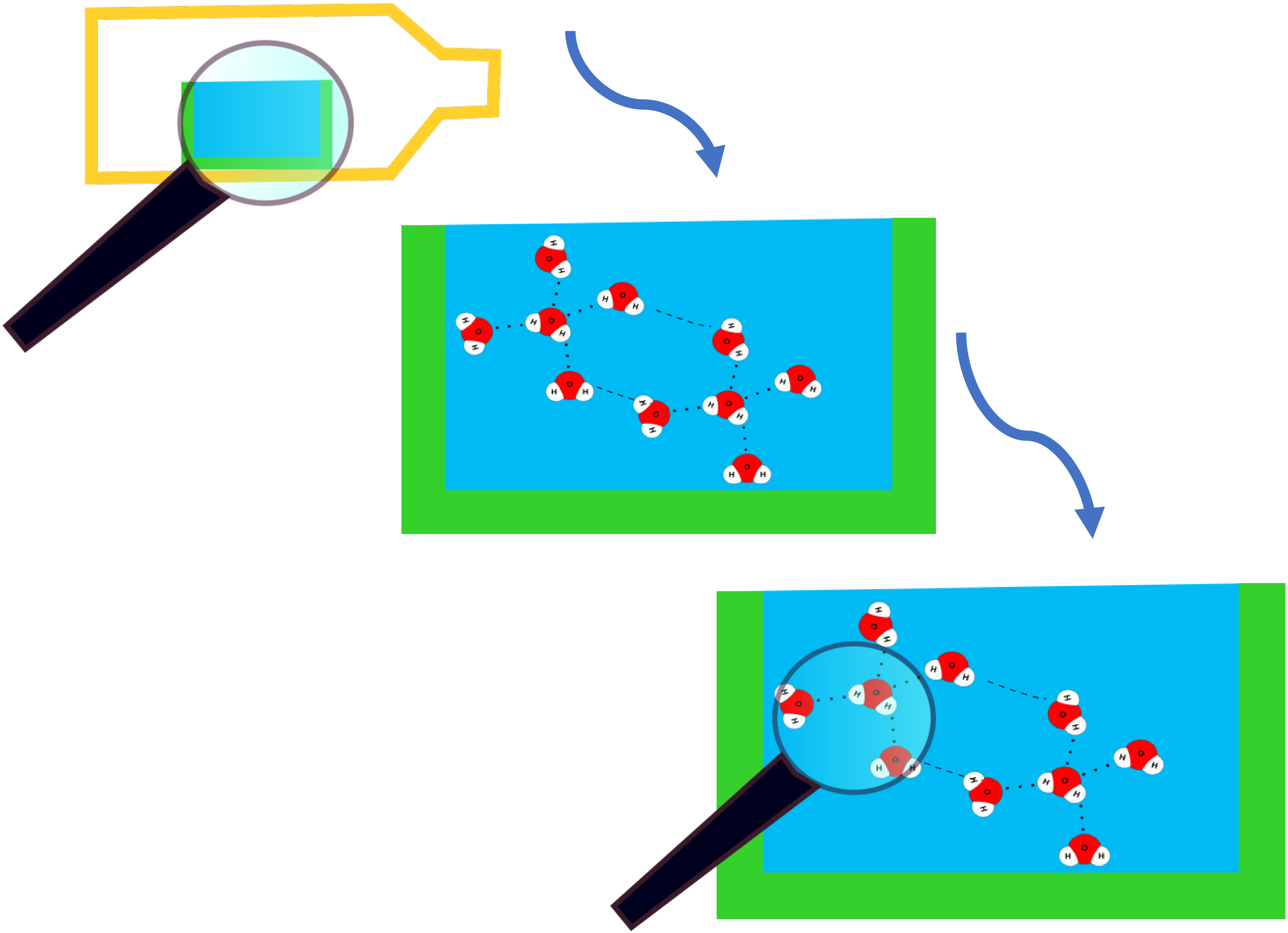
Animation 2. RH increase in a dessicator under vacuum after a beaker with water is inserted (please see "Animation" on Pressbooks for video).

The RH in a closed container without air but with liquid water increases. The reaction hypothesis cannot be retained and the bond breaking hypothesis will be retained

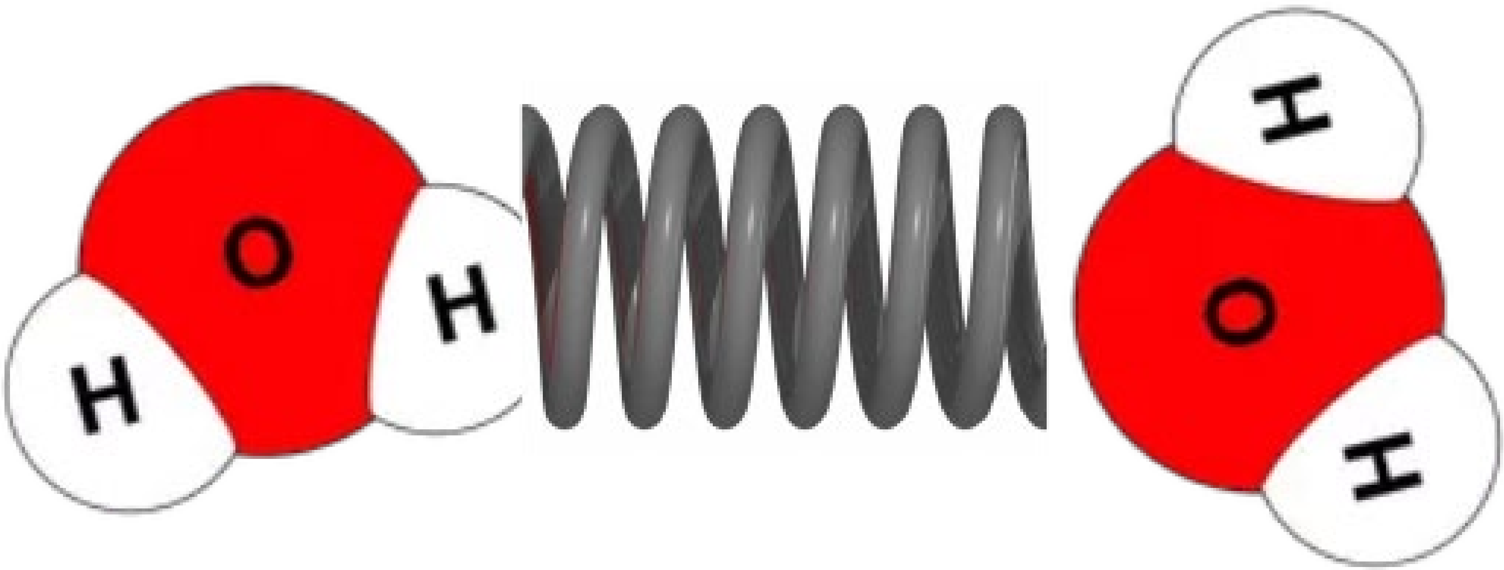
We want to understand:

Why and when the RH stops increasing

If the water level in the small container decreases



Energy of Hydrogen Bonding = 6-30 kJ/mol



If work is done on this system (=2 H_2O molecules connected by an hydrogen bonding) the „spring“ can be stretched as far as to break it

Which type of work?

Kinetic work= Put molecules in motion= increase temperature

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}k_BT$$

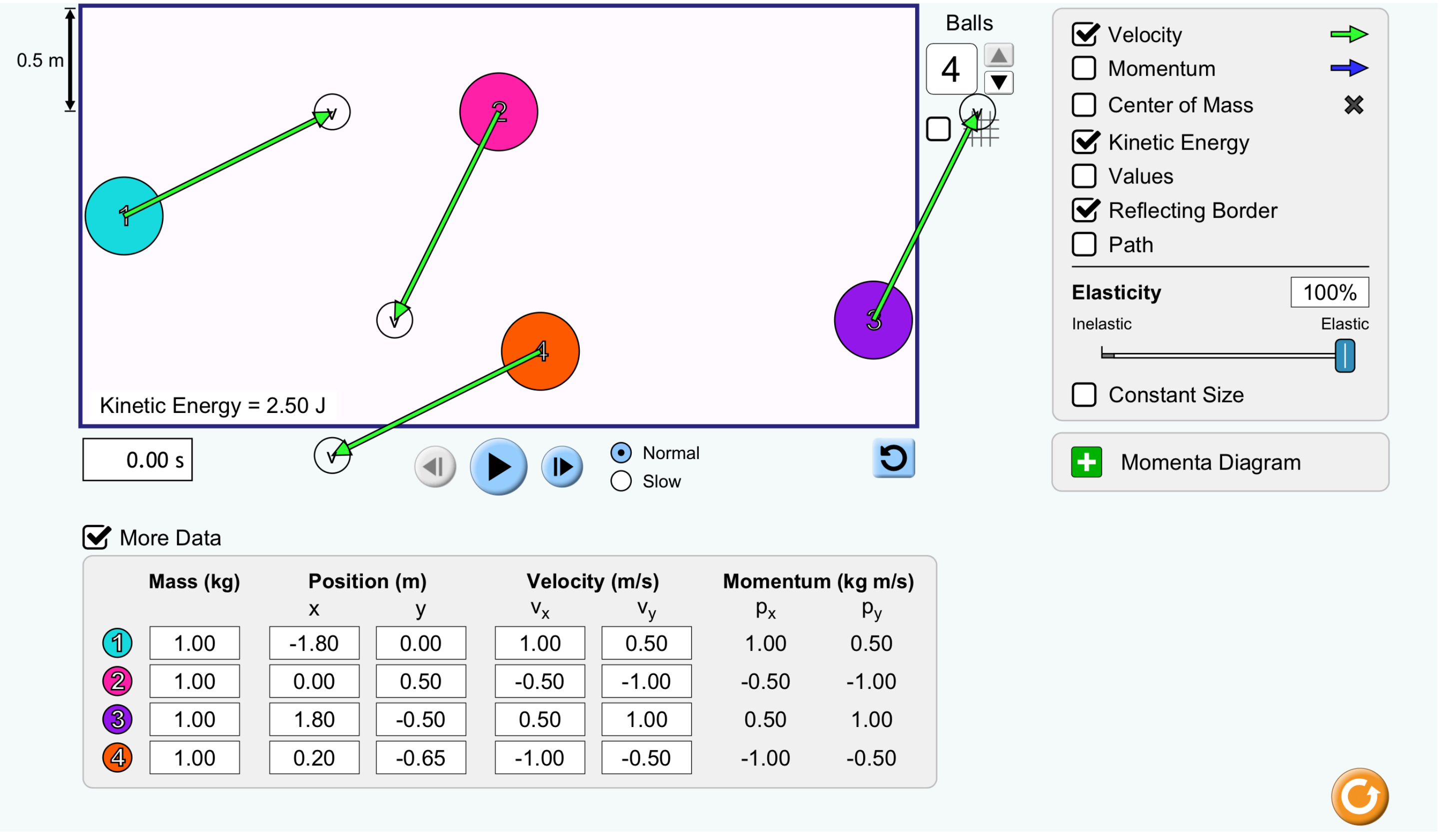
m= mass
v= speed
k_B= Boltzmann‘s constant
T= temprature (in Kelvin)
(in an ideal gas)

The molecules in liquid water move all the time.

At constant temperature they do not have the same velocity therefore also not the same kinetic energy

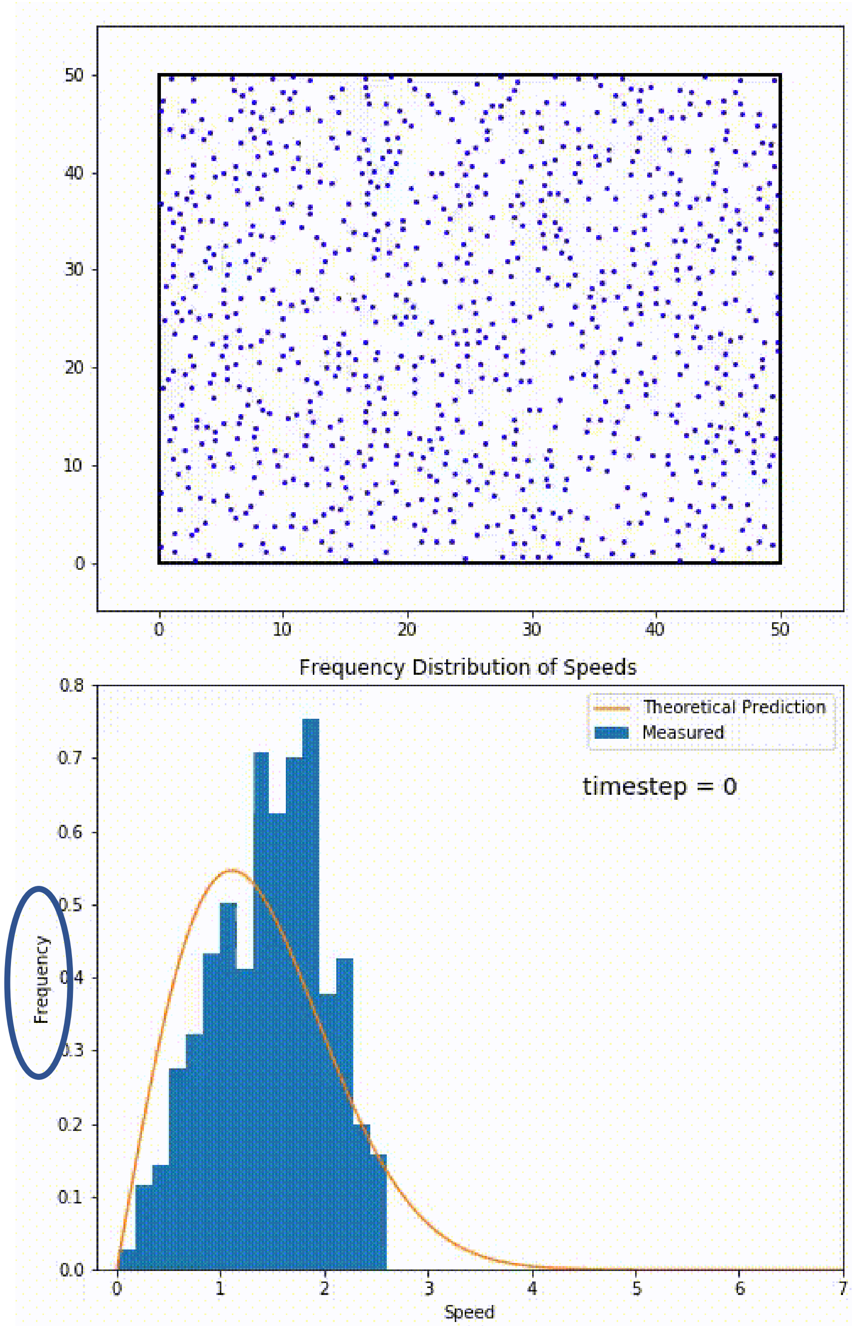
Why the molecules do not have all the same velocity?

Simulation: 4 balls, all with the same mass and initial speed that undergo only elastic collisions (collisions where the total kinetic energy is conserved)



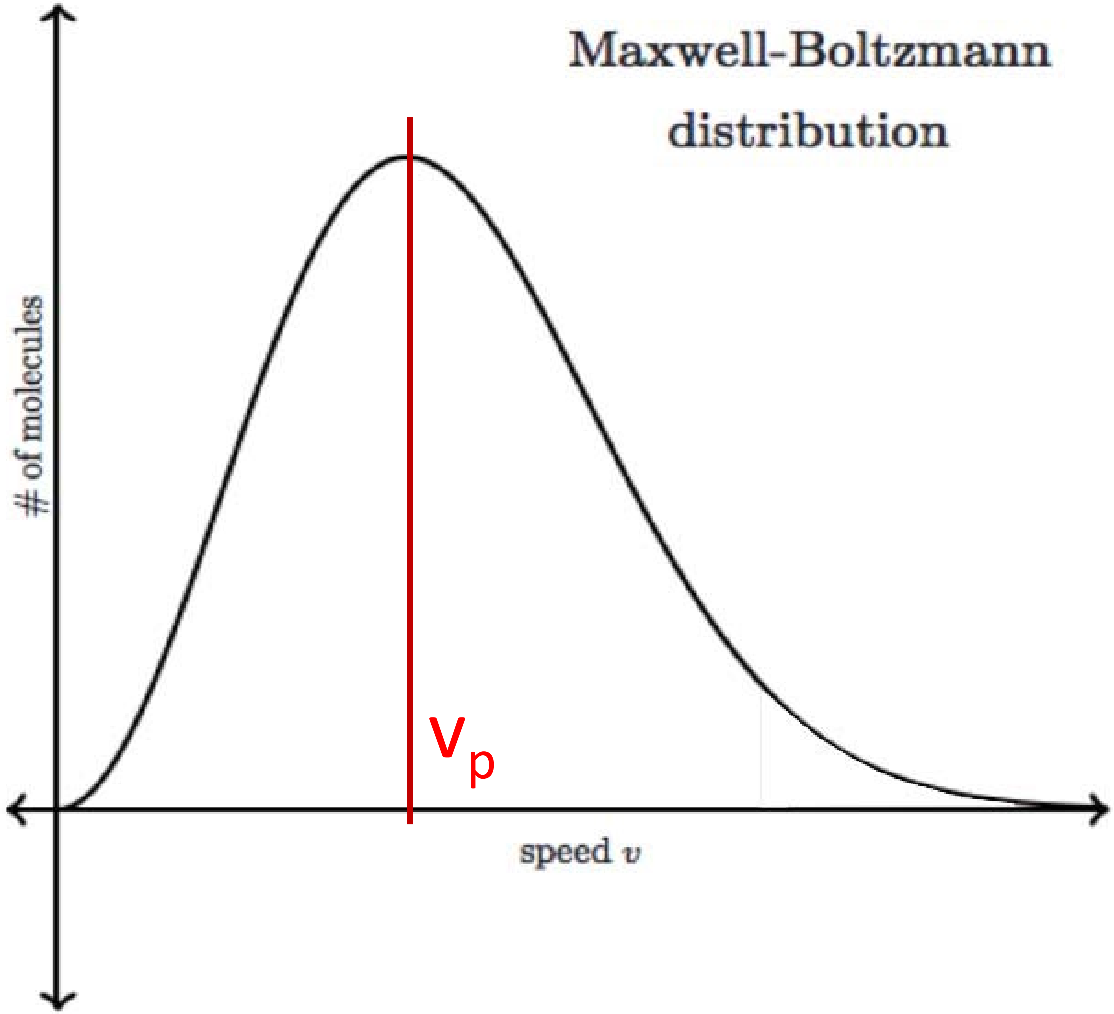
Collision lab at http://pHET.colorado.edu/

Frequency



50
40
30
20
10
0
0
10
20
30
40
50
Frequency Distribution of Speeds
Theoretical Prediction
Measured
timestep = 0
Frequency
Speed

Distribution of speed in a gas

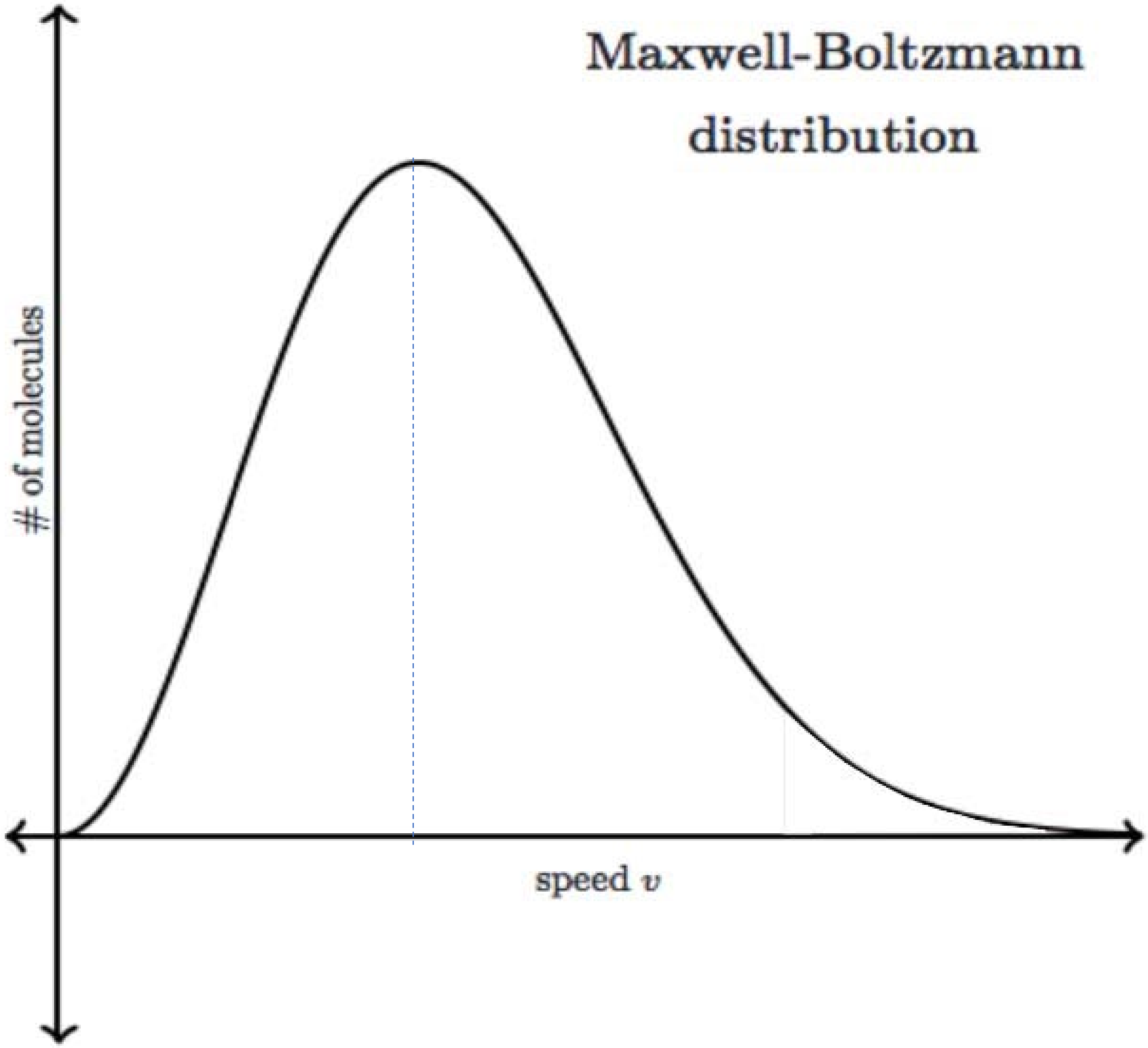


v_p = most probable speed

$$v_p = \sqrt{\frac{2RT}{M}}$$

R= Gas constant
T= temperature (Kelvin)
M=Molar Mass

Distribution of speed in a liquid is also Maxwell-Boltzmann



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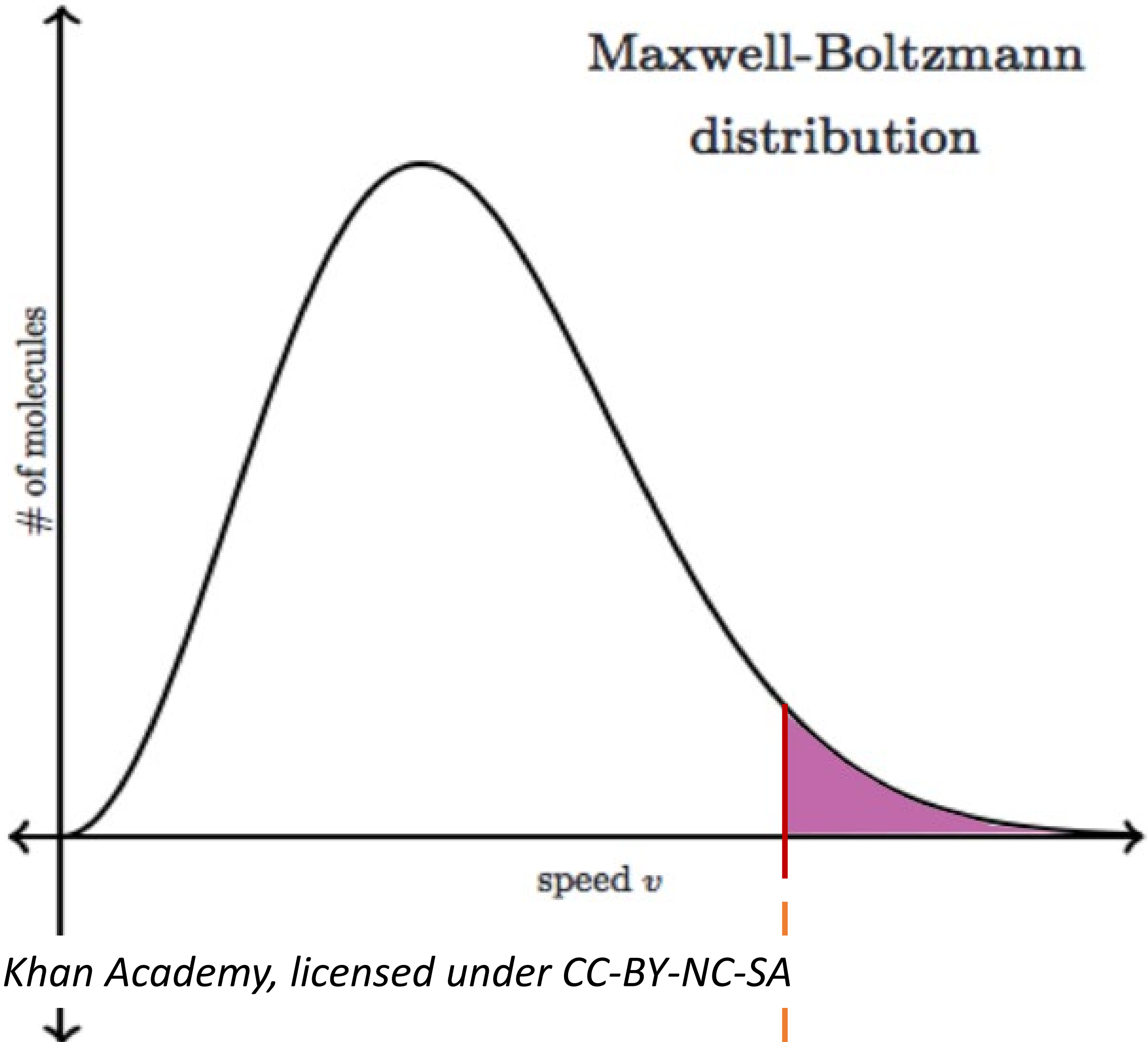
molecules will move with a large range of speeds. The faster molecules have also a higher kinetic energy
$E_k=1/2\ m\ v^2$

This energy can be used to break the H-bonds.



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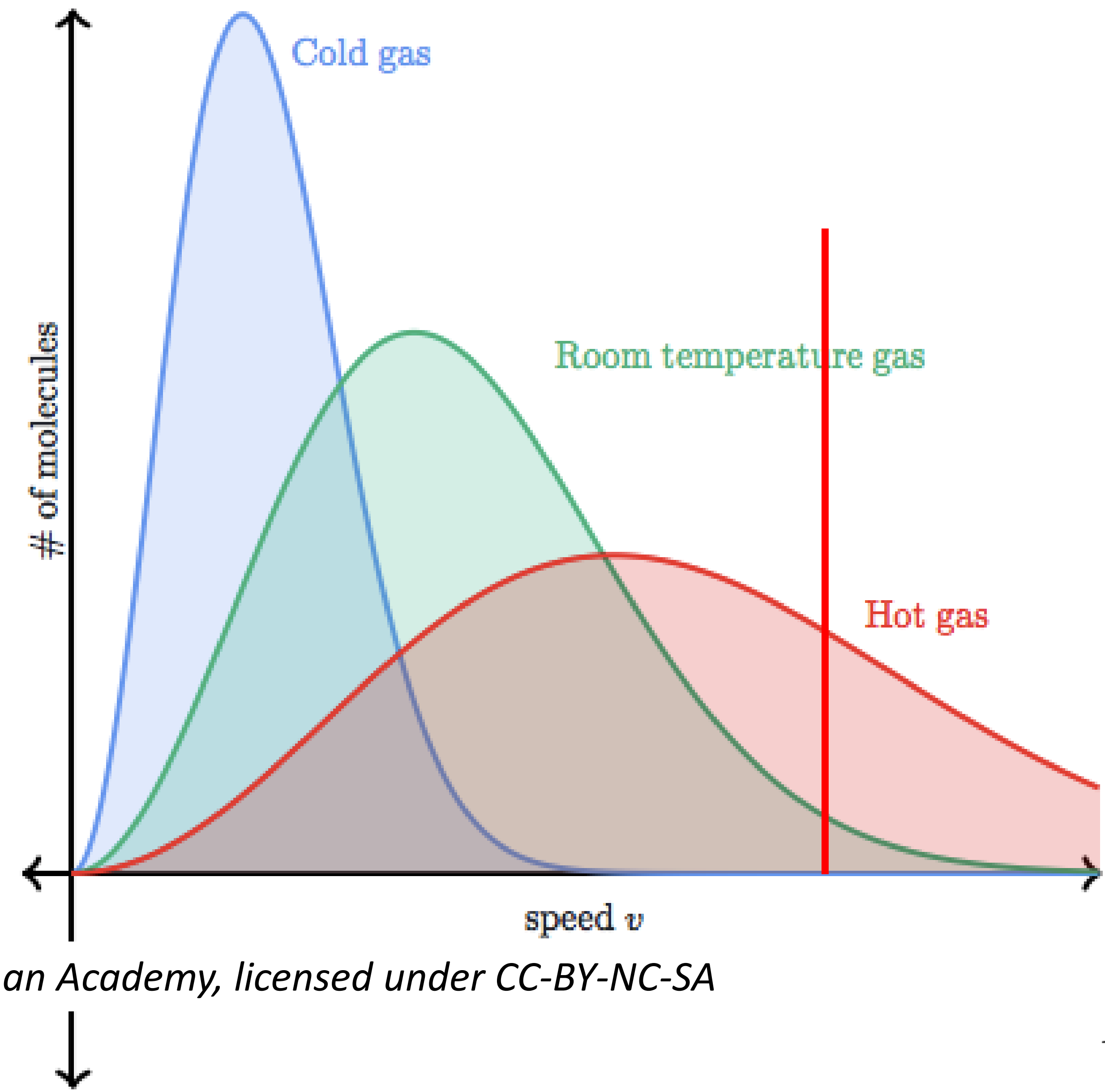
speed corresponding to the kinetic energy necessary to break the hydrogen bonds

All molecules whose velocity is higher than a certain value can break the hydrogen bonds and evaporate (if they are close to the surface)

The number of molecules breaking off from the liquid phase in a unit time is called the evaporation rate



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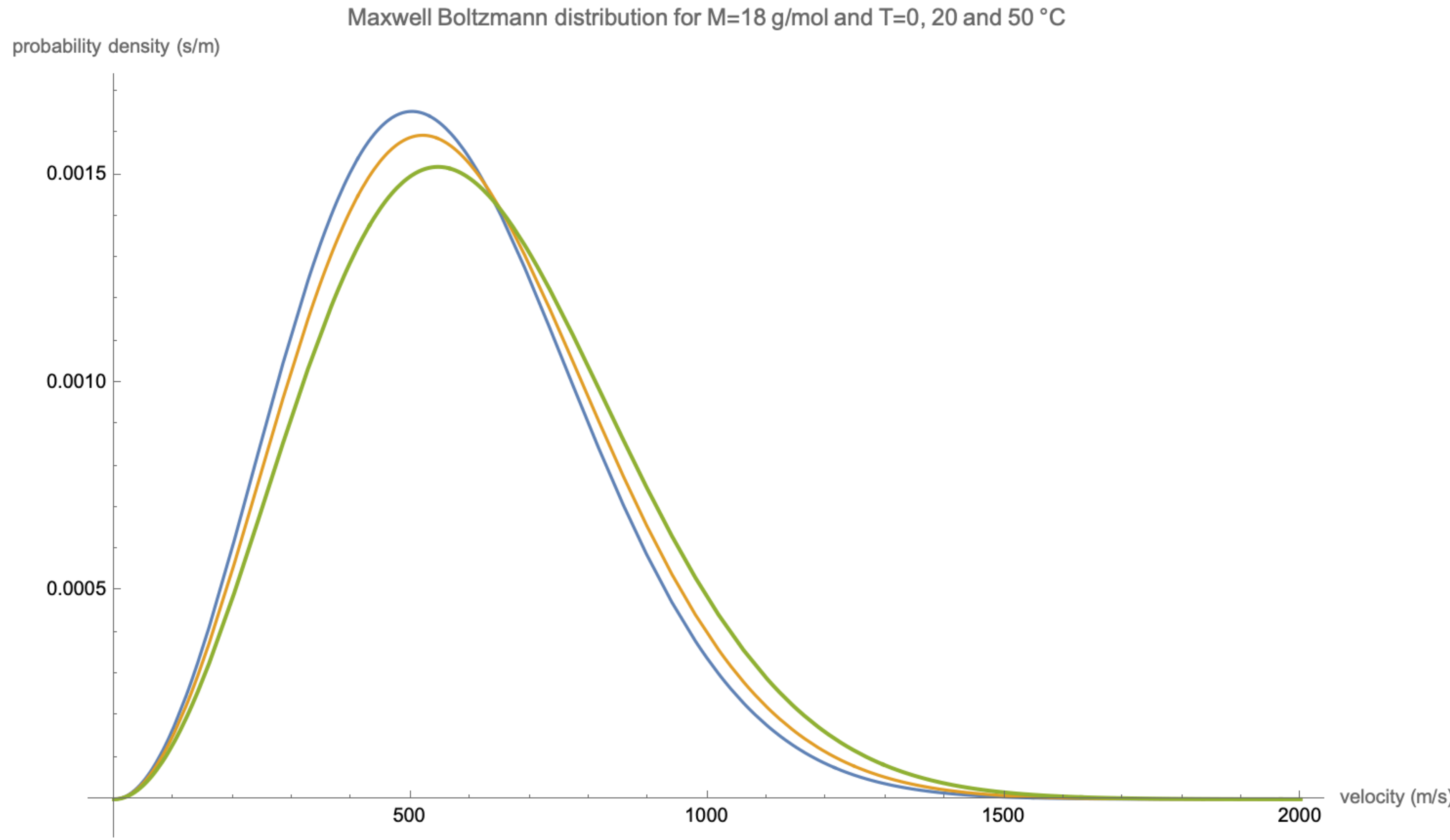
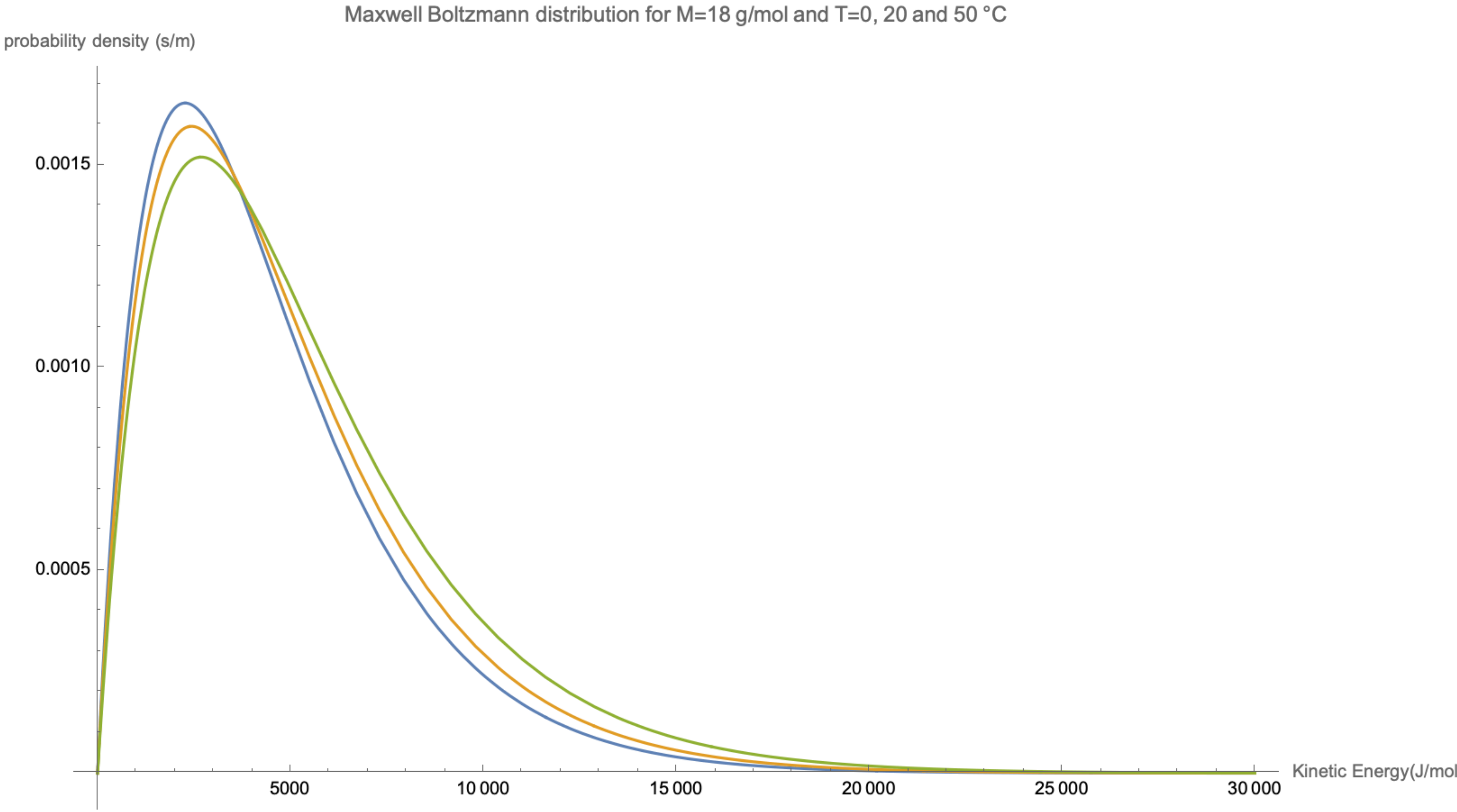
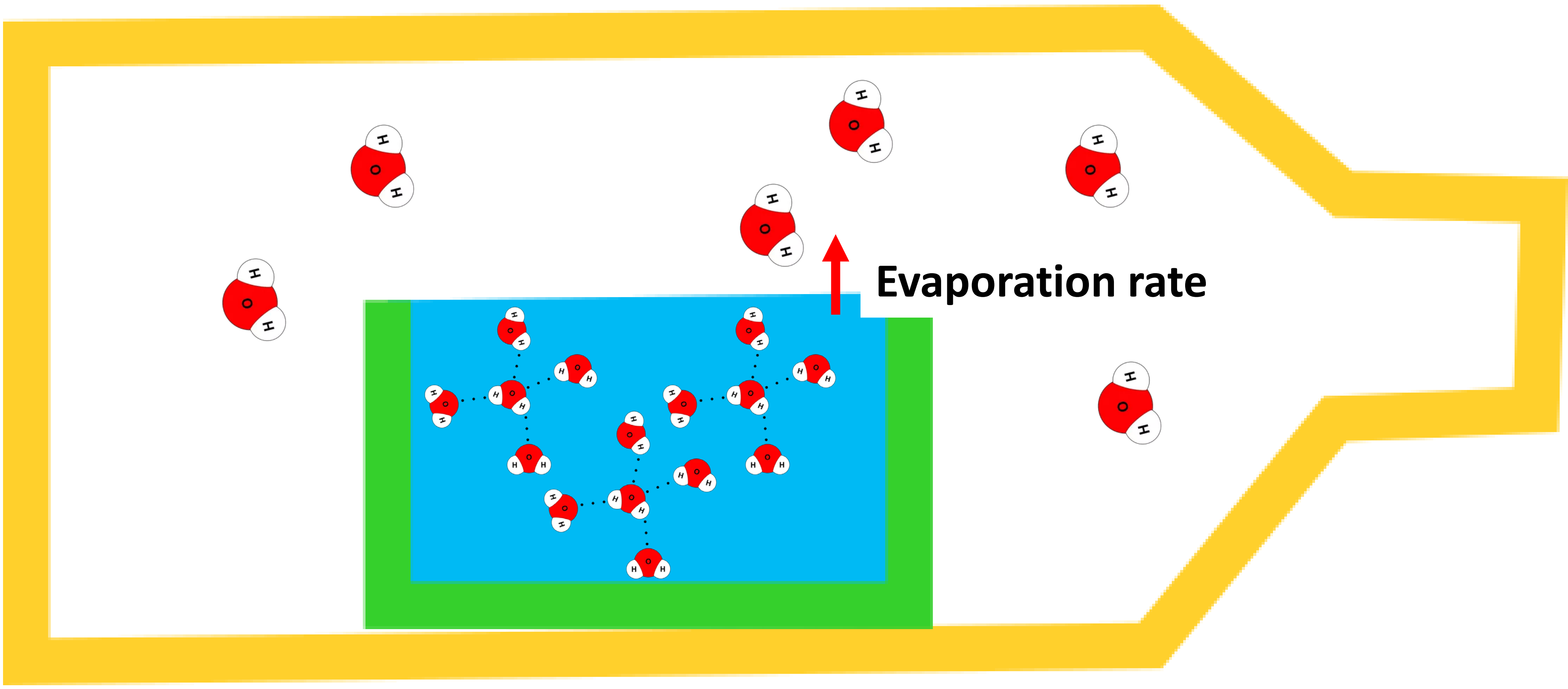
The higher the temperature, the higher the amount of molecules that can evaporate == the higher is the evaporation rate

$$v_p = \sqrt{\frac{2RT}{M}}$$

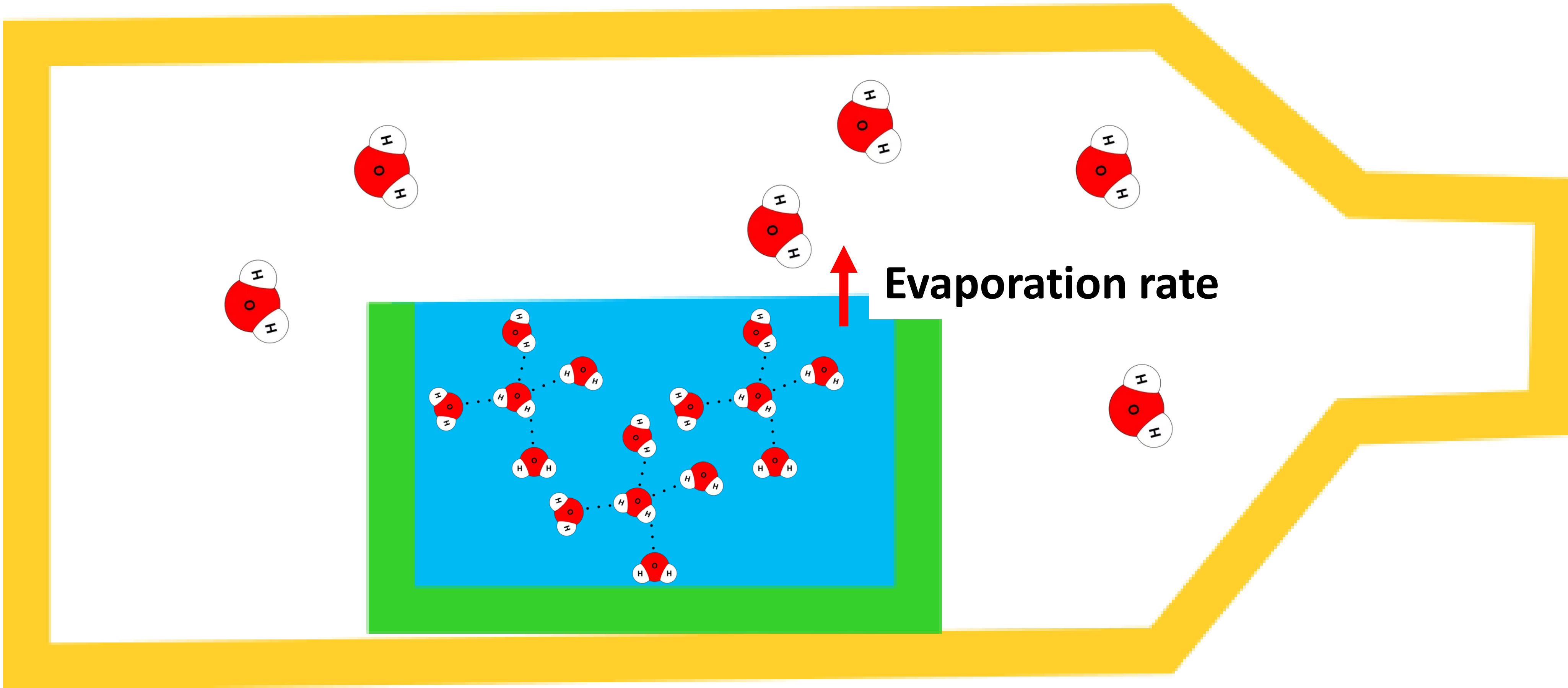

Maxwell Boltzmann distribution for M=18 g/mol and T=0, 20 and 50 °C
probability density (s/m)
0.0015
0.0010
0.0005
500
1000
1500
2000
velocity (m/s)



Maxwell Boltzmann distribution for M=18 g/mol and T=0, 20 and 50 °C
probability density (s/m)
0.0015
0.0010
0.0005
5000
10 000
15 000
20 000
25 000
30 000
Kinetic Energy(J/mol)

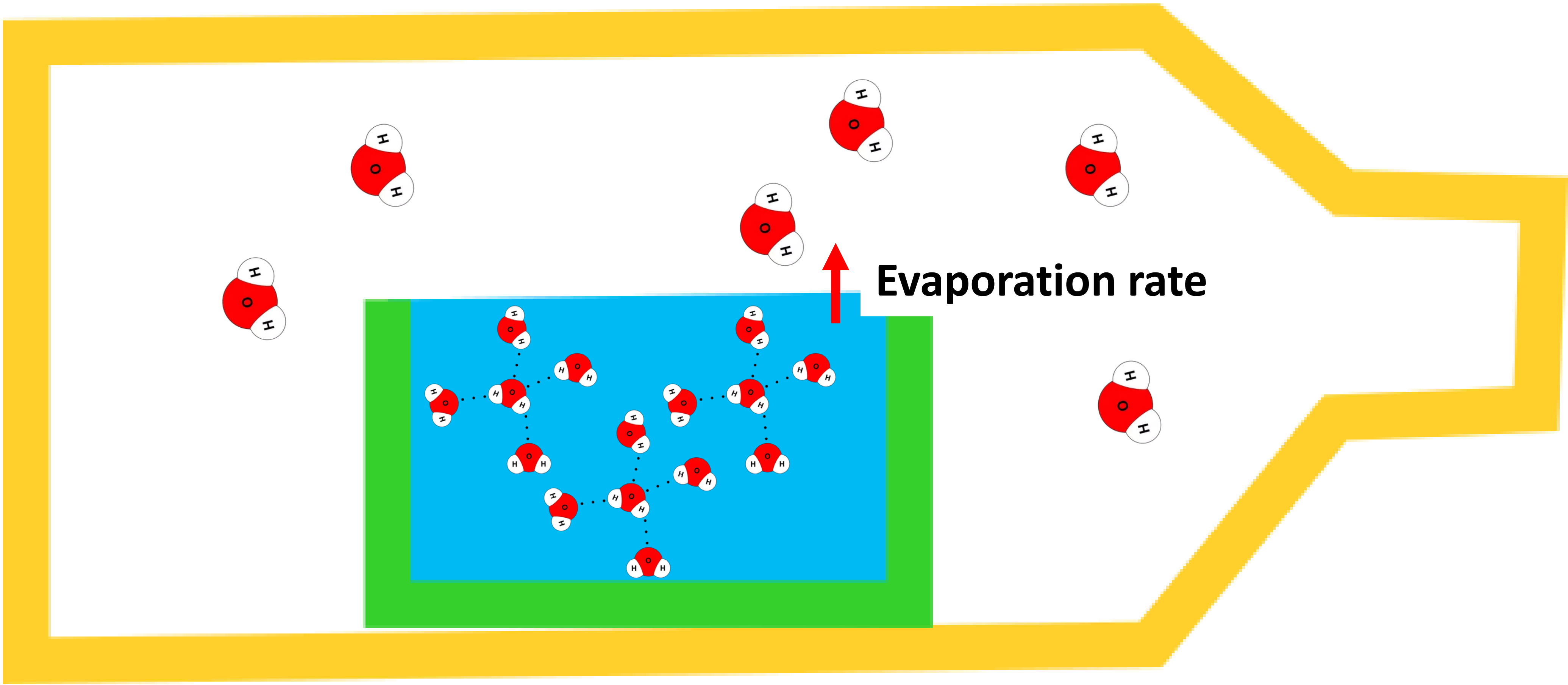


Evaporation rate = Number of molecules that evaporate in one second



Question: The evaporation rate:

1. increases with the temperature
2. decreses with the temperature
3. does not depend on the temperature



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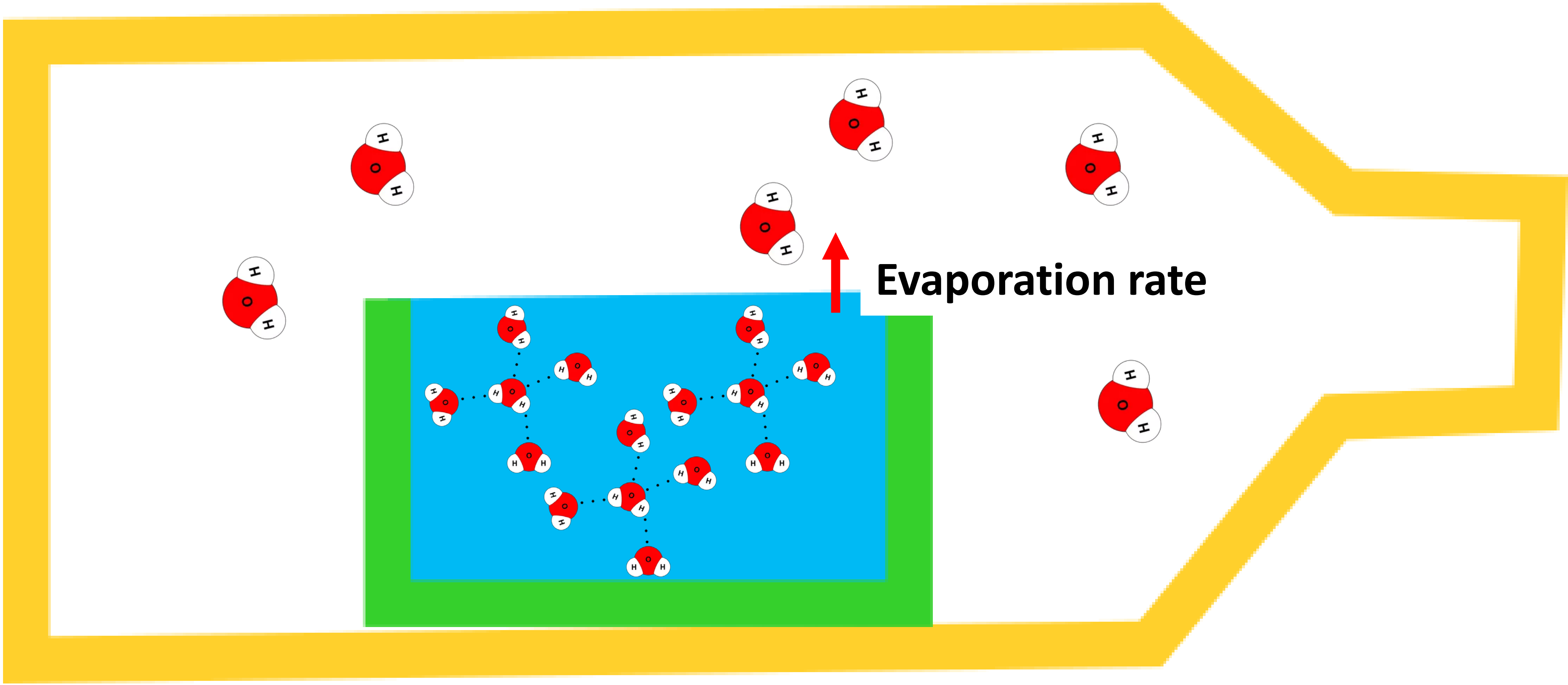
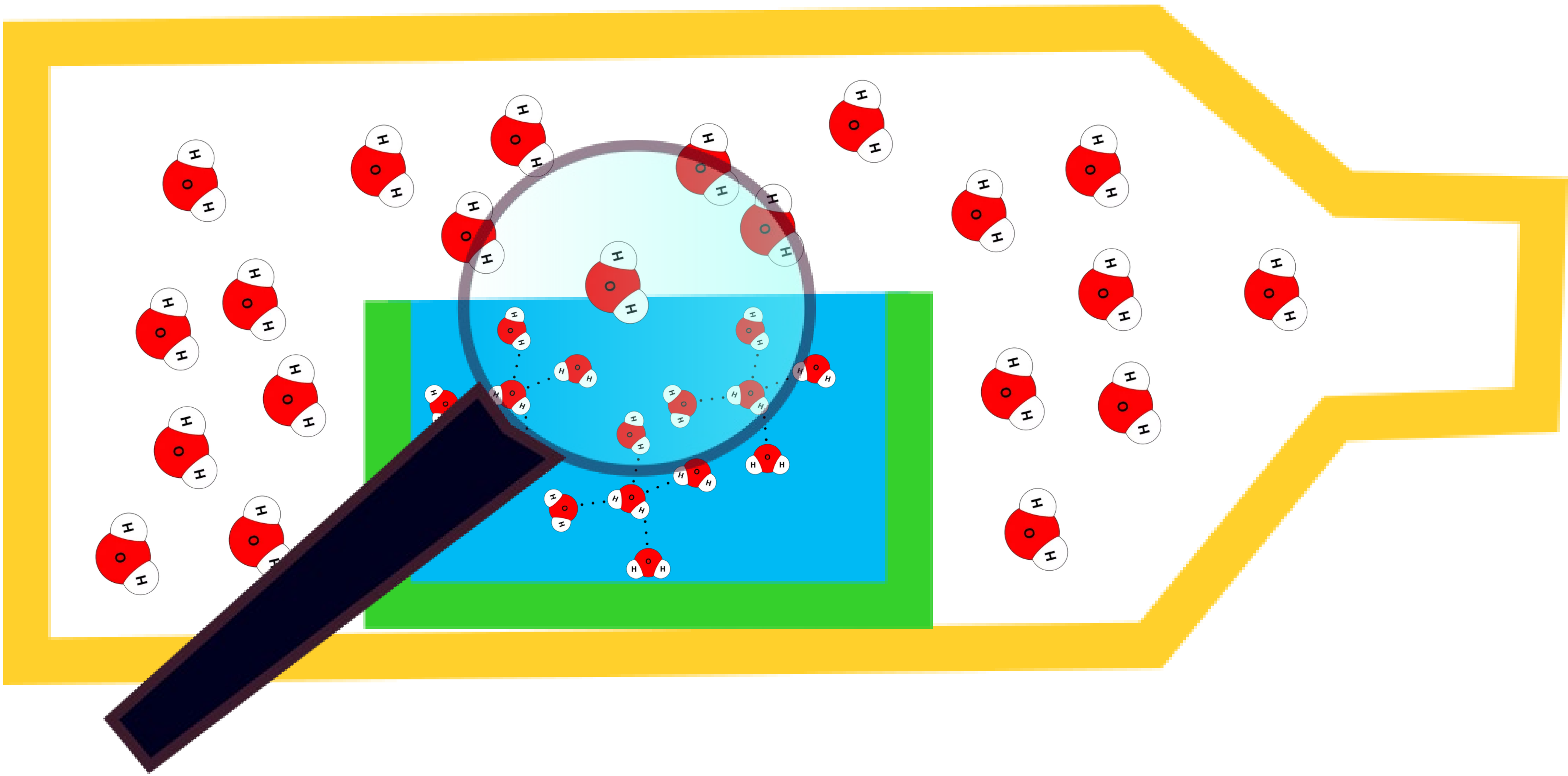
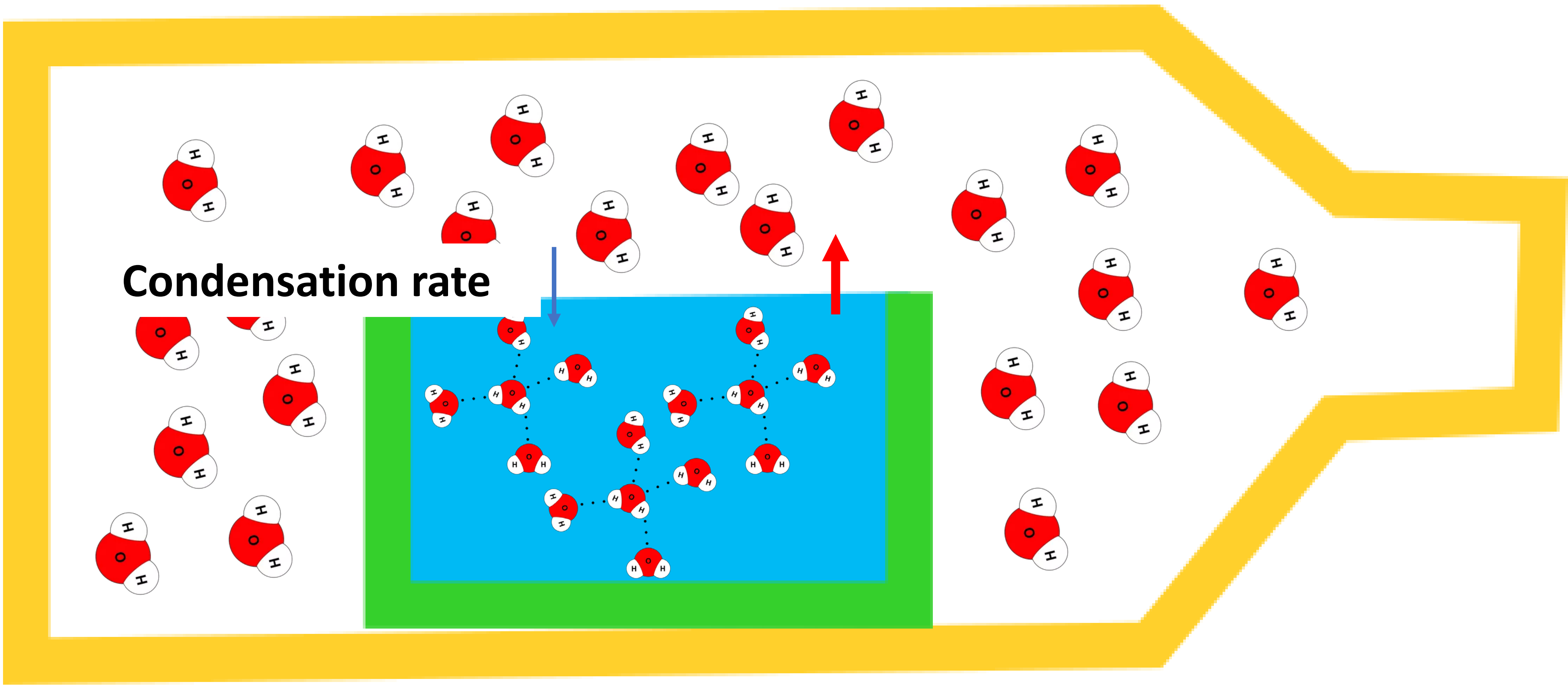


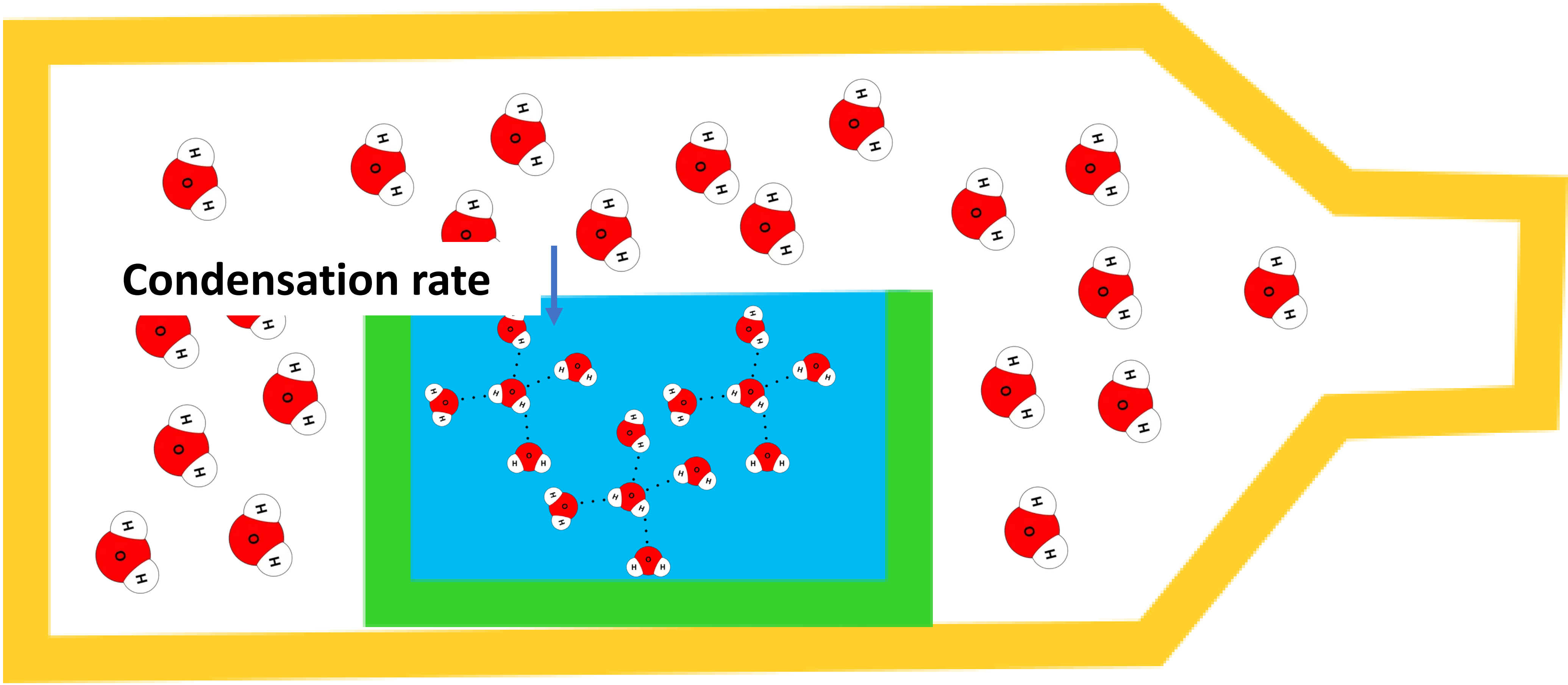
The evaporation rate is controlled by the temperature and it increases with the temperature



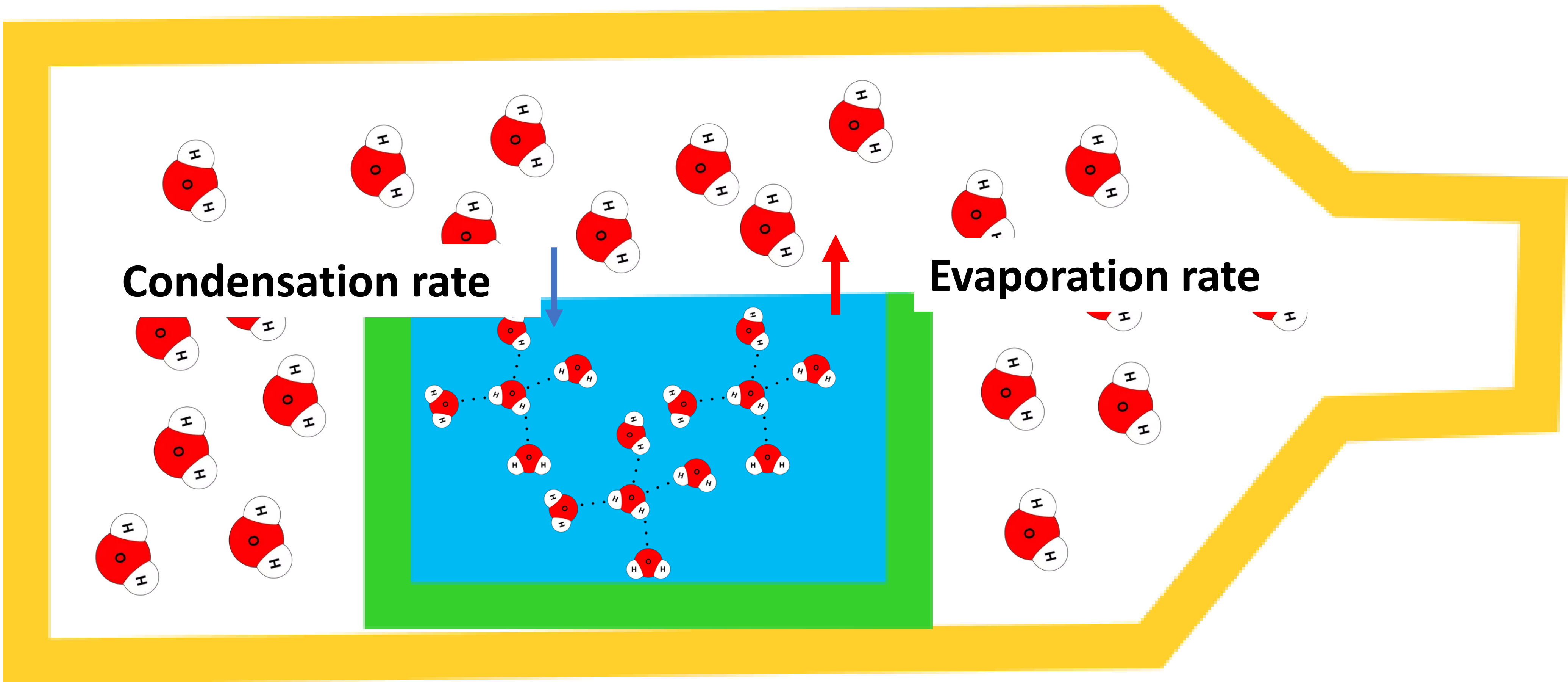
If a water vapour molecule collides with liquid water or with the walls, it can condense.



Condensation rate=Number of molecules that condense per second



The condensation rate increases with increasing concentration of water vapour molecules. The condensation rate is controlled by the number of molecules present in the air volume.


Condensation rate
Evaporation rate

We want to understand:

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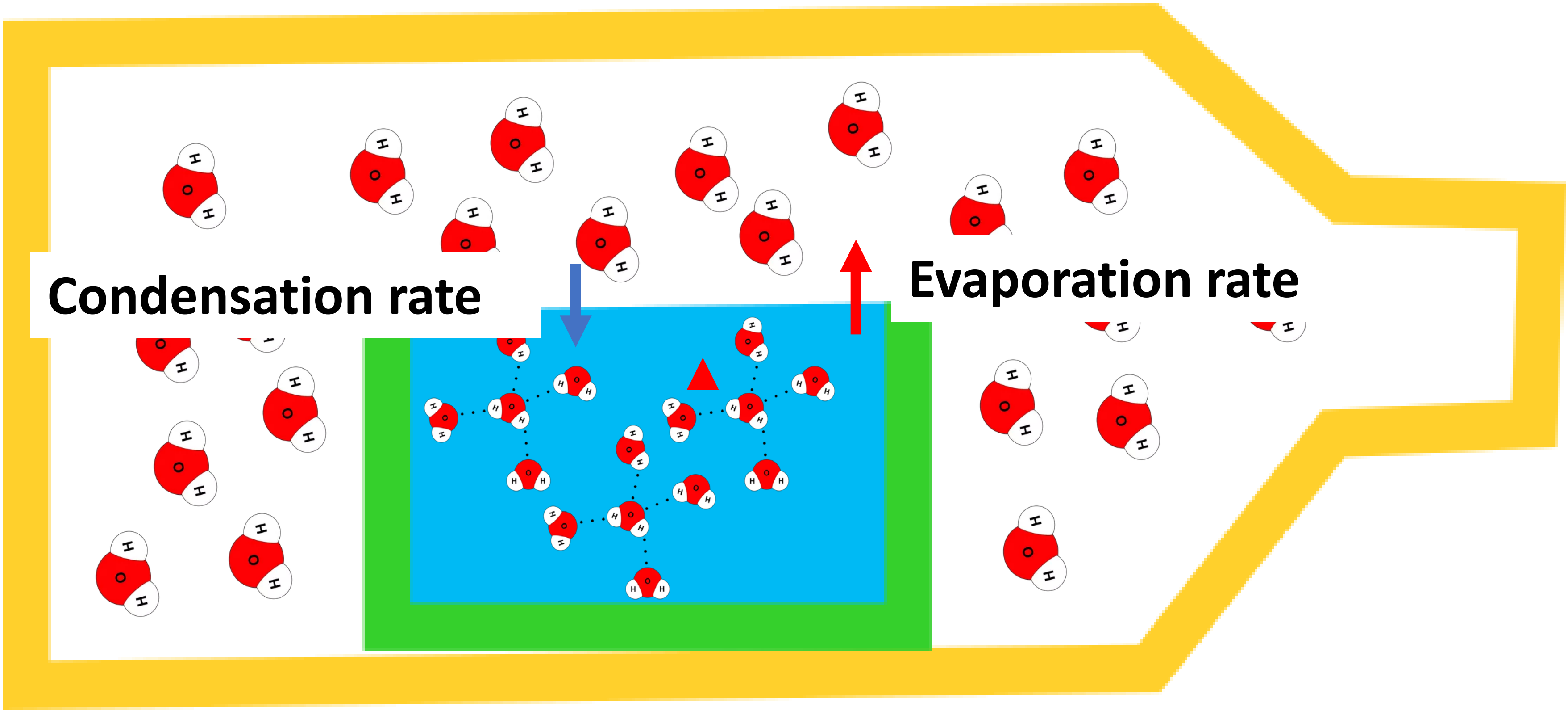
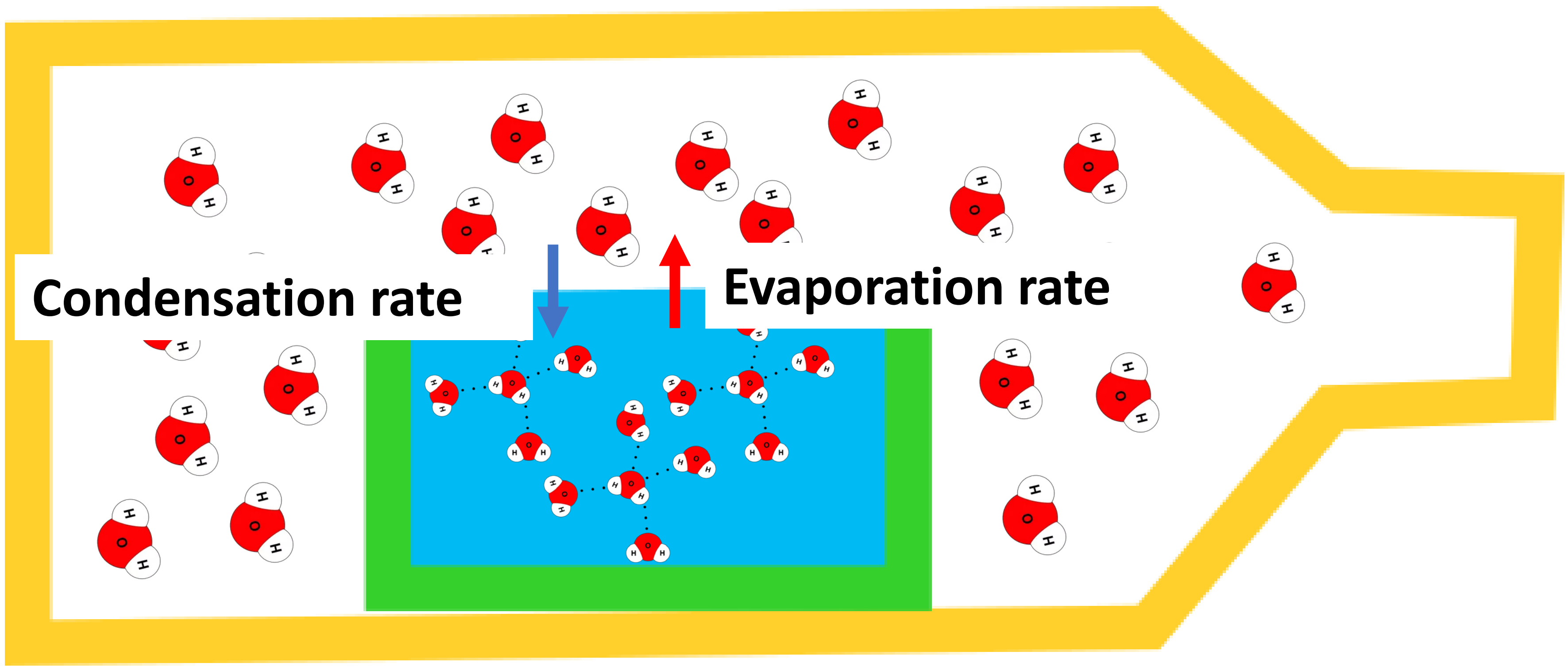
If the water level in the small container decreases

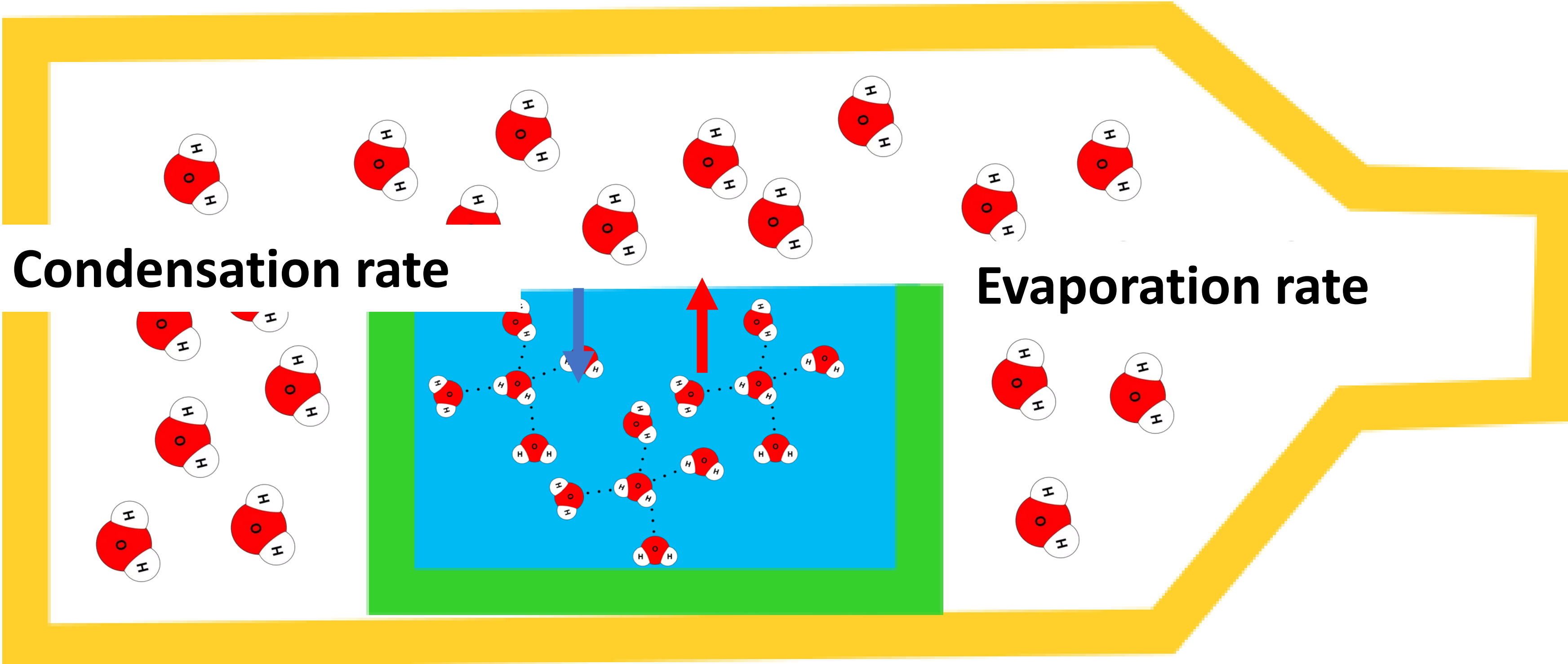


The amount of water vapour molecules in the bottle increases as long as the evaporation rate is larger than the condensation rate. When the evaporation rate becomes equal to the condensation rate, the amount of water vapour molecules in the bottle stops increasing.



Evaporation rate= condensation rate

Dynamic equilibrium==amount of water vapour molecules is constant but water molecules evaporate and condense all the time



Evaporation rate= condensation rate

Max number of water molecules in the bottle

In the air volume the concentration of water vapour molecules has reached saturation

$$\mathbf{RH}=\frac{\text{Concentration of water molecules in a volume}}{\text{Max concentration of water molecules in the volume}} \times 100$$

Concentration of water molecules in a volume=Absolute Humidity

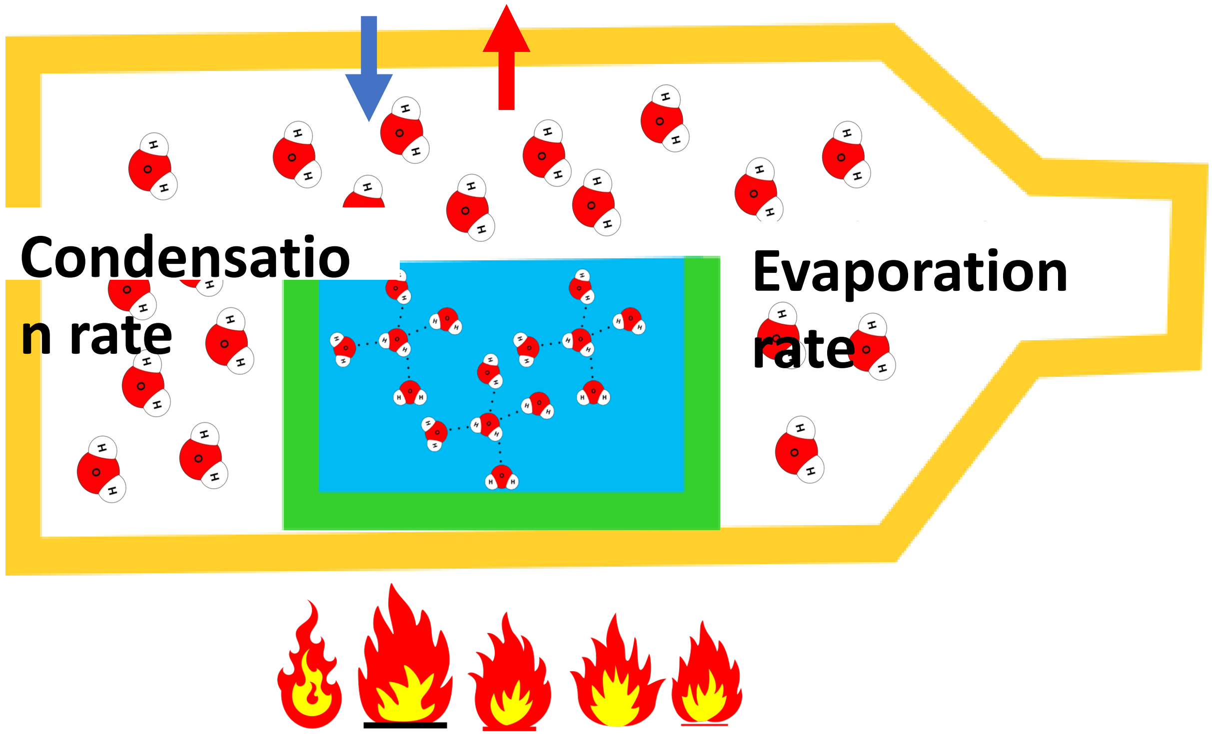
Max concentration of water molecules in a volume= c_{sat}

If AH=c_{sat} ->RH=100%

A definition of relative humidity that better clarifies the process going on :

$$\mathbf{RH=} \frac{\text{condensation rate}}{\text{evaporation rate}} \times 100$$

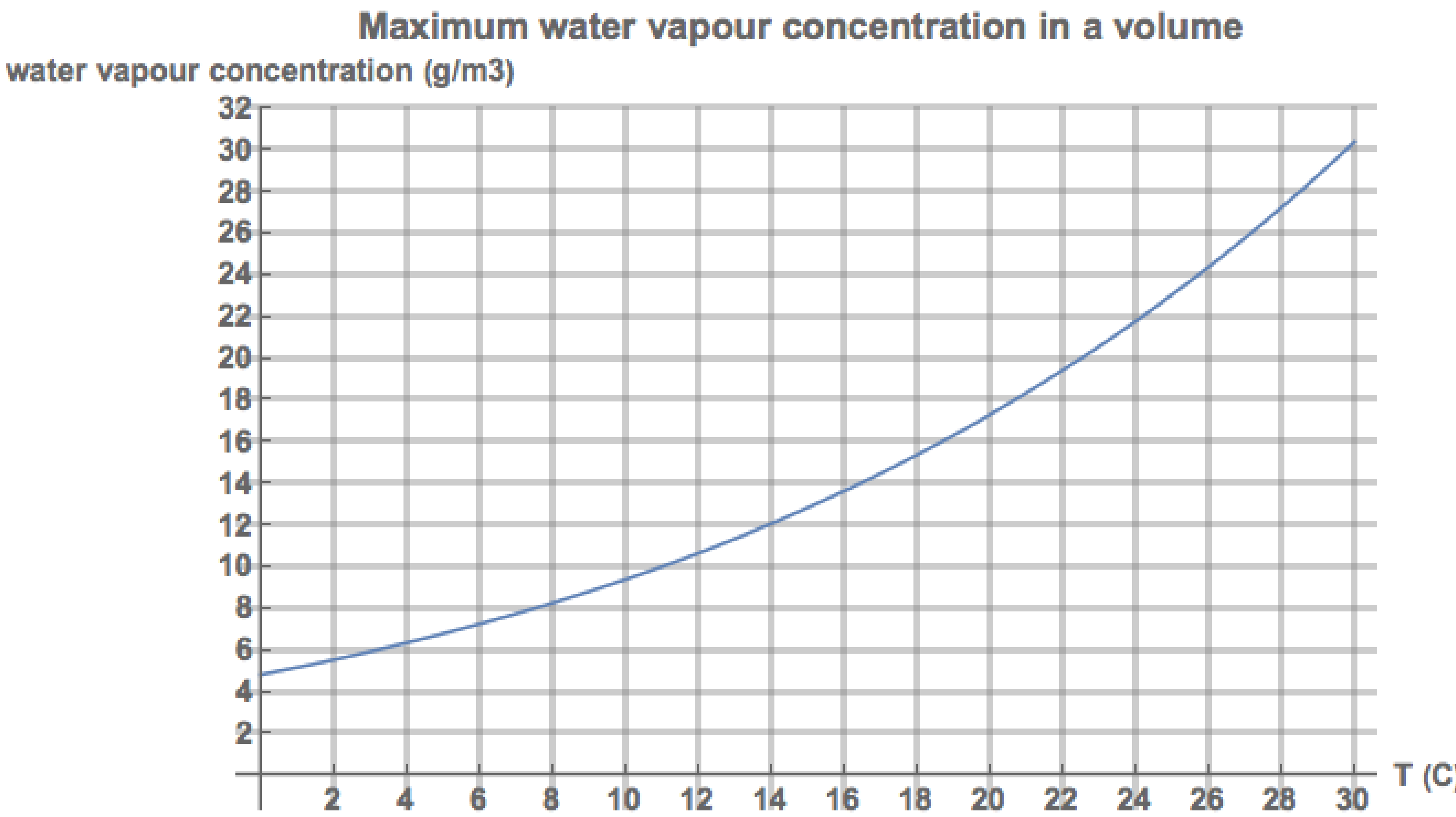
Temperature dependency of the maximum concentration of water vapour in the volume



T increases → evaporation rate increases →condensation rate increases

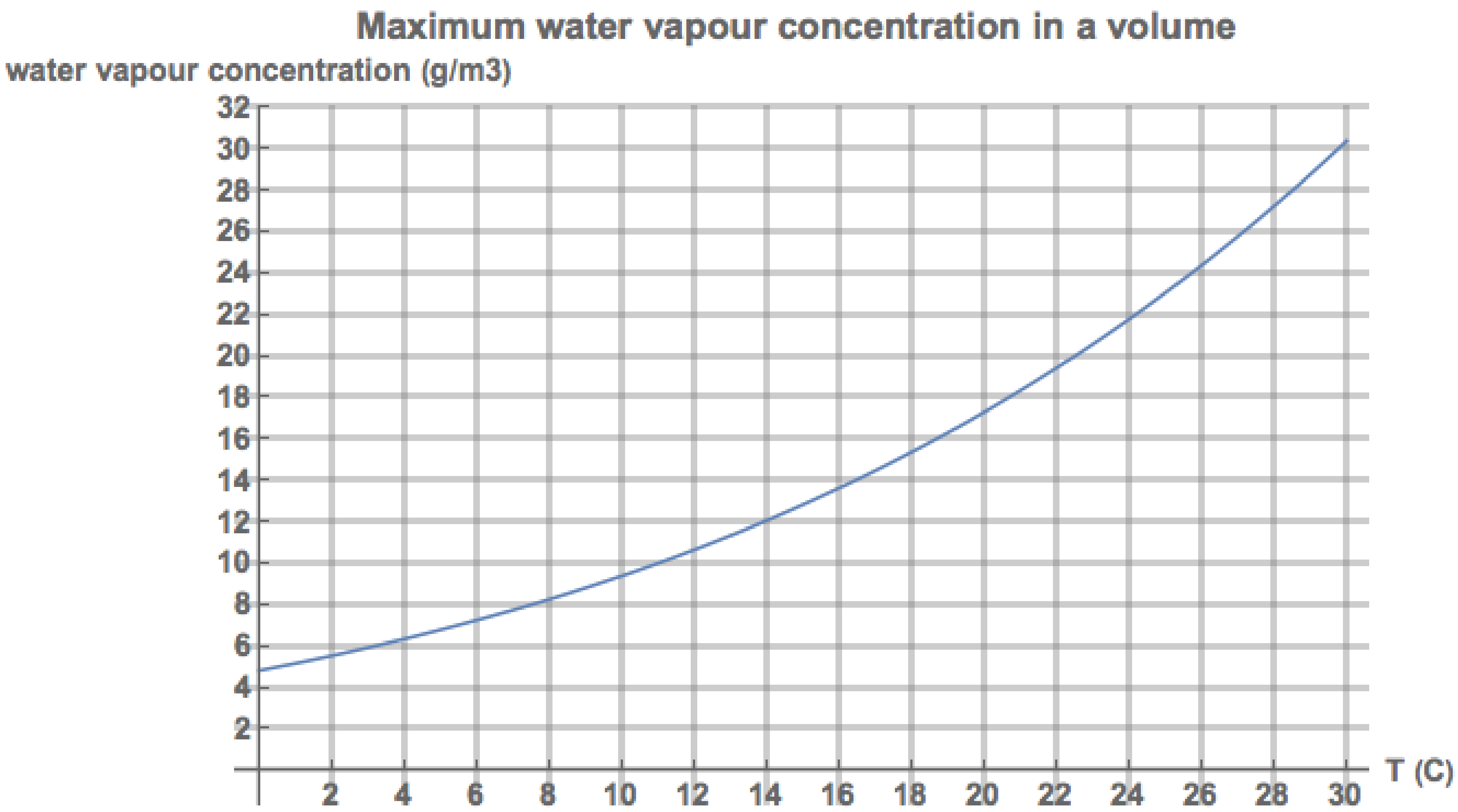
when evaporation rate=condensation rate → RH=100%

equilibrium established at a higher absolute humidity temperature dependency of c_{sat}

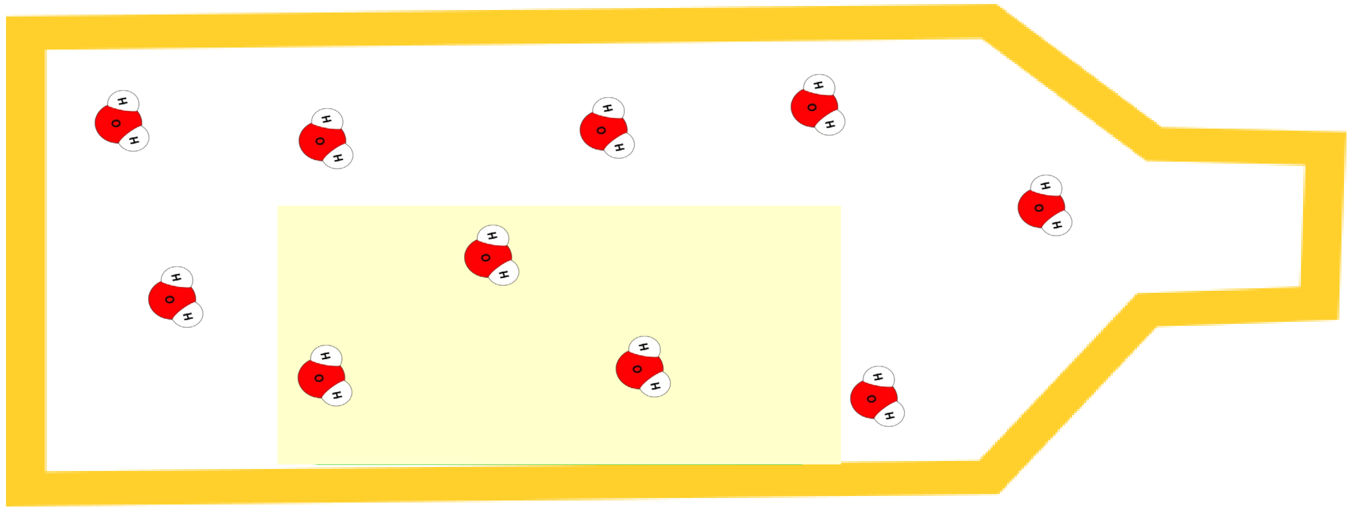


The volume of the bottle is 2L, the temperature 20 °C. Which is the mass of water necessary to saturate this volume?

temperature dependency of c_{sat}



The volume of the bottle is 2L, the temperature 20 °C. Which is the mass of water necessary to saturate this volume?0.034 g – at saturation water vapour molecules do not «fill» the volume

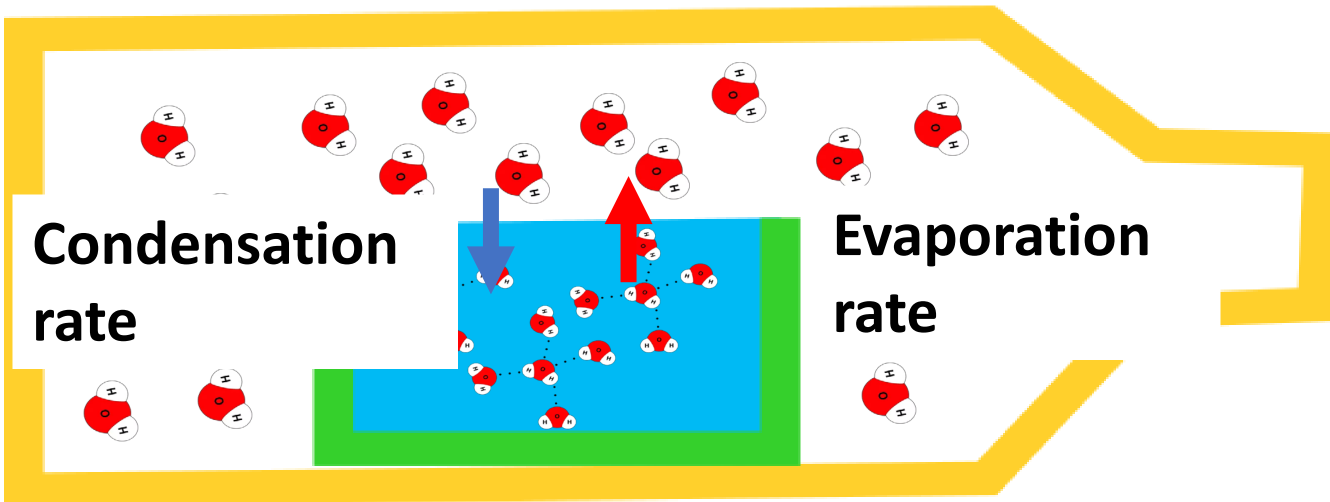


Containers or rooms usually do not contain liquid water.

relative humidity, absolute humidity and saturation concentration can still be defined.

Optional

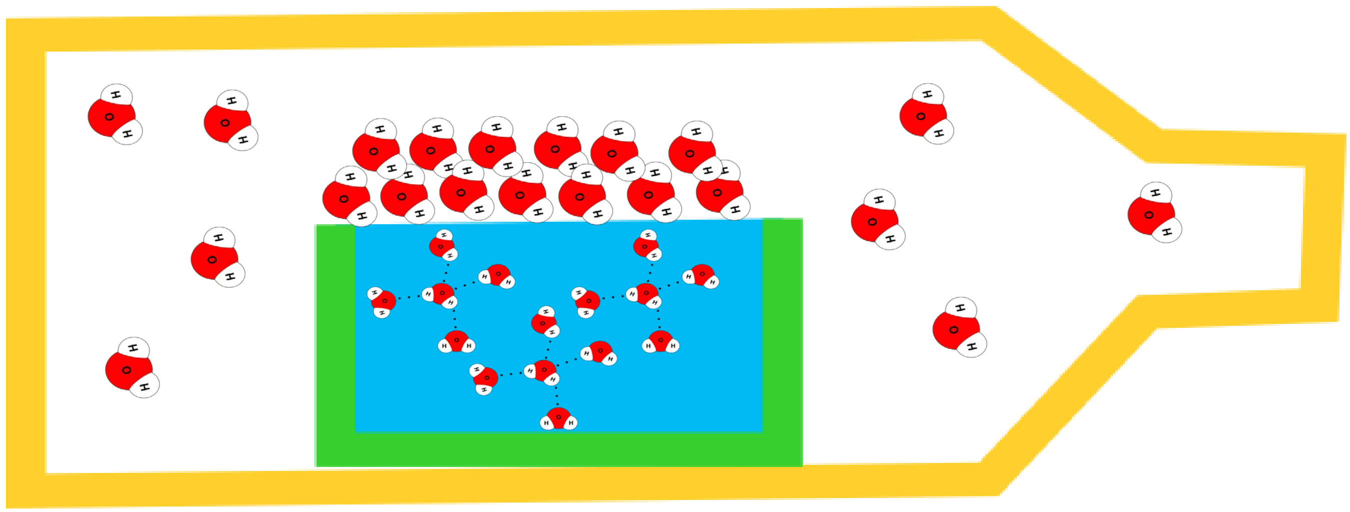
Factors affecting the time necessary to reach equilibrium



The time necessary to reach dynamic equilibrium depends on:

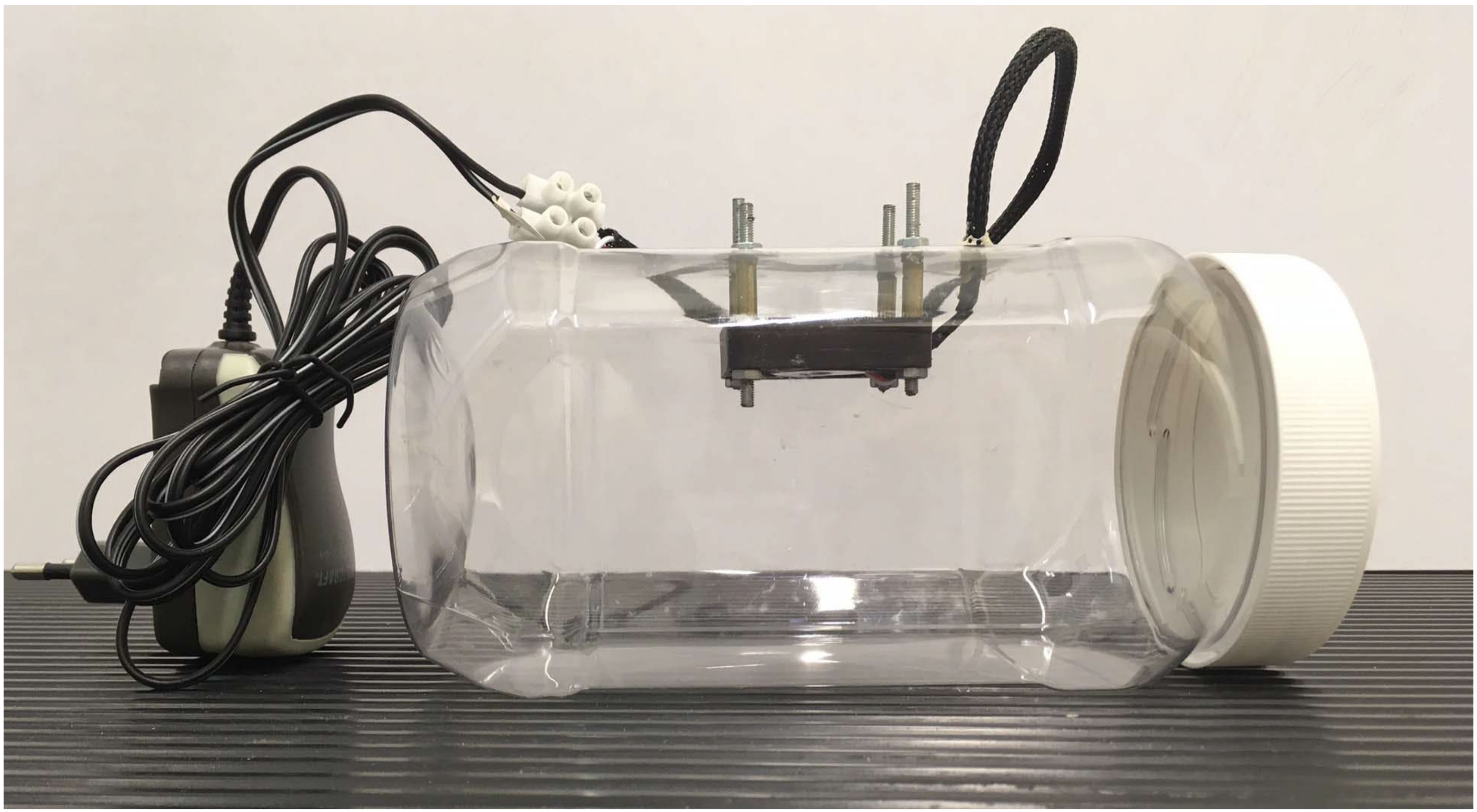
- RH in the bottle
- Temperature of the air and water
- Concentration gradients in the bottle
- Temperature gradients in the water

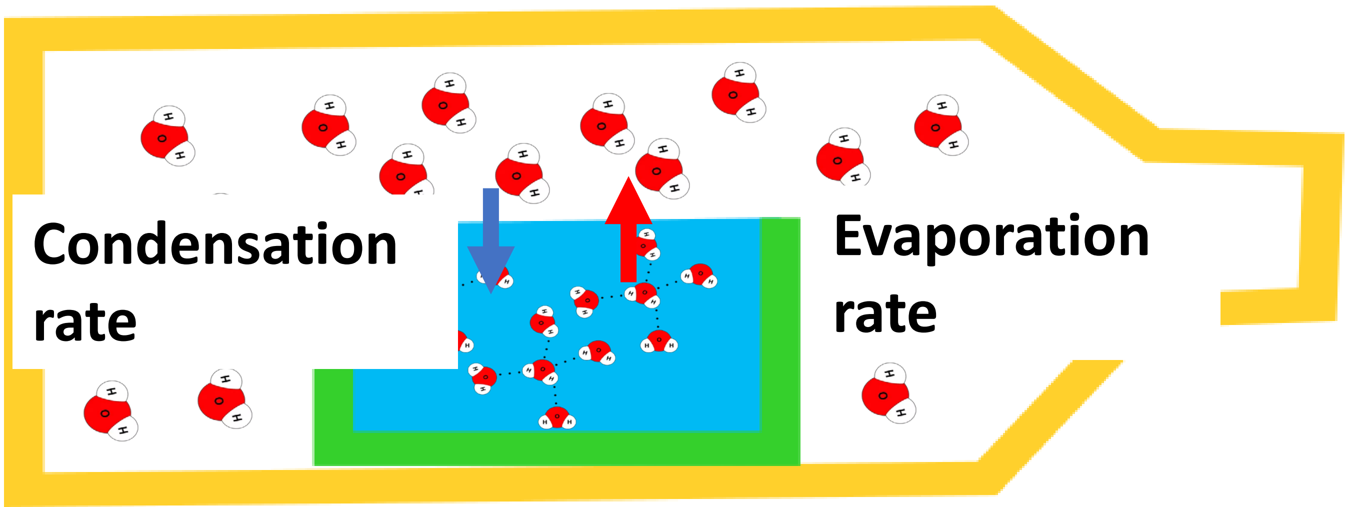
Concentration gradients in the volume



layers of water vapour close to the surface create a local equilibrium == a layer at RH=100% that decreases net evaporation

Ventilation removes concentration gradients



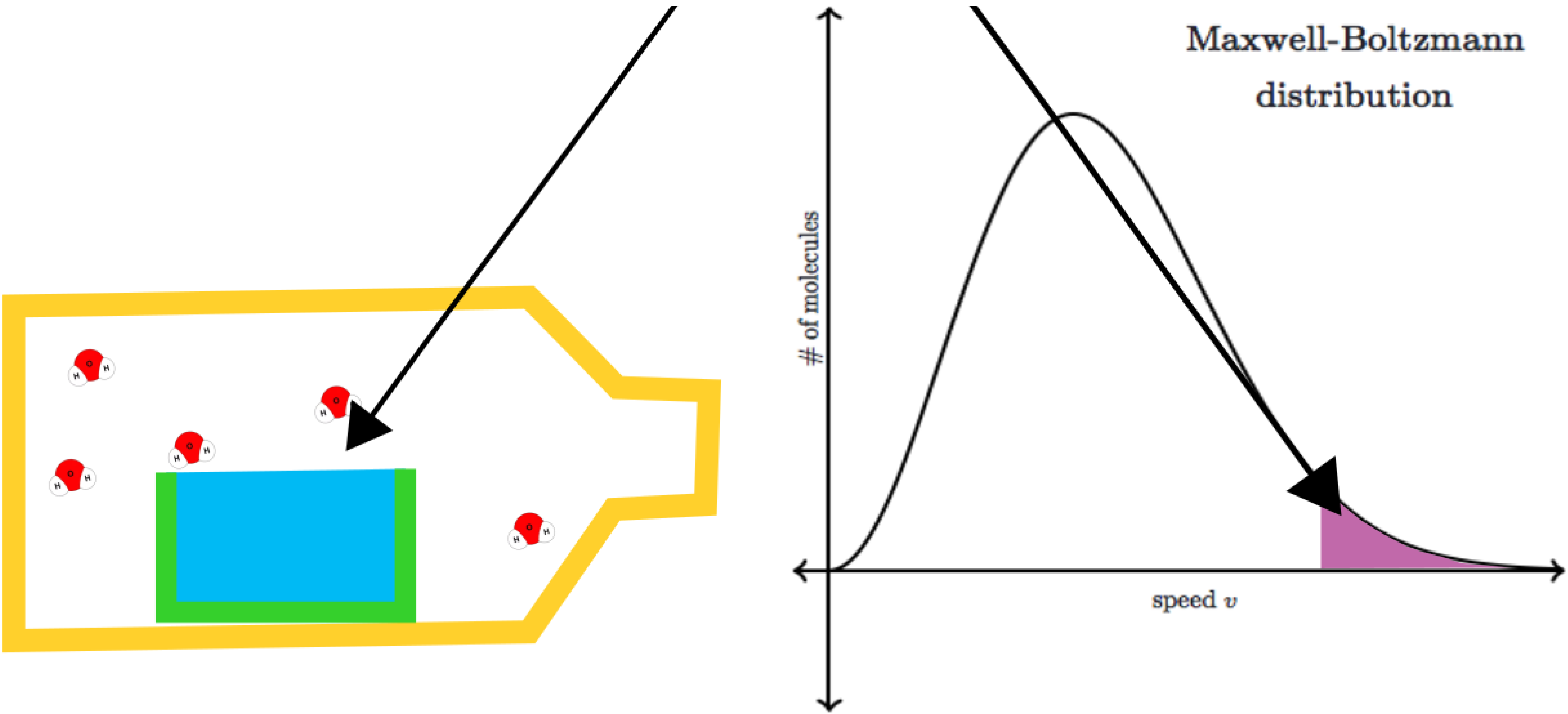


The time necessary to reach dynamic equilibrium depends on:

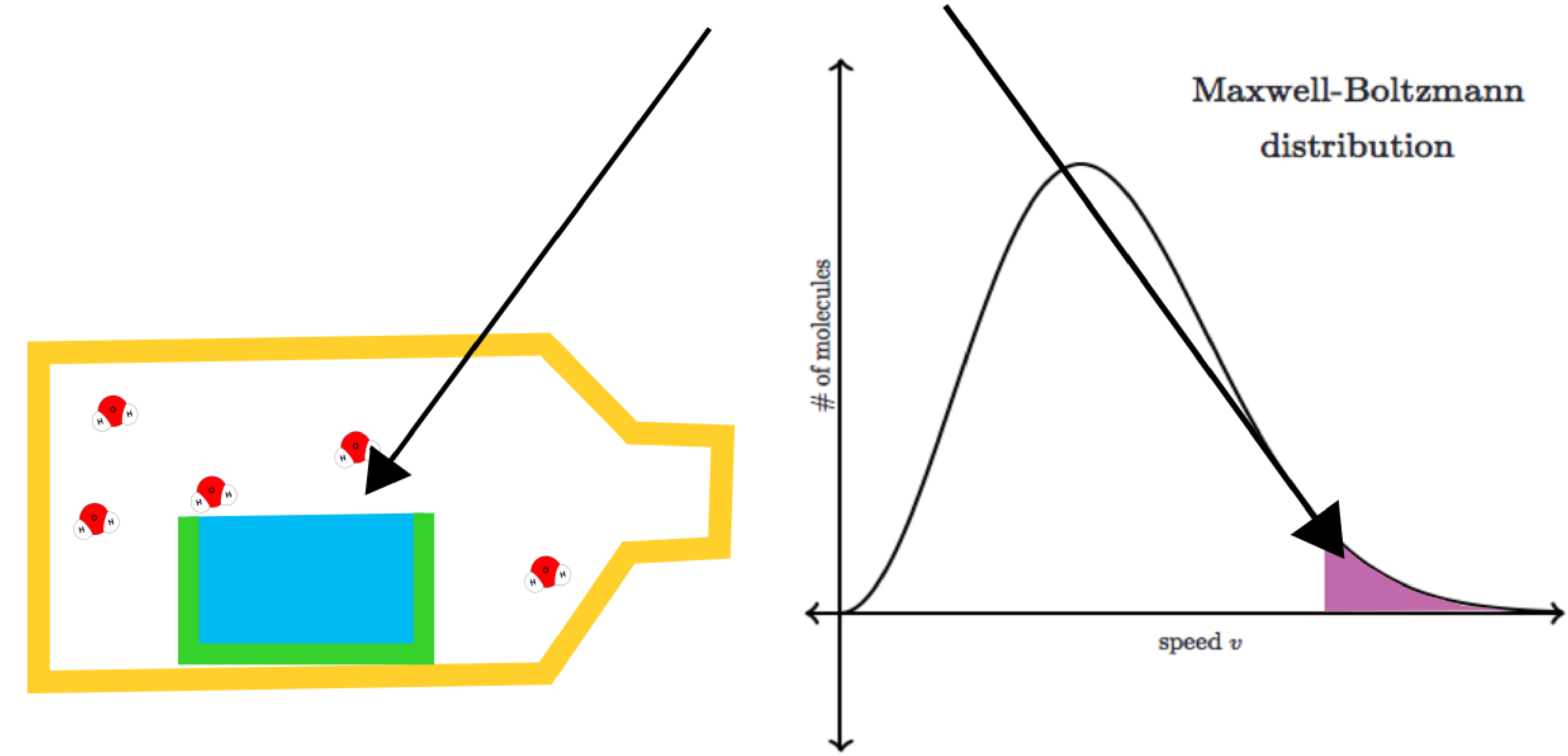
- RH in the bottle
- Temperature of the air and water
- Concentration gradients in the bottle
- Temperature gradients in the water

Temperature gradients in the water

the fast molecules evaporates and the average molecular velocity decreases

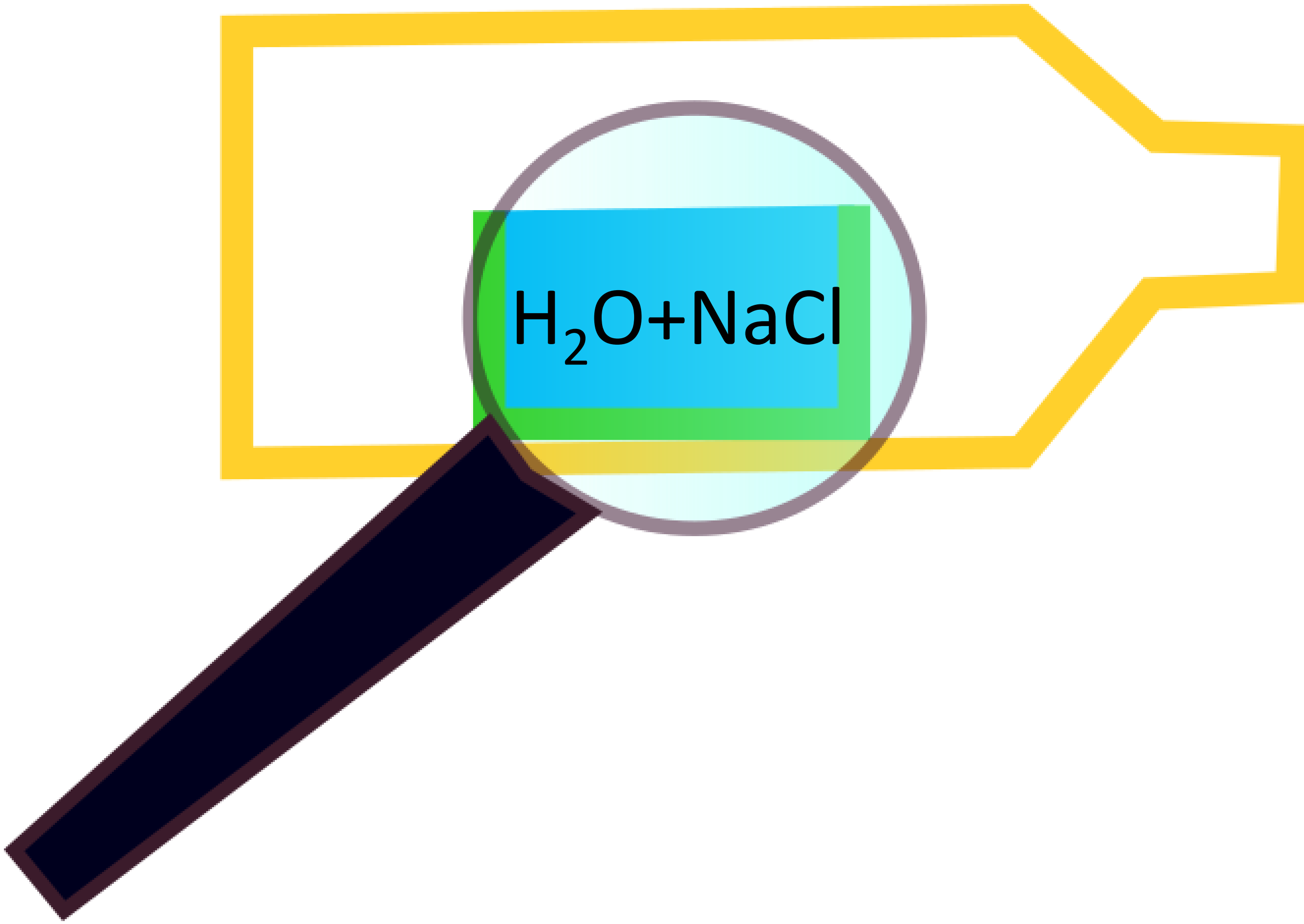


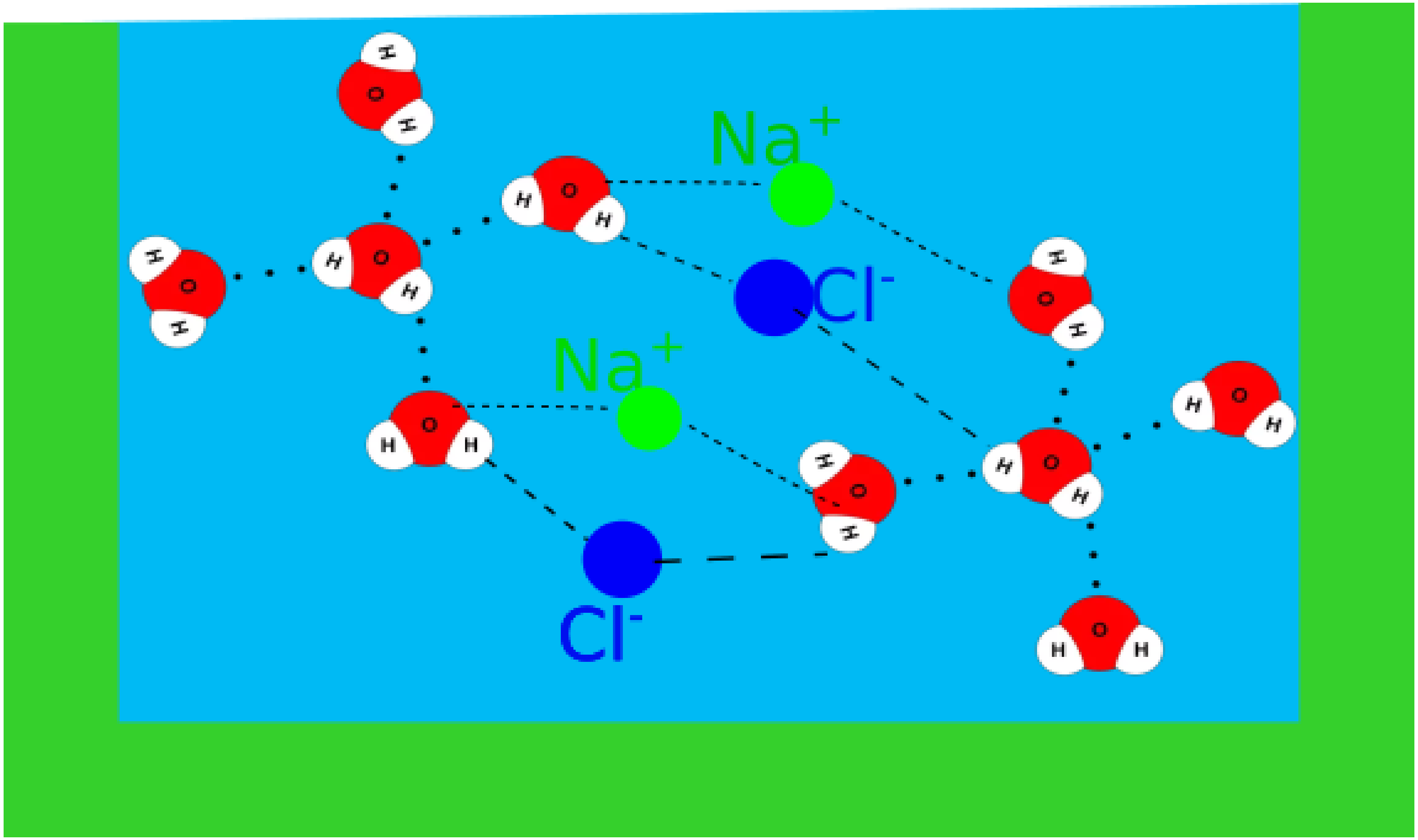
Die "schnelle" Moleküle können verdunsten



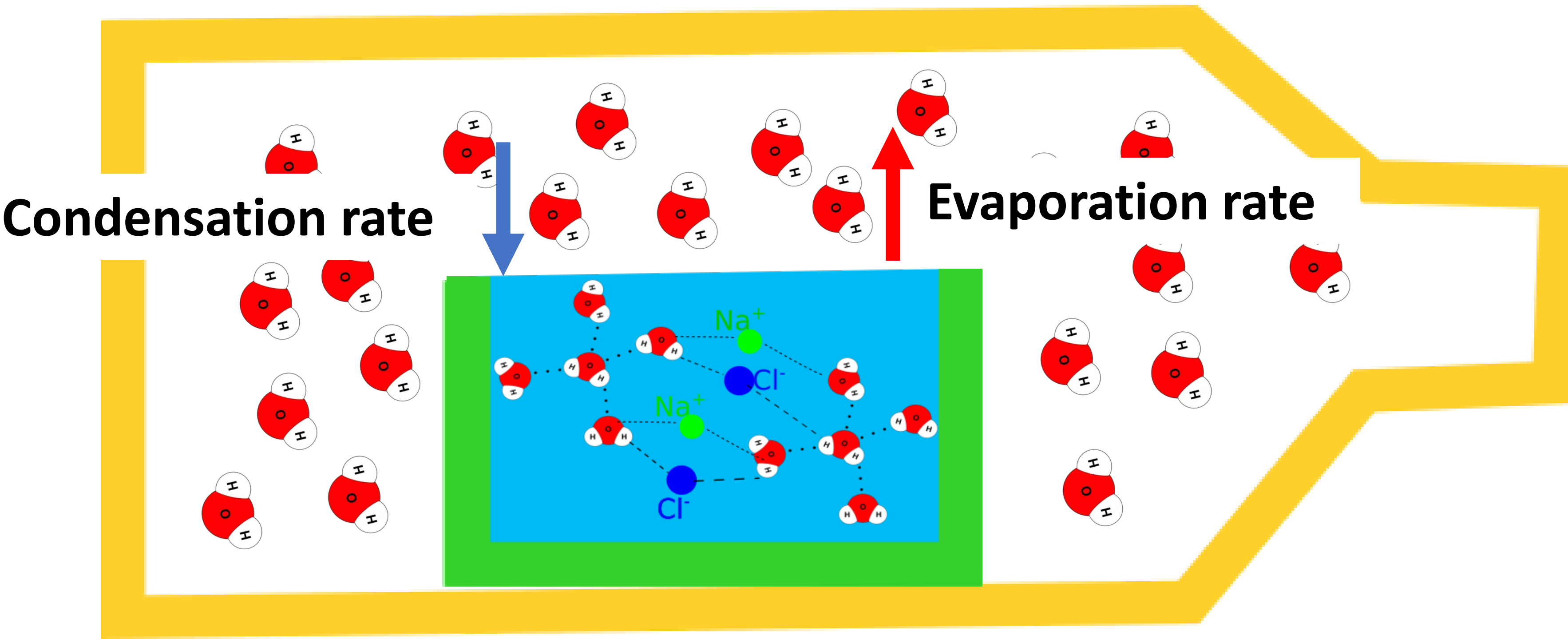
The temperature of the water at the surface decreases-> the evaporation rate decreases = evaporative cooling

Optional
The RH in equilibrium with saturated salt solutions


$H_2O+NaCl$

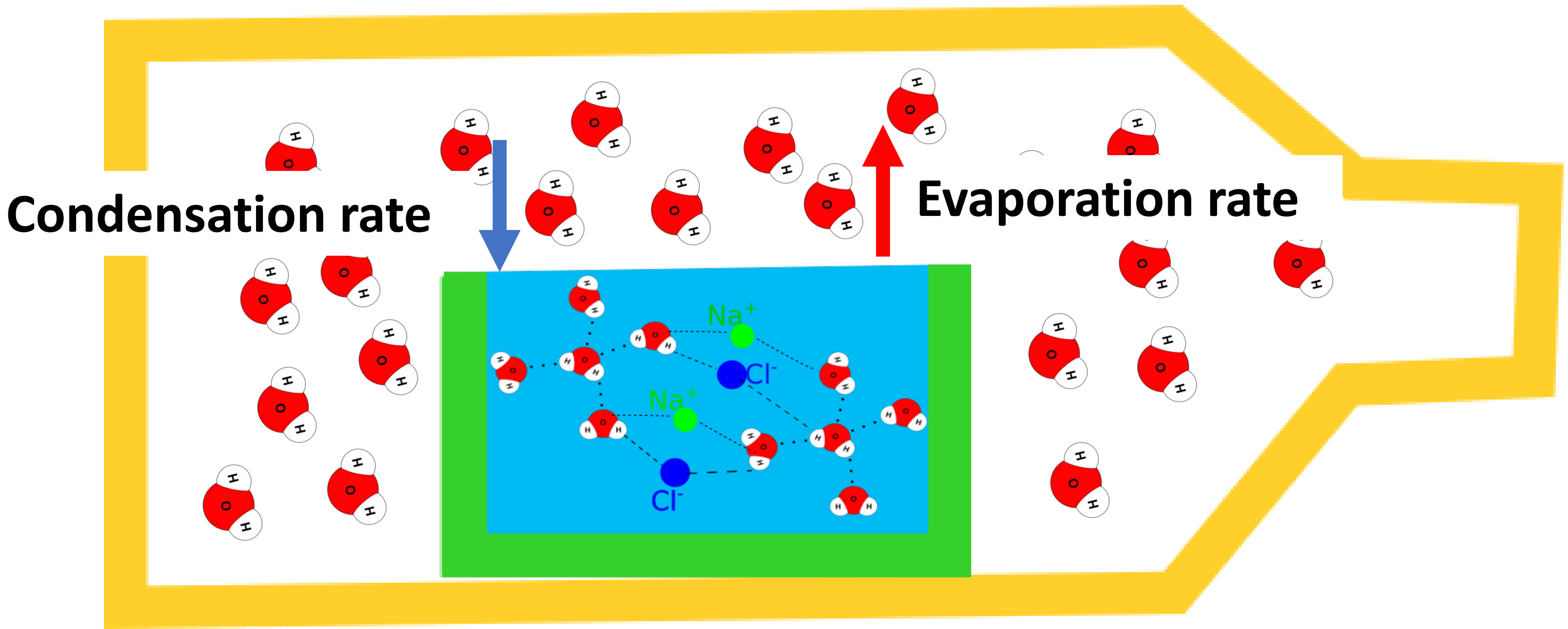


The Na+ and Cl- ions place themselves between the water molecules



The evaporation rate is

A) equal to the evaporation rate in pure water
B) higher
C) lower



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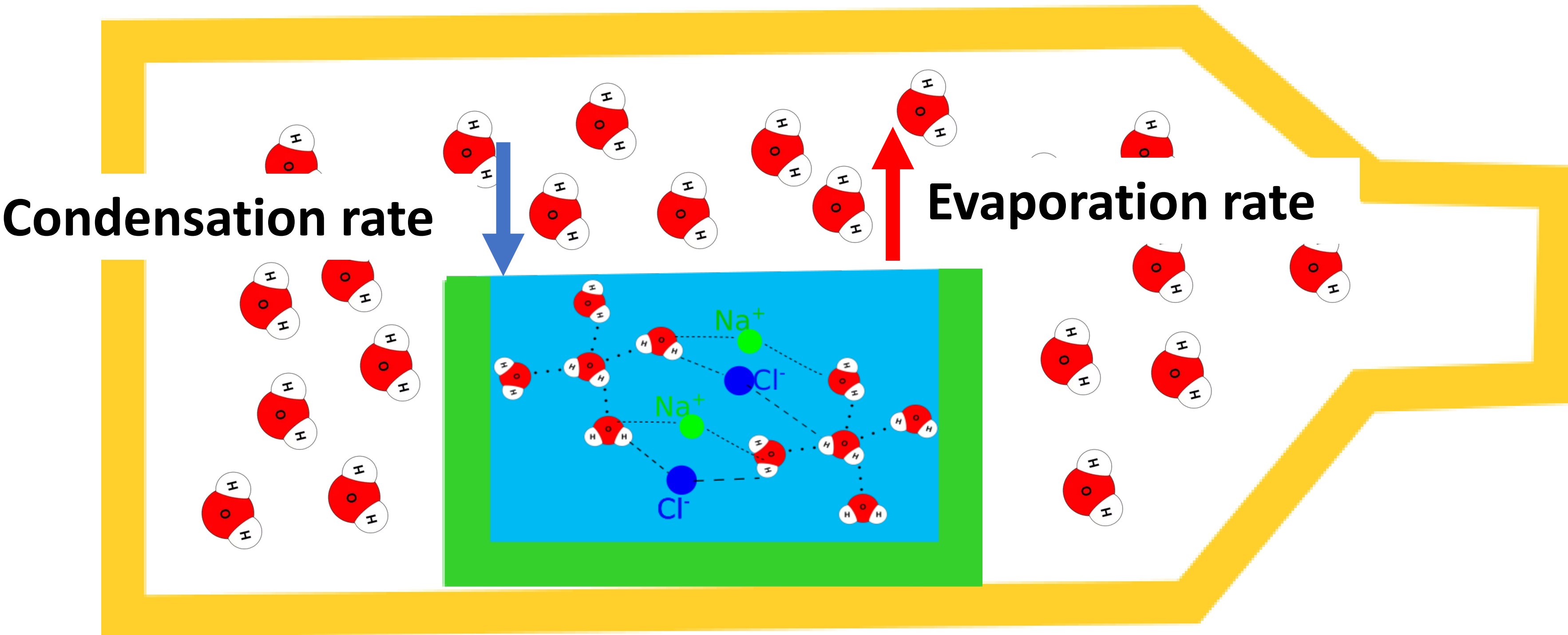

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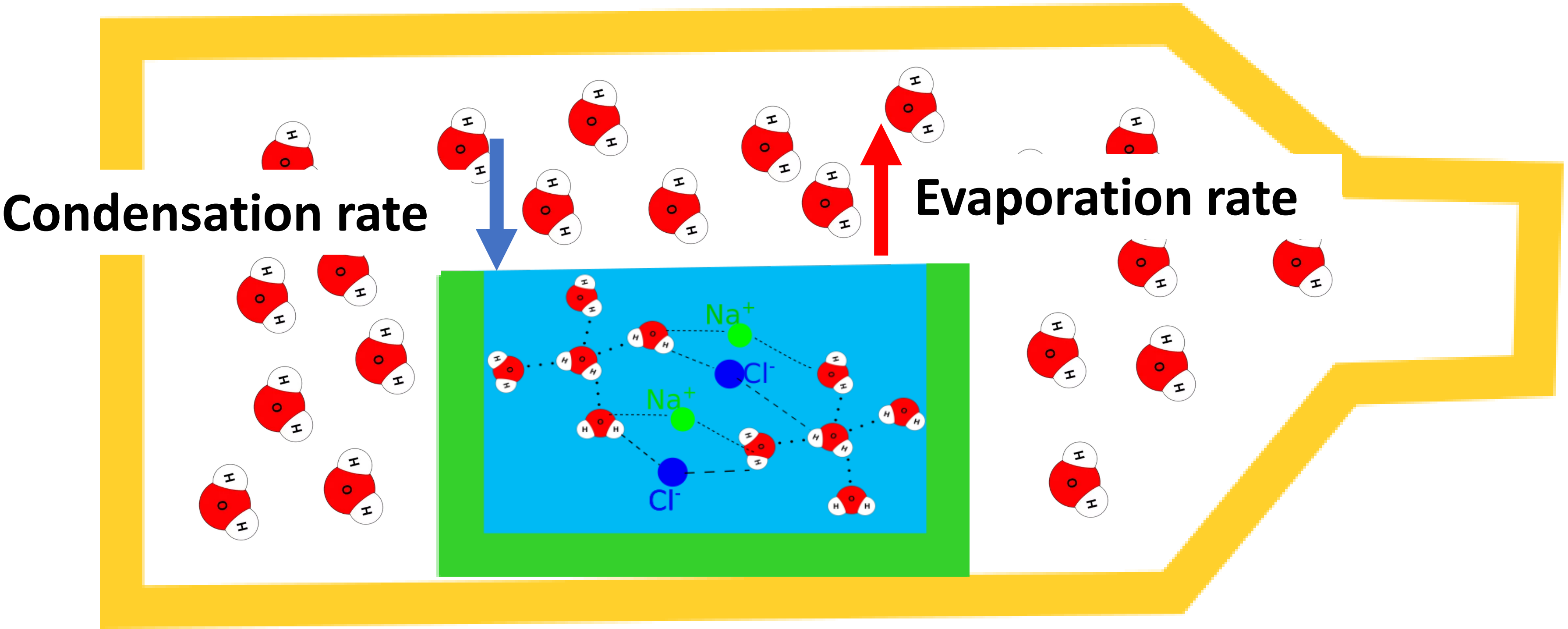

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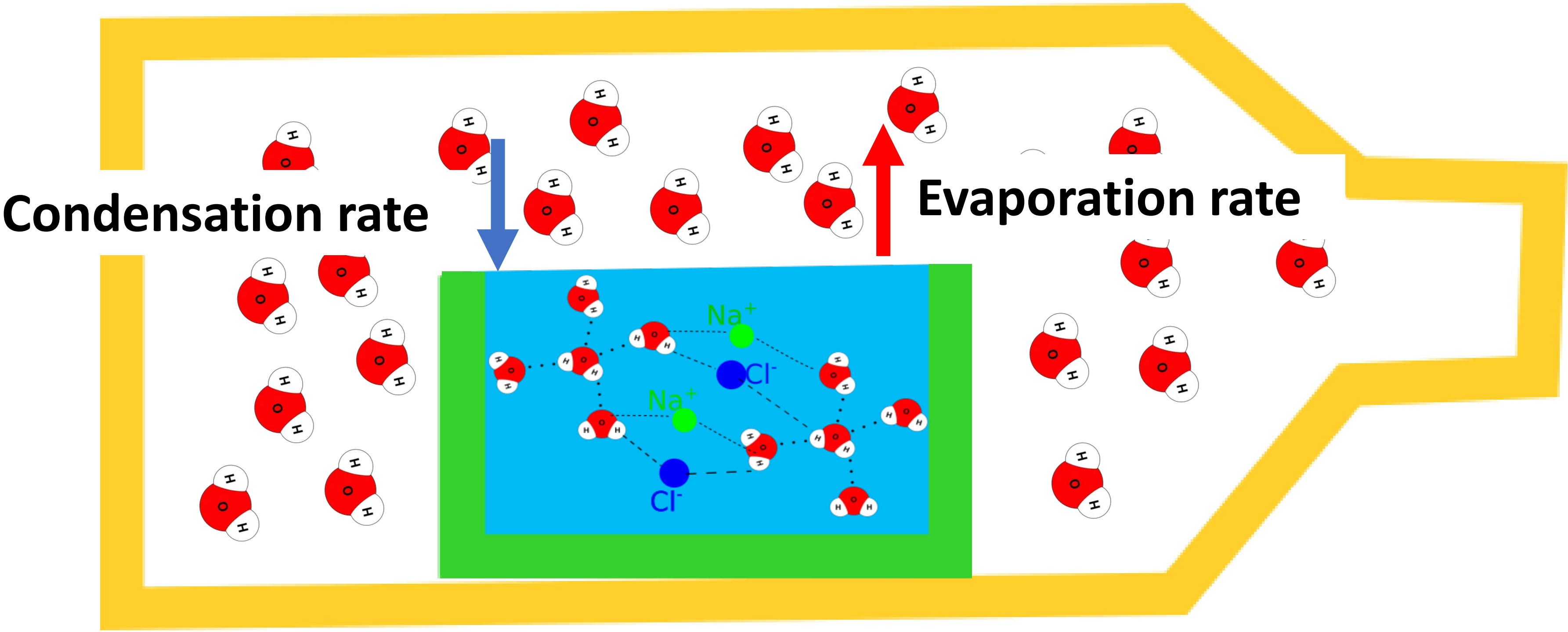
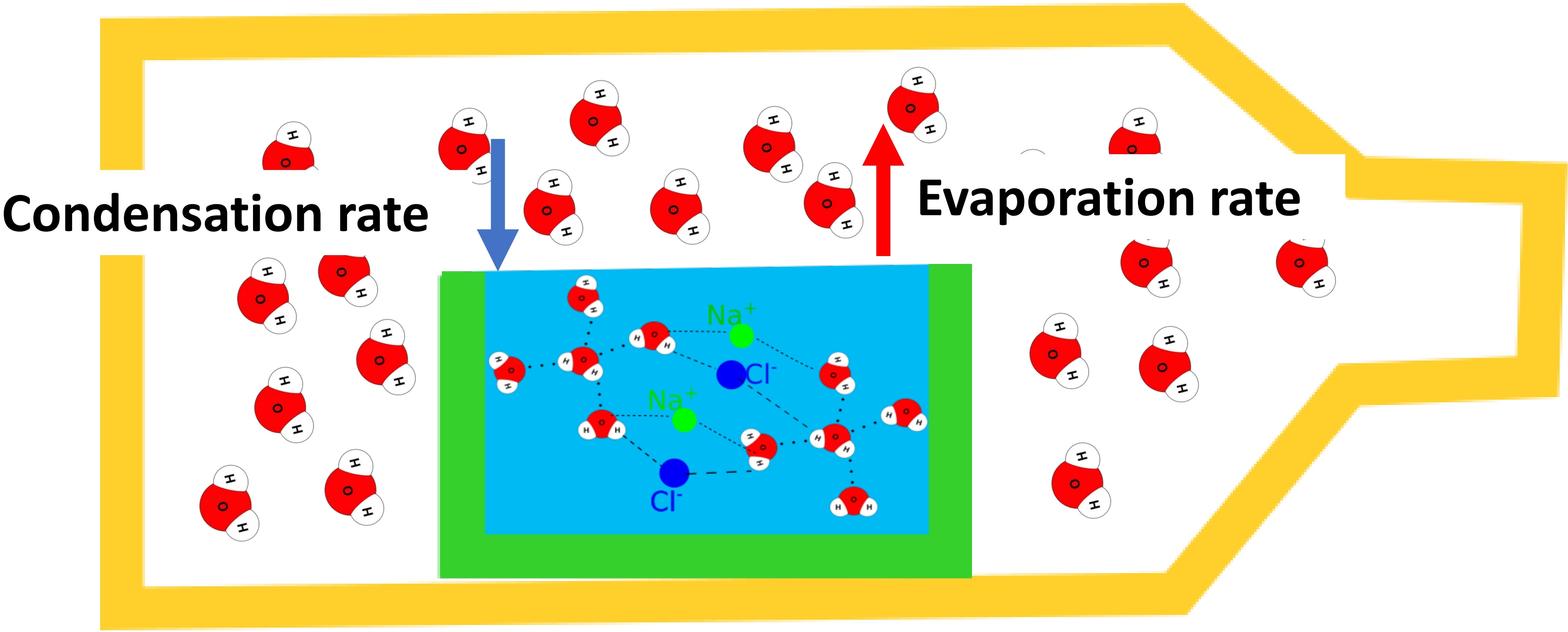


As the condensation rate= evaporation rate
the amount of water vapour molecules in the bottle is

A) equal to the pure water case
B) higher
C) lower



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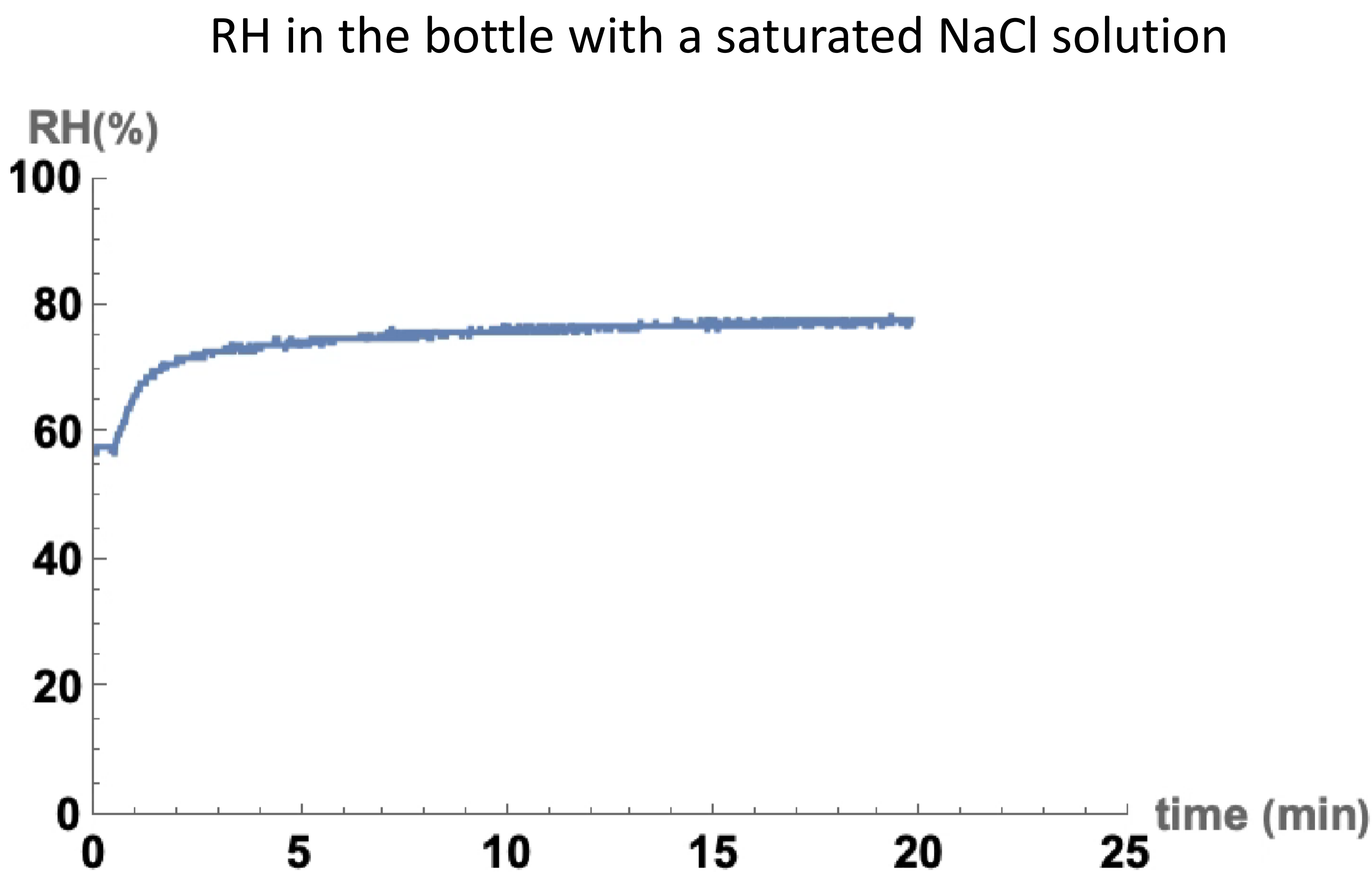


Animation 3. RH in the Bottle with a Saturated NaCl Solution (please see "Animation" on Pressbooks for video).

TABLE 2. *Equilibrium Relative Humidity of Selected Saturated Salt Solutions from 0 to 100 °C*

T °C	Relative Humidity, %									
	Cesium Fluoride	Lithium Bromide	Zinc Bromide	Potassium Hydroxide	Sodium Hydroxide	Lithium Chloride	Calcium Bromide	Lithium Iodide	Potassium Acetate	Potassium Fluoride
0		7.75 ± 0.83				11.23 ± 0.54				
5	5.52 ± 1.9	7.43 ± 0.76	8.86 ± 0.89	14.34 ± 1.7		11.26 ± 0.47		21.68 ± 0.30		
10	4.89 ± 1.6	7.14 ± 0.69	8.49 ± 0.74	12.34 ± 1.4		11.29 ± 0.41	21.62 ± 0.50	20.61 ± 0.25	23.38 ± 0.53	
15	4.33 ± 1.4	6.86 ± 0.63	8.19 ± 0.61	10.68 ± 1.1	9.57 ± 2.8	11.30 ± 0.35	20.20 ± 0.50	19.57 ± 0.20	23.40 ± 0.32	
20	3.83 ± 1.1	6.61 ± 0.58	7.94 ± 0.49	9.32 ± 0.90	8.91 ± 2.4	11.31 ± 0.31	18.50 ± 0.50	18.56 ± 0.16	23.11 ± 0.25	
25	3.39 ± 0.94	6.37 ± 0.52	7.75 ± 0.39	8.23 ± 0.72	8.24 ± 2.1	11.30 ± 0.27	16.50 ± 0.20	17.56 ± 0.13	22.51 ± 0.32	30.85 ± 1.3
30	3.01 ± 0.77	6.16 ± 0.47	7.62 ± 0.31	7.38 ± 0.56	7.58 ± 1.7	11.28 ± 0.24		16.57 ± 0.10	21.61 ± 0.53	27.27 ± 1.1
35	2.69 ± 0.63	5.97 ± 0.43	7.55 ± 0.25	6.73 ± 0.44	6.92 ± 1.5	11.25 ± 0.22		15.57 ± 0.08		24.59 ± 0.94
40	2.44 ± 0.52	5.80 ± 0.39	7.54 ± 0.20	6.26 ± 0.35	6.26 ± 1.2	11.21 ± 0.21		14.55 ± 0.06		22.68 ± 0.81
45	2.24 ± 0.44	5.65 ± 0.35	7.59 ± 0.17	5.94 ± 0.29	5.60 ± 1.0	11.16 ± 0.21		13.49 ± 0.05		21.46 ± 0.70
50	2.11 ± 0.40	5.53 ± 0.31	7.70 ± 0.16	5.72 ± 0.27	4.94 ± 0.85	11.10 ± 0.22		12.38 ± 0.05		20.80 ± 0.62
55	2.04 ± 0.38	5.42 ± 0.28	7.87 ± 0.17	5.58 ± 0.28	4.27 ± 0.73	11.03 ± 0.23		11.22 ± 0.05		20.60 ± 0.56
60	2.03 ± 0.40	5.33 ± 0.25	8.09 ± 0.19	5.49 ± 0.32	3.61 ± 0.65	10.95 ± 0.26		9.98 ± 0.06		20.77 ± 0.53
65	2.08 ± 0.44	5.27 ± 0.23	8.38 ± 0.24	5.41 ± 0.39	2.95 ± 0.60	10.86 ± 0.29		8.65 ± 0.07		21.18 ± 0.53
70	2.20 ± 0.52	5.23 ± 0.21	8.72 ± 0.30	5.32 ± 0.50	2.29 ± 0.60	10.75 ± 0.33		7.23 ± 0.09		21.74 ± 0.56
75	2.37 ± 0.62	5.20 ± 0.19			1.63 ± 0.64	10.64 ± 0.38				22.33 ± 0.61
80	2.61 ± 0.76	5.20 ± 0.18				10.51 ± 0.44				22.85 ± 0.69
85		5.22 ± 0.17				10.38 ± 0.51				23.20 ± 0.80
90		5.26 ± 0.17				10.23 ± 0.59				23.27 ± 0.93
95		5.32 ± 0.16				10.07 ± 0.67				
100		5.41 ± 0.17				9.90 ± 0.77				

TABLE 2. *Equilibrium Relative Humidity of Selected Saturated Salt Solutions from 0 to 100 °C—Continued*

T °C	Relative Humidity, %									
	Magnesium Chloride	Sodium Iodide	Potassium Carbonate	Magnesium Nitrate	Sodium Bromide	Cobalt Chloride	Potassium Iodide	Strontium Chloride	Sodium Nitrate	Sodium Chloride
0	33.66 ± 0.33		43.13 ± 0.66	60.35 ± 0.55						75.51 ± 0.34
5	33.60 ± 0.28	42.42 ± 0.99	43.13 ± 0.50	58.86 ± 0.43	63.51 ± 0.72		73.30 ± 0.34	77.13 ± 0.12	78.57 ± 0.52	75.65 ± 0.27
10	33.47 ± 0.24	41.83 ± 0.83	43.14 ± 0.39	57.36 ± 0.33	62.15 ± 0.60		72.11 ± 0.31	75.66 ± 0.09	77.53 ± 0.45	75.67 ± 0.22
15	33.30 ± 0.21	40.88 ± 0.70	43.15 ± 0.33	55.87 ± 0.27	60.68 ± 0.51		70.98 ± 0.28	74.13 ± 0.06	76.46 ± 0.39	75.61 ± 0.18
20	33.07 ± 0.18	39.65 ± 0.59	43.16 ± 0.33	54.38 ± 0.23	59.14 ± 0.44		69.90 ± 0.26	72.52 ± 0.05	75.36 ± 0.35	75.47 ± 0.14
25	32.78 ± 0.16	38.17 ± 0.50	43.16 ± 0.39	52.89 ± 0.22	57.57 ± 0.40	64.92 ± 3.5	68.86 ± 0.24	70.85 ± 0.04	74.25 ± 0.32	75.29 ± 0.12
30	32.44 ± 0.14	36.15 ± 0.43	43.17 ± 0.50	51.40 ± 0.24	56.03 ± 0.38	61.83 ± 2.8	67.89 ± 0.23	69.12 ± 0.03	73.14 ± 0.31	75.09 ± 0.11
35	32.05 ± 0.13	34.73 ± 0.39		49.91 ± 0.29	54.55 ± 0.38	58.63 ± 2.2	66.96 ± 0.23		72.06 ± 0.32	74.87 ± 0.12
40	31.60 ± 0.13	32.88 ± 0.37		48.42 ± 0.37	53.17 ± 0.41	55.48 ± 1.8	66.09 ± 0.23		71.00 ± 0.34	74.68 ± 0.13
45	31.10 ± 0.13	31.02 ± 0.37		46.93 ± 0.47	51.95 ± 0.47	52.56 ± 1.5	65.26 ± 0.24		69.99 ± 0.37	74.52 ± 0.16
50	30.54 ± 0.14	29.21 ± 0.40		45.44 ± 0.60	50.93 ± 0.55	50.01 ± 1.4	64.49 ± 0.26		69.04 ± 0.42	74.43 ± 0.19
55	29.93 ± 0.16	27.50 ± 0.45			50.15 ± 0.65	48.02 ± 1.4	63.78 ± 0.28		68.15 ± 0.49	74.41 ± 0.24
60	29.26 ± 0.18	25.95 ± 0.52			49.66 ± 0.78	46.74 ± 1.5	63.11 ± 0.31		67.35 ± 0.57	74.50 ± 0.30
65	28.54 ± 0.21	24.62 ± 0.62			49.49 ± 0.94	46.33 ± 1.9	62.50 ± 0.34		66.64 ± 0.67	74.71 ± 0.37
70	27.77 ± 0.25	23.57 ± 0.74			49.70 ± 1.1	46.97 ± 2.3	61.93 ± 0.38		66.04 ± 0.78	75.06 ± 0.45
75	26.94 ± 0.29	22.85 ± 0.88			50.33 ± 1.3	48.80 ± 2.9	61.43 ± 0.43		65.56 ± 0.91	75.58 ± 0.55
80	26.05 ± 0.34	22.52 ± 1.0			51.43 ± 1.5	52.01 ± 3.7	60.97 ± 0.48		65.22 ± 1.1	76.29 ± 0.65
85	25.11 ± 0.39	22.63 ± 1.2					60.56 ± 0.54		65.03 ± 1.2	
90	24.12 ± 0.46	23.25 ± 1.4					60.21 ± 0.61		65.00 ± 1.4	
95	23.07 ± 0.52									
100	21.97 ± 0.60									

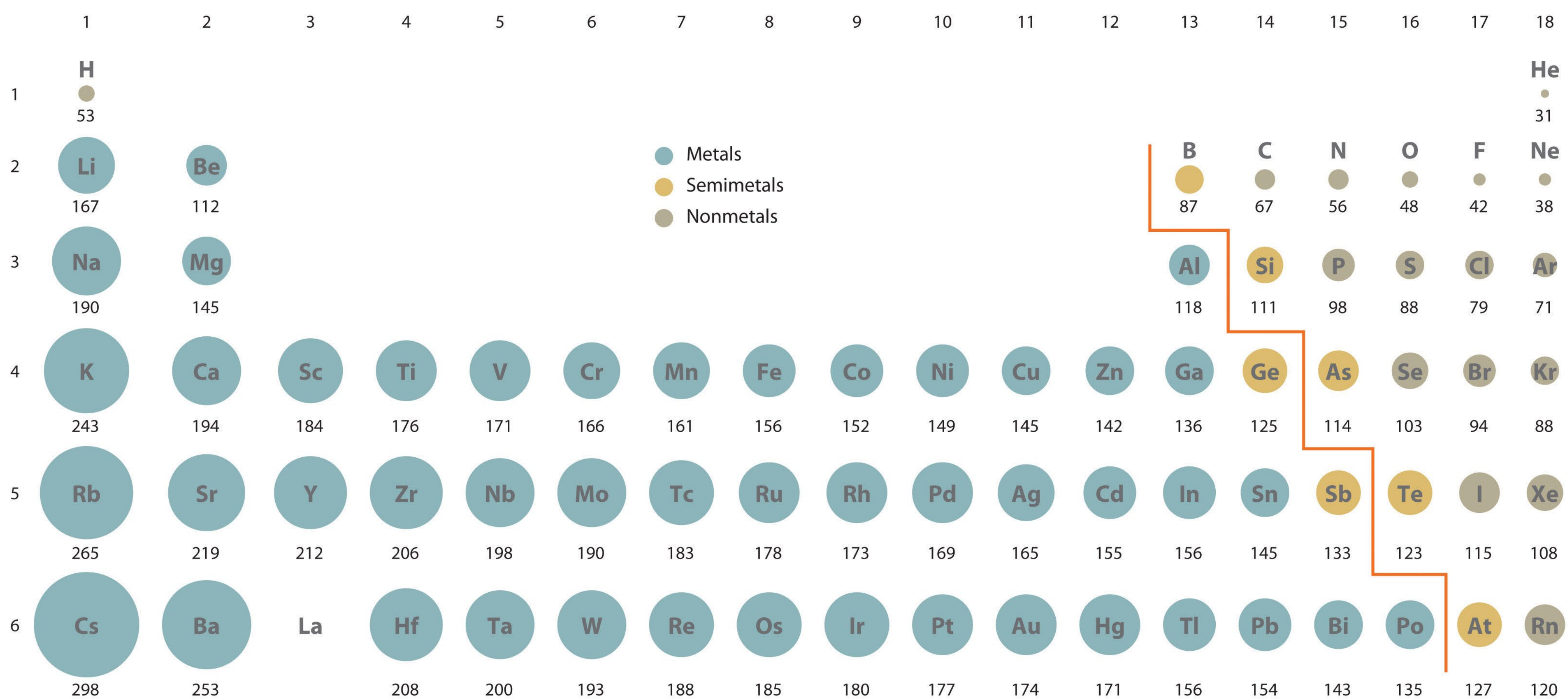
TABLE 2. *Equilibrium Relative Humidity of Selected Saturated Salt Solutions from 0 to 100 °C—Continued*

T °C	Relative Humidity, %							
	Ammonium Chloride	Potassium Bromide	Ammonium Sulfate	Potassium Chloride	Strontium Nitrate	Potassium Nitrate	Potassium Sulfate	Potassium Chromate
0			82.27 ± 0.90	88.61 ± 0.53		96.33 ± 2.9	98.77 ± 1.1	
5		85.09 ± 0.26	82.42 ± 0.68	87.67 ± 0.45	92.38 ± 0.56	96.27 ± 2.1	98.48 ± 0.91	
10	80.55 ± 0.96	83.75 ± 0.24	82.06 ± 0.51	86.77 ± 0.39	90.55 ± 0.38	95.96 ± 1.4	98.18 ± 0.76	
15	79.89 ± 0.59	82.62 ± 0.22	81.70 ± 0.38	85.92 ± 0.33	88.72 ± 0.28	95.41 ± 0.96	97.89 ± 0.63	
20	79.23 ± 0.44	81.67 ± 0.21	81.34 ± 0.31	85.11 ± 0.29	86.89 ± 0.29	94.62 ± 0.66	97.59 ± 0.53	
25	78.57 ± 0.40	80.89 ± 0.21	80.99 ± 0.28	84.34 ± 0.26	85.06 ± 0.38	93.58 ± 0.55	97.30 ± 0.45	97.88 ± 0.49
30	77.90 ± 0.57	80.27 ± 0.21	80.63 ± 0.30	83.62 ± 0.25		92.31 ± 0.60	97.00 ± 0.40	97.08 ± 0.41
35		79.78 ± 0.22	80.27 ± 0.37	82.95 ± 0.25		90.79 ± 0.83	96.71 ± 0.38	96.42 ± 0.37
40		79.43 ± 0.24	79.91 ± 0.49	82.32 ± 0.25		89.03 ± 1.2	96.41 ± 0.38	95.89 ± 0.37
45		79.18 ± 0.26	79.56 ± 0.65	81.74 ± 0.28		87.03 ± 1.8	96.12 ± 0.40	95.50 ± 0.40
50		79.02 ± 0.28	79.20 ± 0.87	81.20 ± 0.31		84.78 ± 2.5	95.82 ± 0.45	95.25 ± 0.48
55		78.95 ± 0.32		80.70 ± 0.35				
60		78.94 ± 0.35		80.25 ± 0.41				
65		78.99 ± 0.40		79.85 ± 0.48				
70		79.07 ± 0.45		79.49 ± 0.57				
75		79.16 ± 0.50		79.17 ± 0.66				
80		79.27 ± 0.57		78.90 ± 0.77				
85				78.68 ± 0.89				
90				78.50 ± 1.0				
95								
100								

Artikel mit gleichgewichtfeuchte bei gesättigten Salzlösungen: Auf Moodle/Physical Phenomena/Learning Materials/ Additionals

Greenspan, L. HUMIDITY FIXED-POINTS OF BINARY SATURATED AQUEOUS-SOLUTIONS *JOURNAL OF RESEARCH OF THE NATIONAL BUREAU OF STANDARDS SECTION A-PHYSICS AND CHEMISTRY,* **{1977}**, *{81}*, {89-96}

Salz	RF (%)
LiCl	11
MgCl2	33
NaCl	75
KCl	85

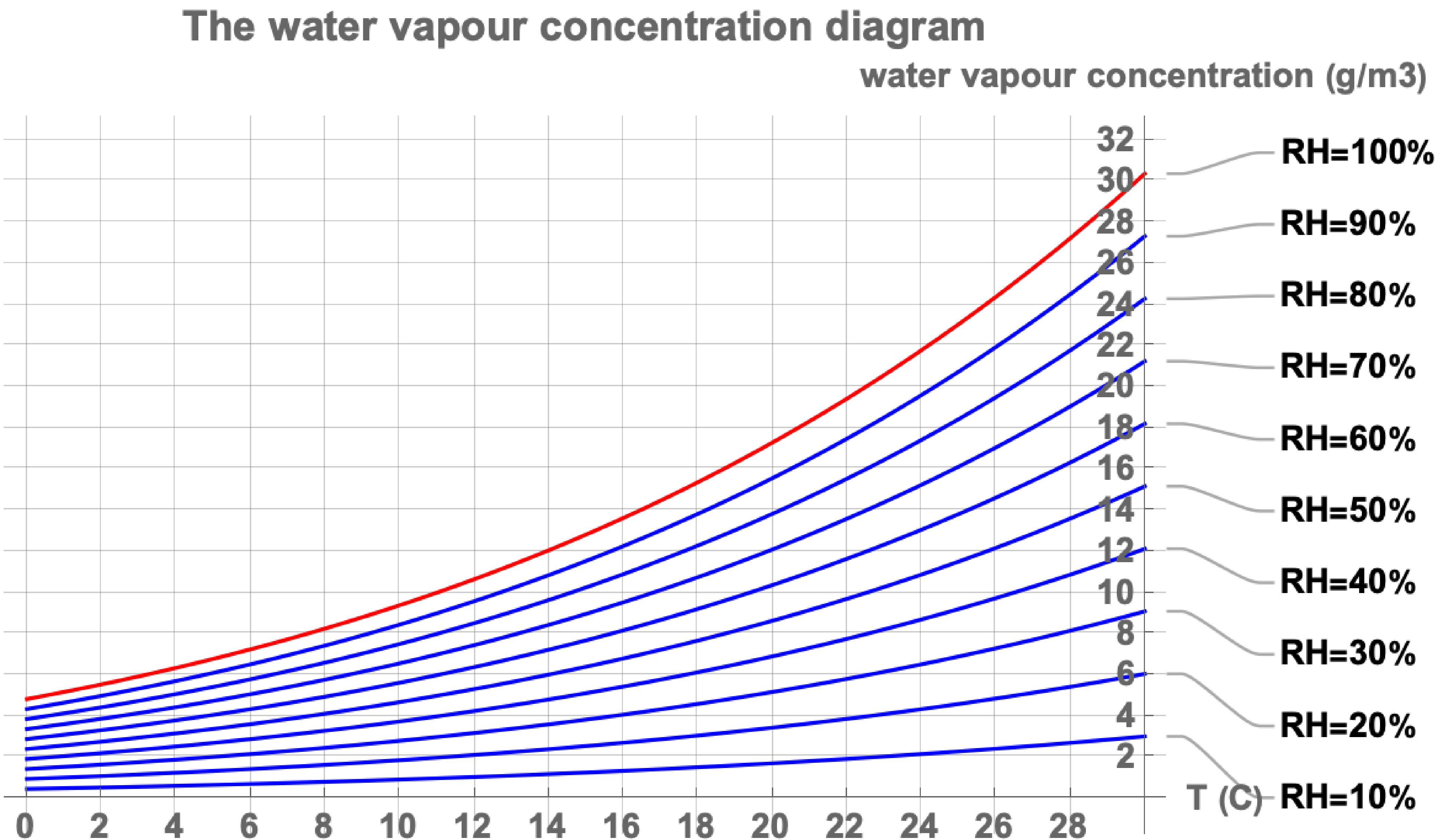


Salz	RF (%)	Radius Ione(nm)
LiCl	11	Li^{+}=0.068
MgCl2	33	Mg(2+)=0.065
NaCl	75	Na^{+}=0.095
KCl	85	K^{+}=0.133

The microclimate in packages, showcases, microclimate vitrines and backing board protected paintings

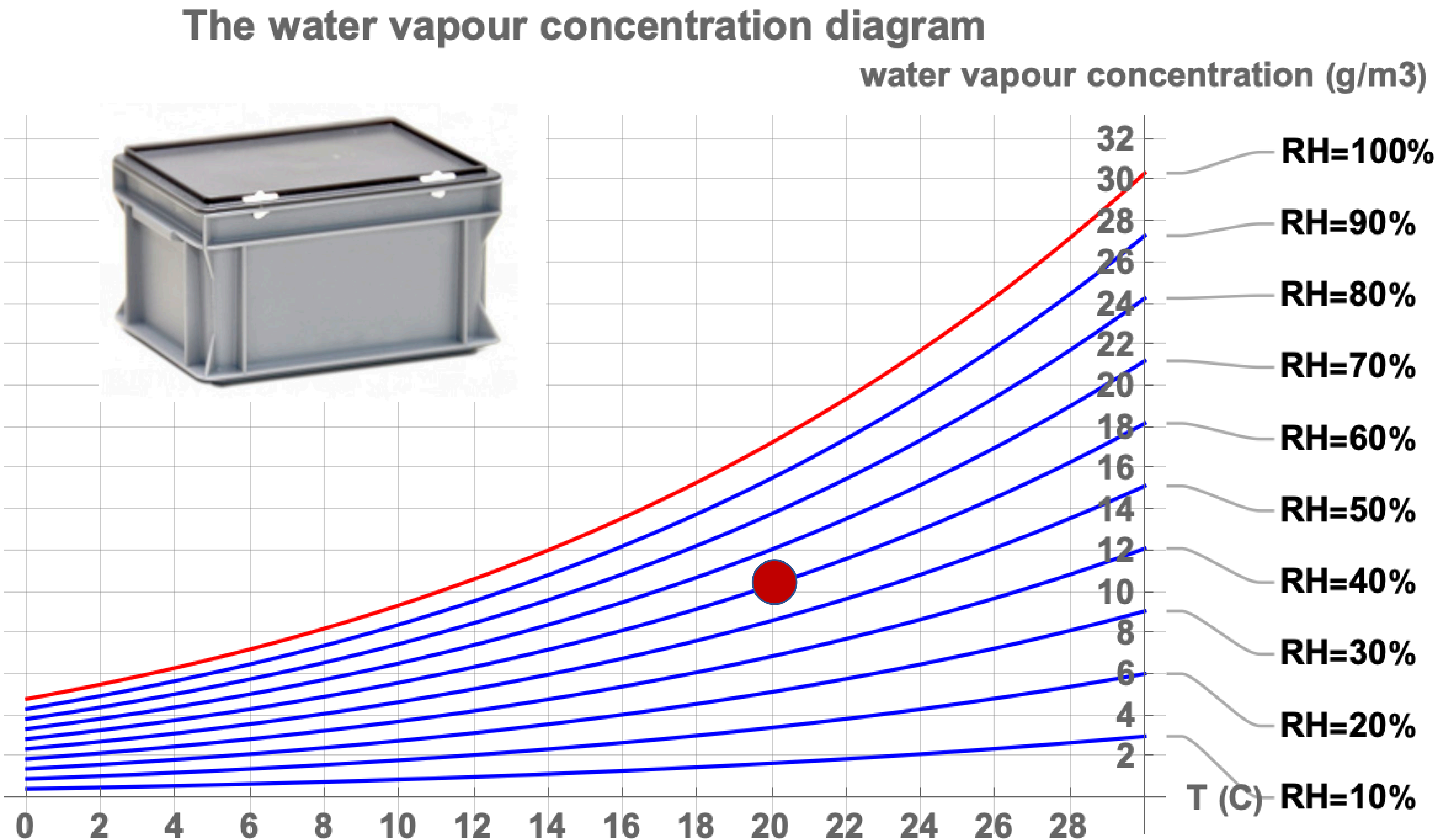
Giovanna Di Pietro, Bern Academy of the Arts, Department of Conservation and Restoration, Switzerland

Lesson 2
the water vapour concentration diagram



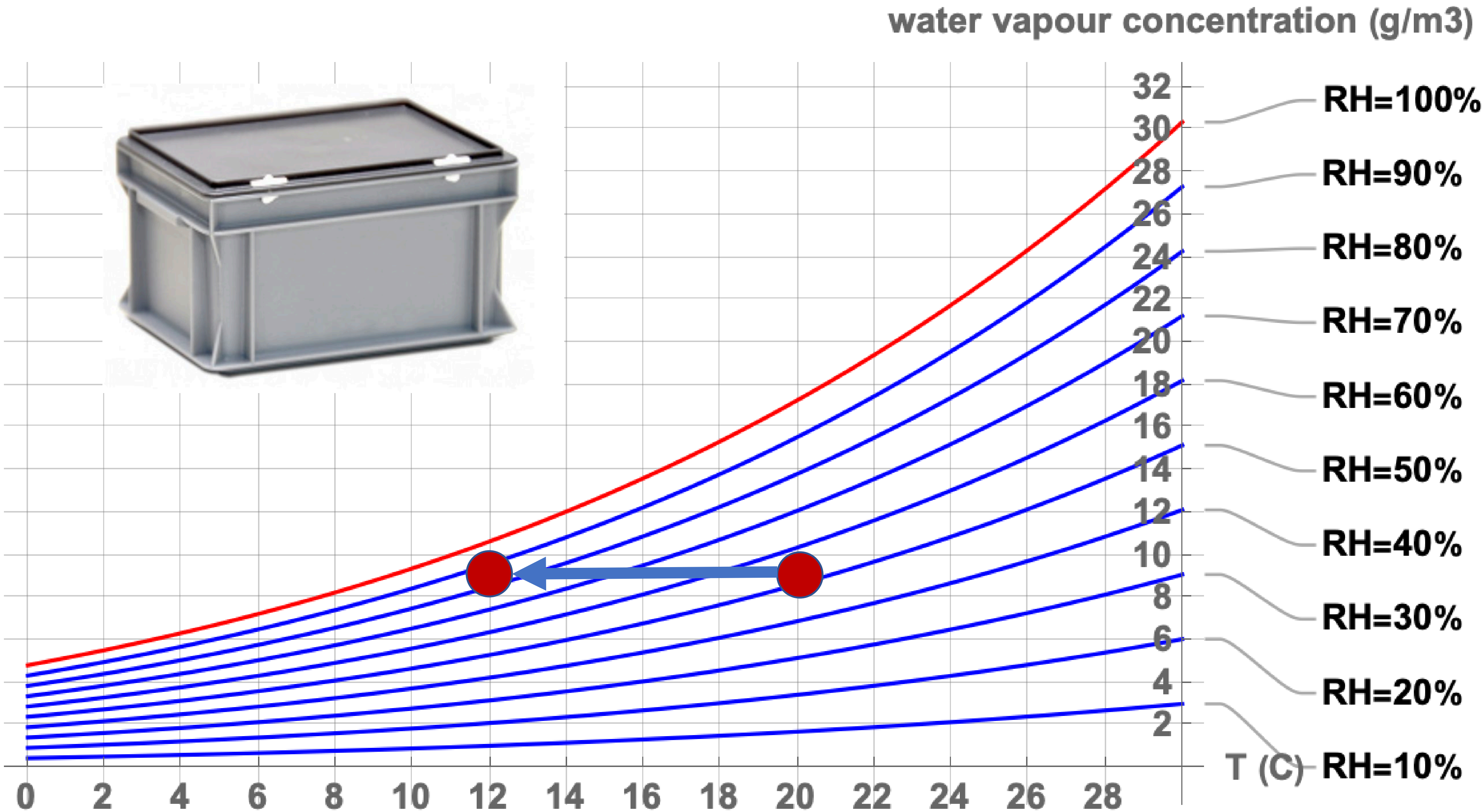
The water vapor concentration diagram describes the relation between absolute humidity, relative humidity and temperature at standard pressure (1 atm) **for inert spaces** or **with minor amount of hygroscopic materials** or **at short times**

1. Uses of the water vapour concentration diagram



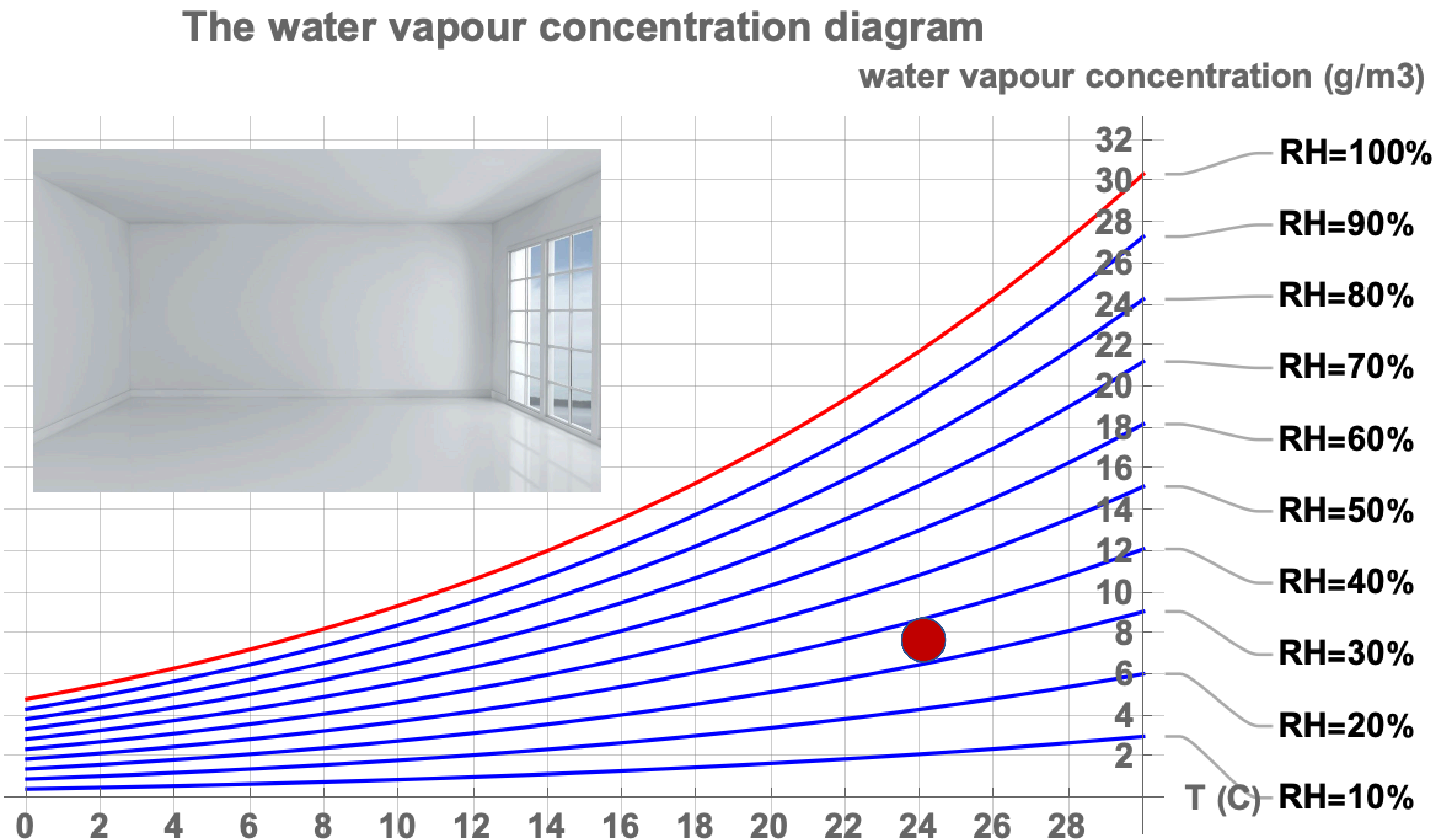
Sealed Raku box at 20 °C and 60%RH: at which temperature do you expect condensation

The water vapour concentration diagram



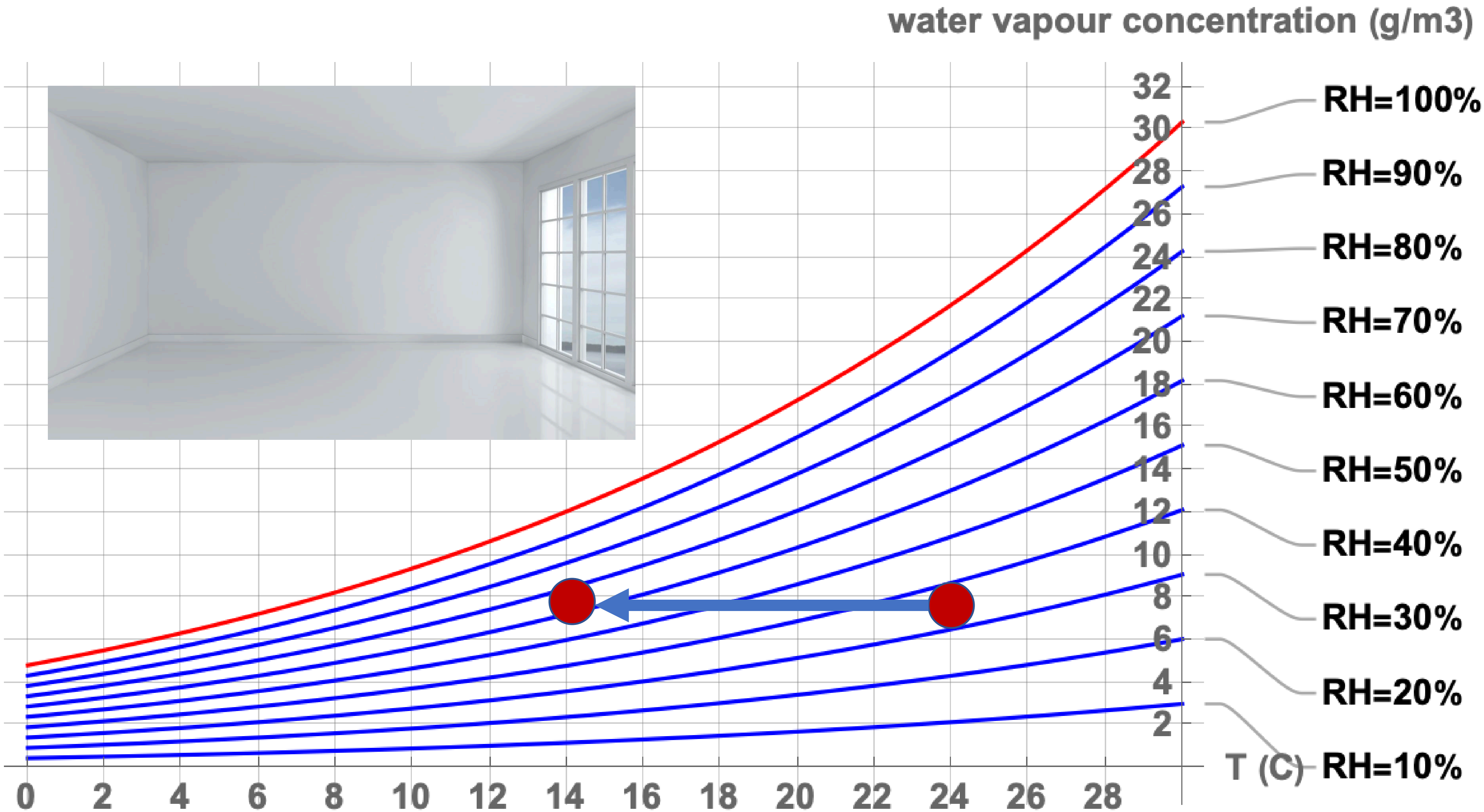
We move horizontally because the system is closed and without hygroscopic materials: the absolute humidity is constant.
Condensation expected at 12 °C. The temperature at which there is condensation is called dew point

2. Uses of the water vapour concentration diagram



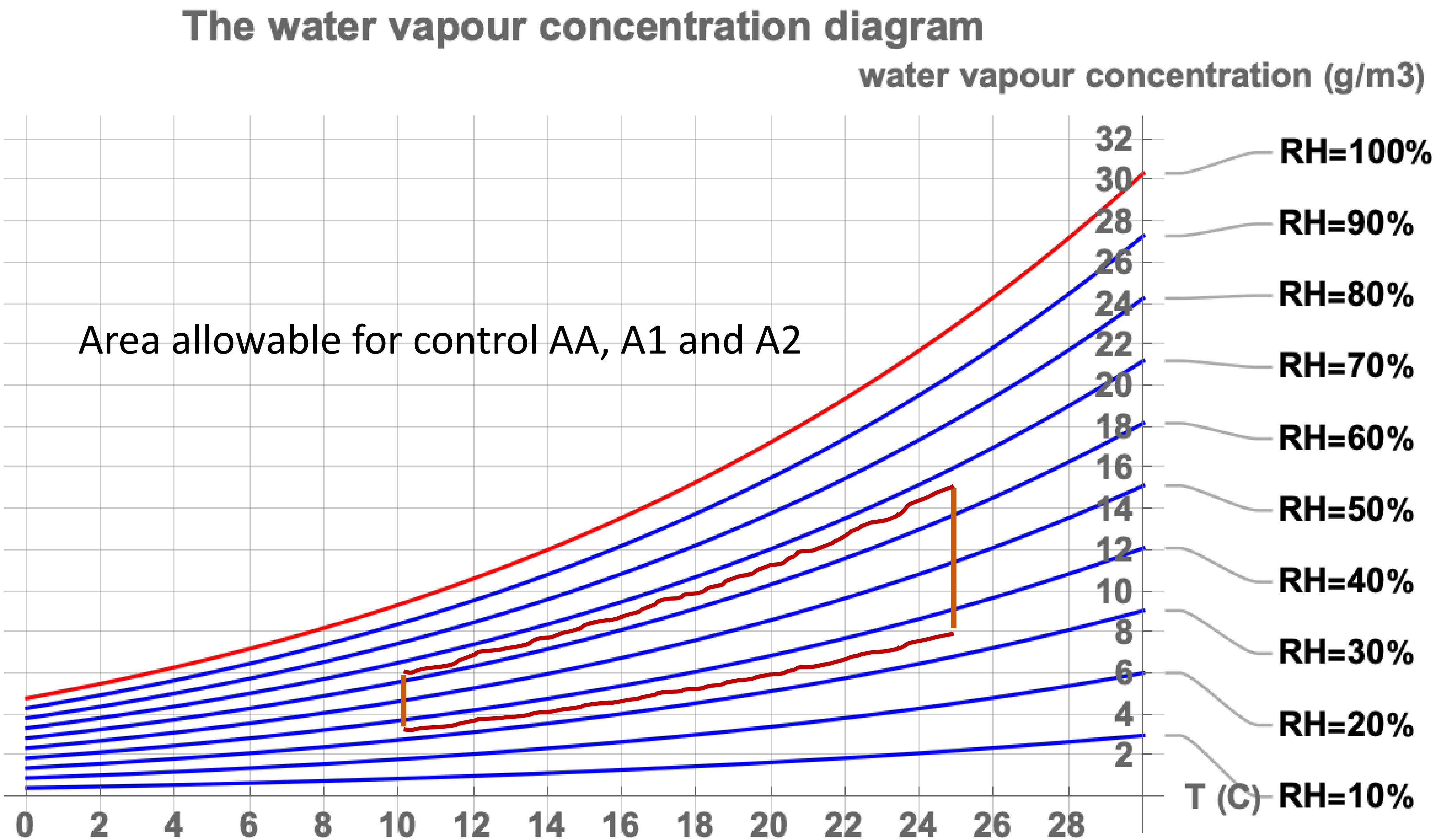
Room at 35% RH and 24 °C. One corner is at 14 °C. Do you expect condensation in that corner?

The water vapour concentration diagram



No, but the RH is expected to be about 65%.

3. Uses of the water vapour concentration diagram



Type of Collection and Building	Type of Control	Long-Term Outer Limits[a]
Museums, Galleries, Archives and Libraries in modern purpose-built buildings or purpose-built rooms Temperature at or near human comfort	**AA** Precision control, no seasonal changes to relative humidity	≥35% rh ≤65% rh ≥10°C ≤25°C
	A1 Precision control, seasonal changes in temperature and relative humidity	≥35% rh ≤65% rh ≥10°C ≤25°C
	A2 Precision control, seasonal changes in temperature only	≥35% rh ≤65% rh ≥10°C ≤25°C
Museums, galleries, archives, and libraries needing to reduce stress on their building (e.g., historic house museums), depending on climate zone[e]	**B** Limited control, seasonal changes in relative humidity and large seasonal changes in temperature.[f]	≥30% rh ≤70% rh ≤30°C
	C Prevent relative humidity extremes (damp or desiccation) and prevent high temperature extremes.	≥25% rh ≤75% rh ≤40°C[g]

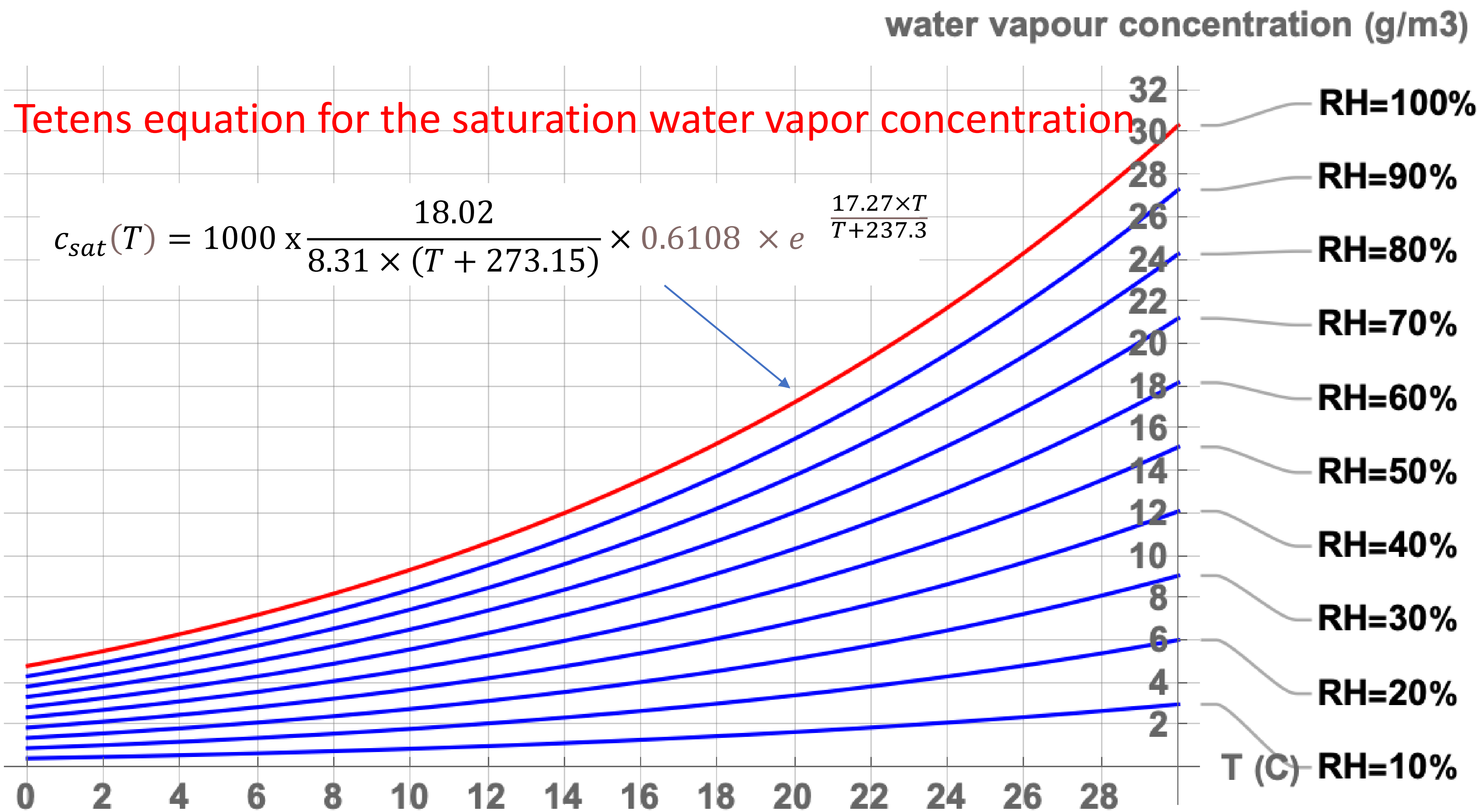
ASHRAE Guidelines for Museums, libraries and archives, 2019

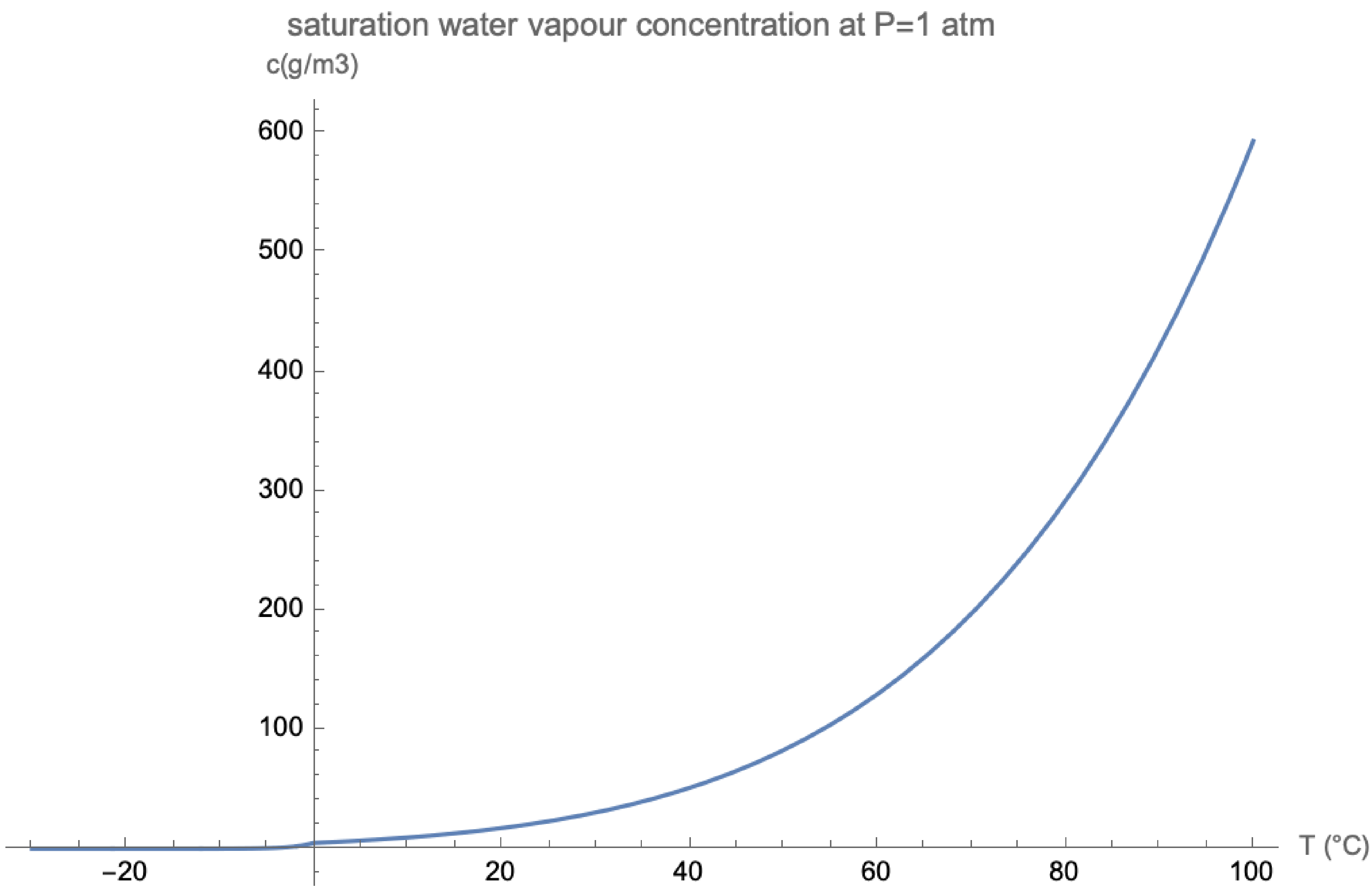
ASHRAE= American Society of Heating, Refrigerating and Air-Conditioning Engineers

The water vapour concentration diagram

Tetens equation for the saturation water vapor concentration

$$c_{sat}(T) = 1000 \text{ x } \frac{18.02}{8.31 \times (T + 273.15)} \times 0.6108 \times e^{\frac{17.27 \times T}{T+237.3}}$$





saturation water vapour concentration at P=1 atm
c(g/m3)
600
500
400
300
200
100
T (°C)
−20
20
40
60
80
100

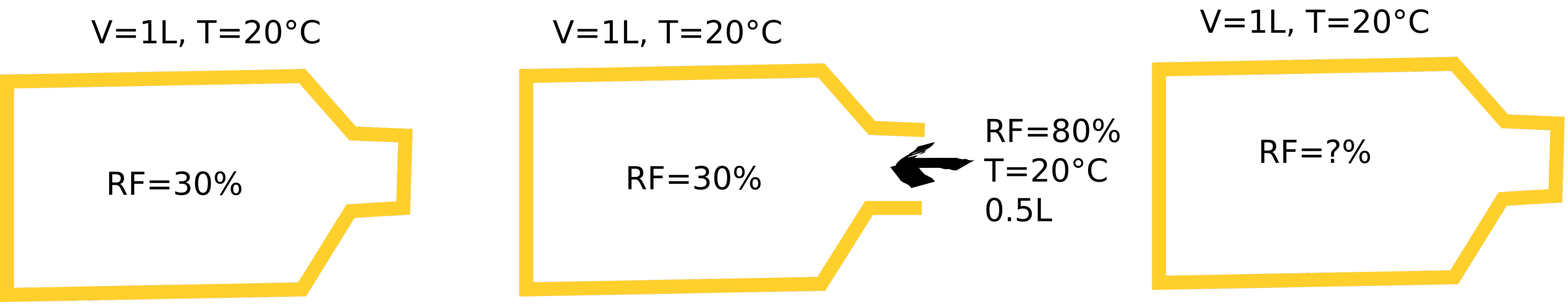
Values of saturation concentration

App for values of saturation concentration, absolute humidity and relative humidity: https://www.conservationphysics.org/atmcalc/atmocalc.html

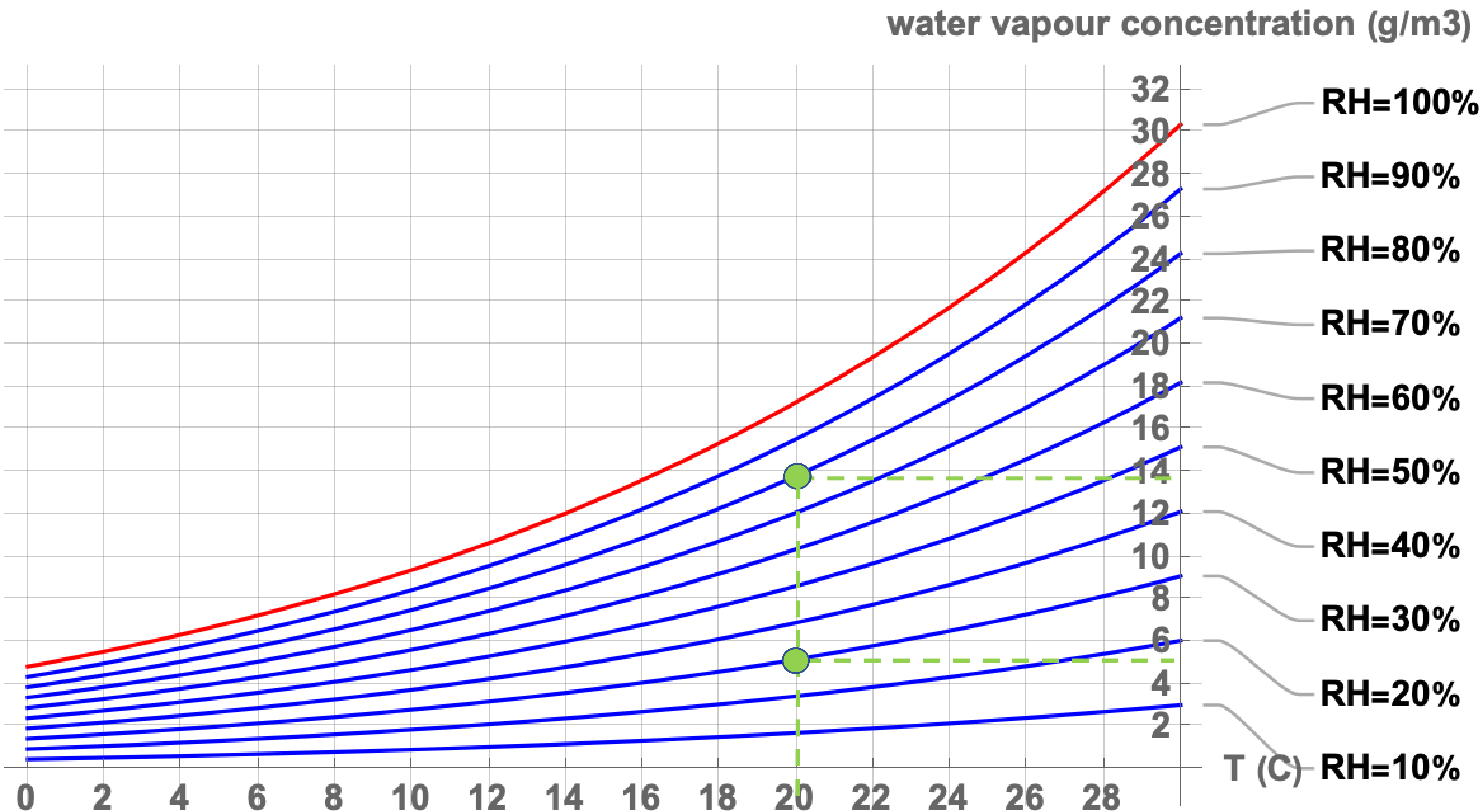
or type the Tetens equation in excel and calculate the saturation concentration for any temperature

4. Uses of the water vapour concentration diagram: mixing of air at different RH

Empty bottle



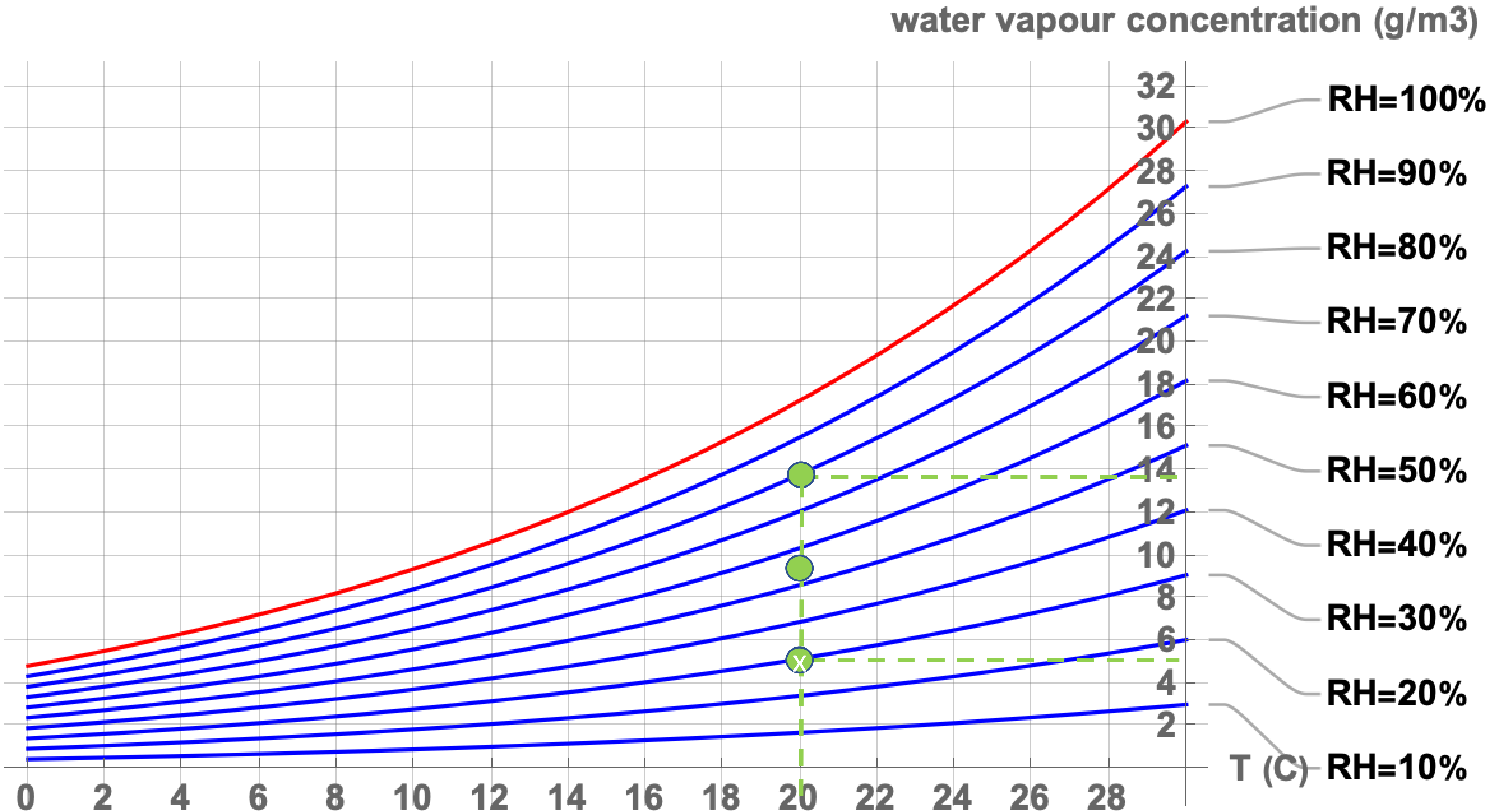
The water vapour concentration diagram



$$AF_1 = 5.2\ \frac{g}{m^3}$$

$$AF_2 = 13.8\ \frac{g}{m^3}$$

The water vapour concentration diagram



$$RF = \frac{AF}{SF} \quad (1)$$

$$SF = 17.2\ \frac{g}{m^3}$$

$$AF = \frac{M_W}{V} \quad (2)$$

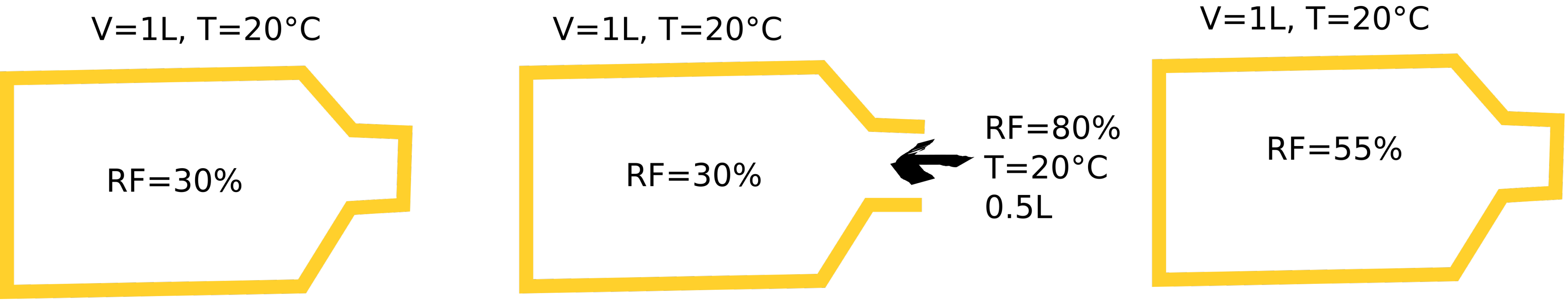
$$M_W = M_{W,1} + M_{W,2} \quad (4)$$

$$M_{W,1} = AF_1 \times V_1 = 5.2\ \frac{g}{m^3} \times 0.5\ \times 0.001\ m^3 = 0.0026\ g \quad (5)$$

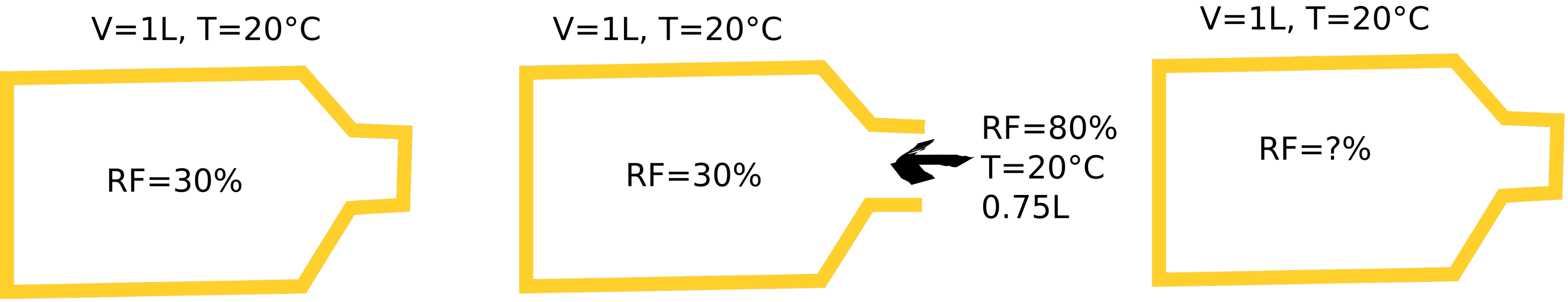
$$M_{W,2} = AF_2 \times V_2 = 13.8\ \frac{g}{m^3} \times 0.5\ \times 0.001\ m^3 = 0.0069\ g \quad (6)$$

$$AF = \frac{(0.0026+0.0069)g}{0.001\ m^3} = 9.5\ \frac{g}{m^3} \quad (7)$$

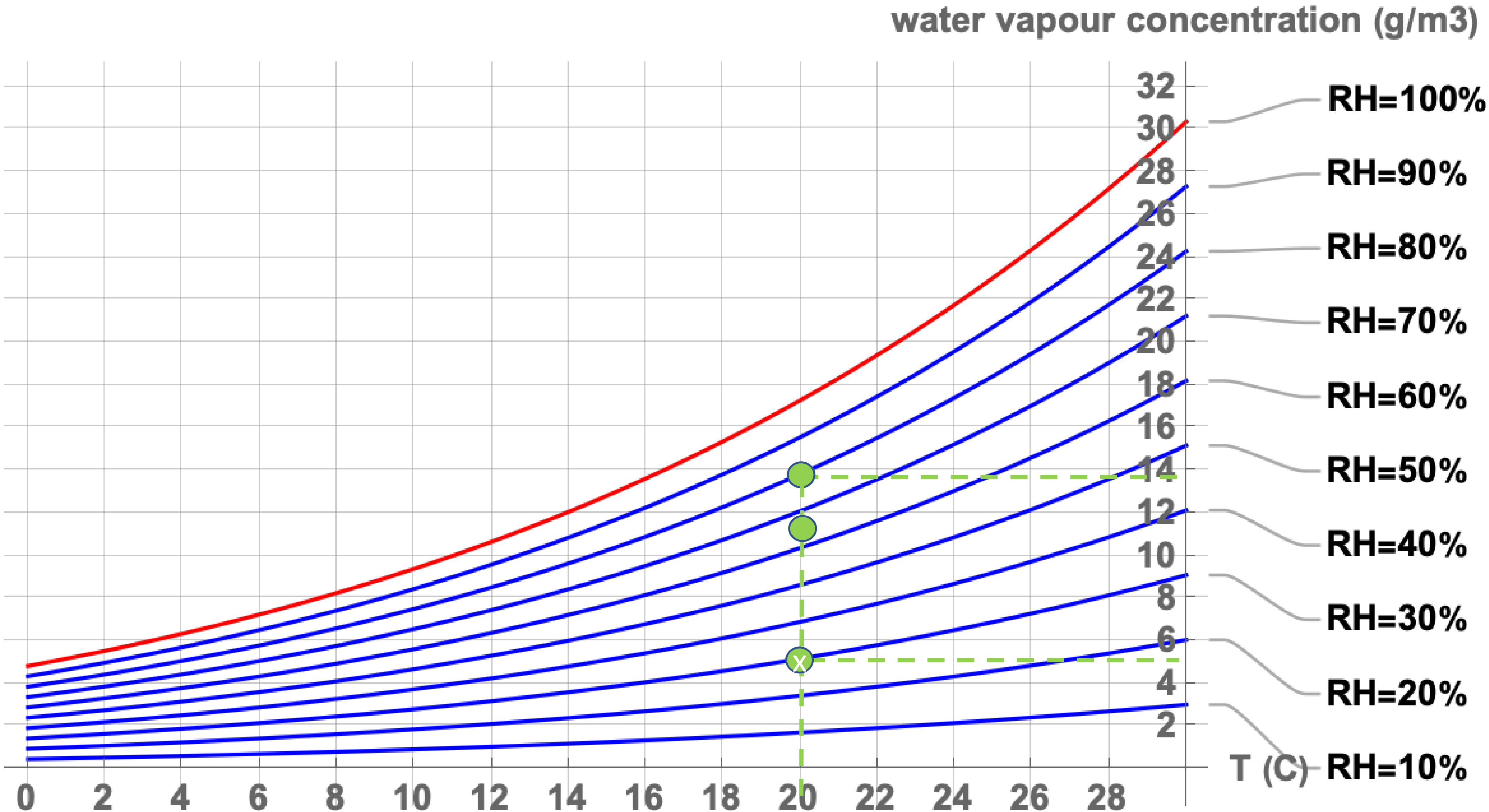
$$RF = \frac{9.5\ g/m^3}{17.2\ g/m^3} = 0.55 \quad (8)$$



V=1L, T=20°C
RF=30%
V=1L, T=20°C
RF=30%
RF=80%
T=20°C
0.5L
V=1L, T=20°C
RF=55%


V=1L, T=20°C
RF=30%
V=1L, T=20°C
RF=30%
RF=80%
T=20°C
0.75L
V=1L, T=20°C
RF=?%

The water vapour concentration diagram



$$RF = \frac{AF}{SF} \quad (1)$$

$$SF = 17.2\ \frac{g}{m^3}$$

$$AF = \frac{M_W}{V} \quad (2)$$

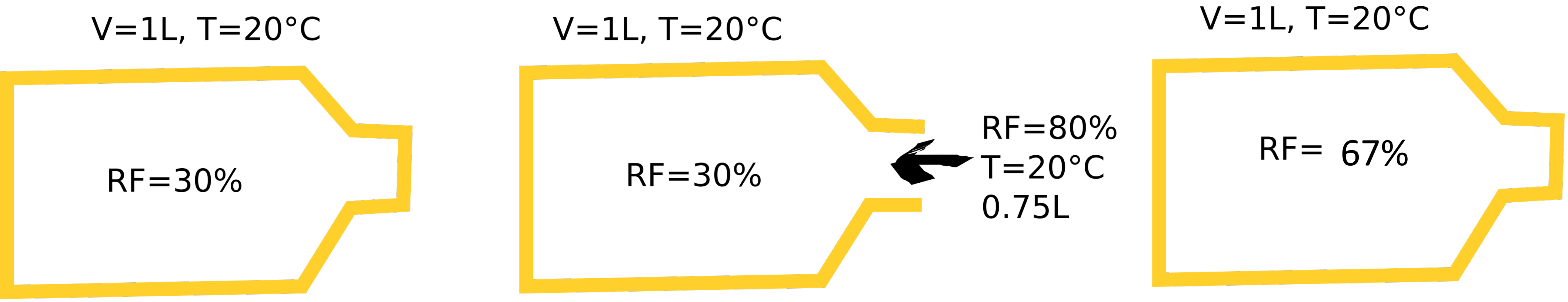
$$M_W = M_{W,1} + M_{W,2} \quad (3)$$

$$M_{W,1} = AF_1 \times V_1 = 5.2\ \frac{g}{m^3} \times 0.25\ \times 0.001\ m^3 = 0.0013\ g \quad (4)$$

$$M_{W,2} = AF_2 \times V_2 = 13.8\ \frac{g}{m^3} \times 0.75\ \times 0.001\ m^3 = 0.010\ g \quad (5)$$

$$AF = \frac{(0.0013 + 0.01)g}{0.001\ m^3} = 11.65\ \frac{g}{m^3} \quad (6)$$

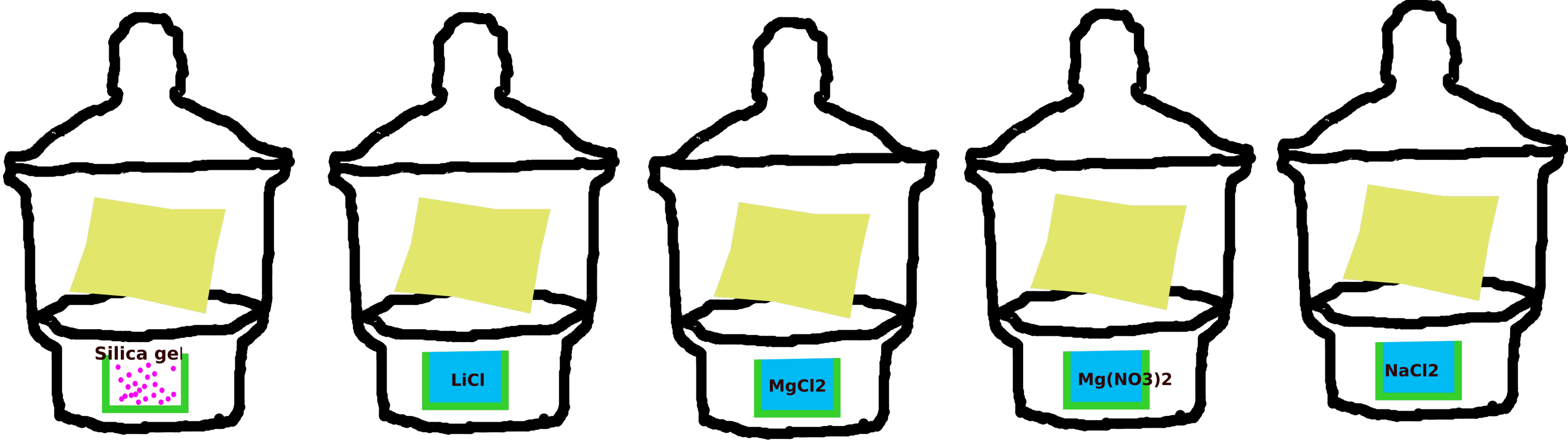
$$RF = \frac{11.65\ g/m^3}{17.2\ g/m^3} = 0.67 \quad (7)$$


V=1L, T=20°C
RF=30%
V=1L, T=20°C
RF=30%
RF=80%
T=20°C
0.75L
V=1L, T=20°C
RF= 67%

The microclimate in packages, showcases, microclimate vitrines and backing board protected paintings

Giovanna Di Pietro, Bern Academy of the Arts, Department of Conservation and Restoration, Switzerland

Lesson 3
the sorption isotherm



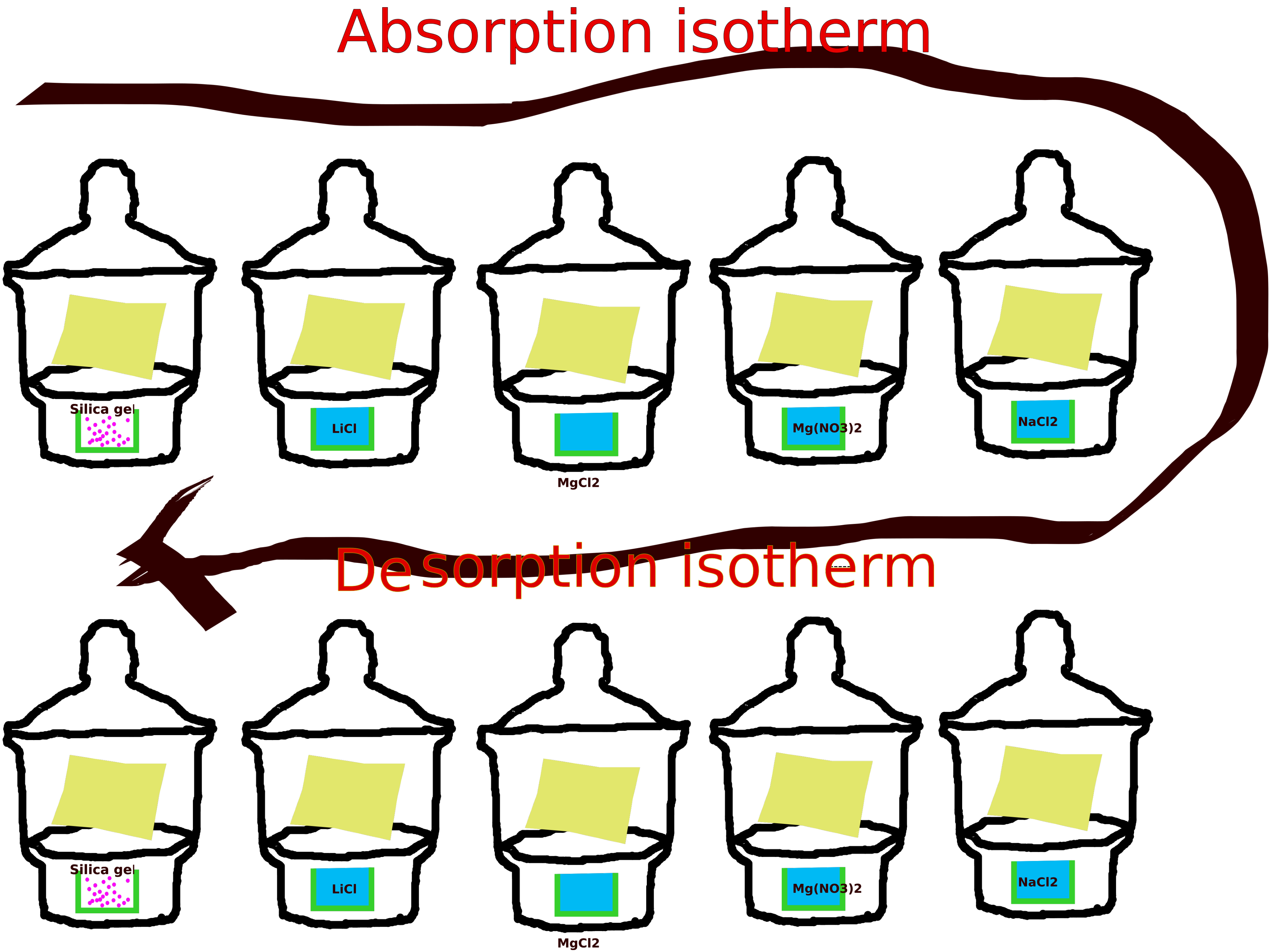
dry mass

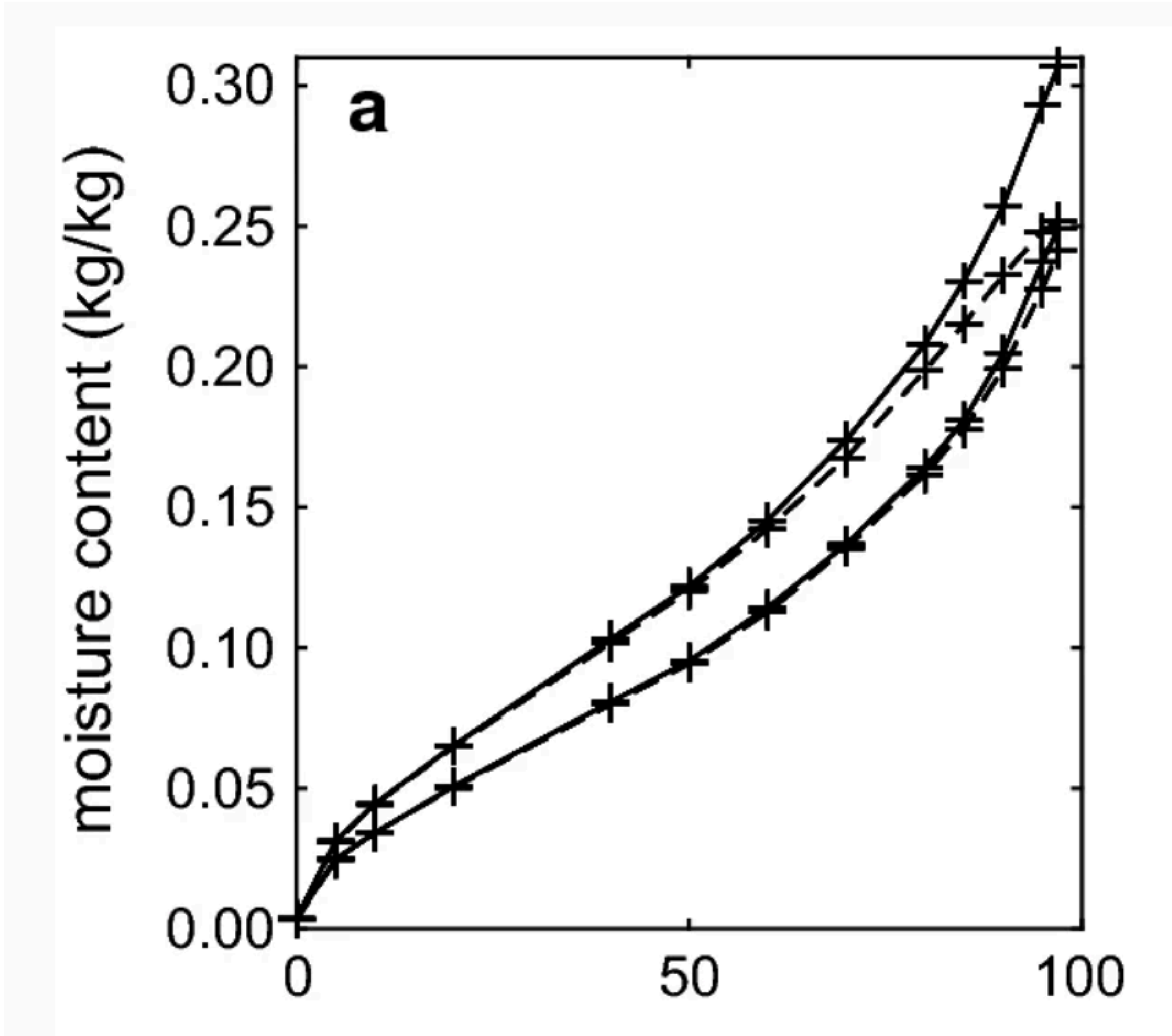
mass at RH 11%

mass at RH 33%

mass at RH 55%

mass at RH 75%


Absorption isotherm
Silica gel
LiCl
Mg(NO3)2
NaCl2
MgCl2
Desorption isotherm
Silica gel
LiCl
Mg(NO3)2
NaCl2
MgCl2



from Fredriksson, M., & Thybring, E. E. (2018). Scanning or desorption isotherms? Characterising sorption hysteresis of wood. *Cellulose*, *25*(8), 4477–4485. https://doi.org/10.1007/s10570-018-1898-9

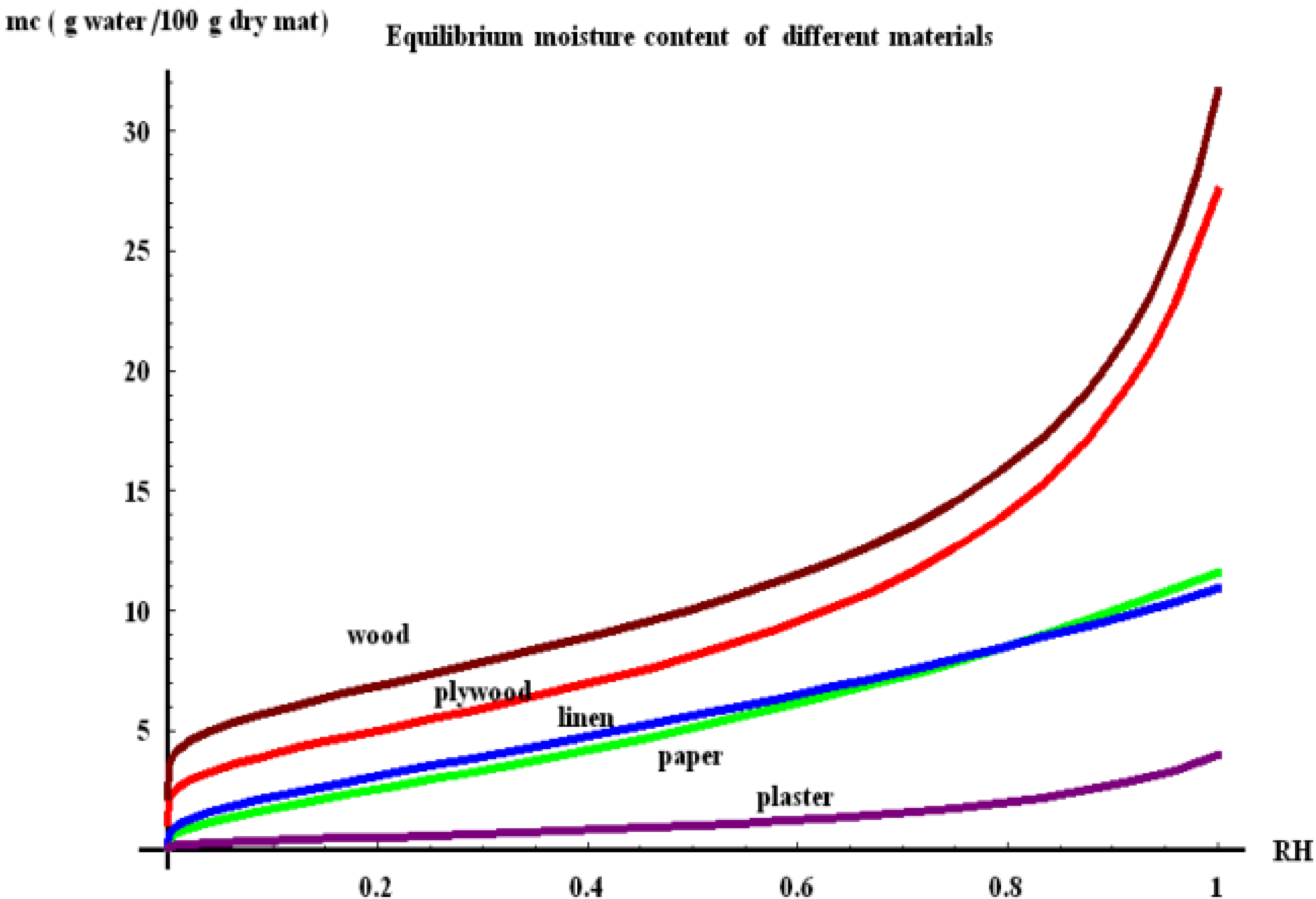
We will neglect the differences between absorption and desorption

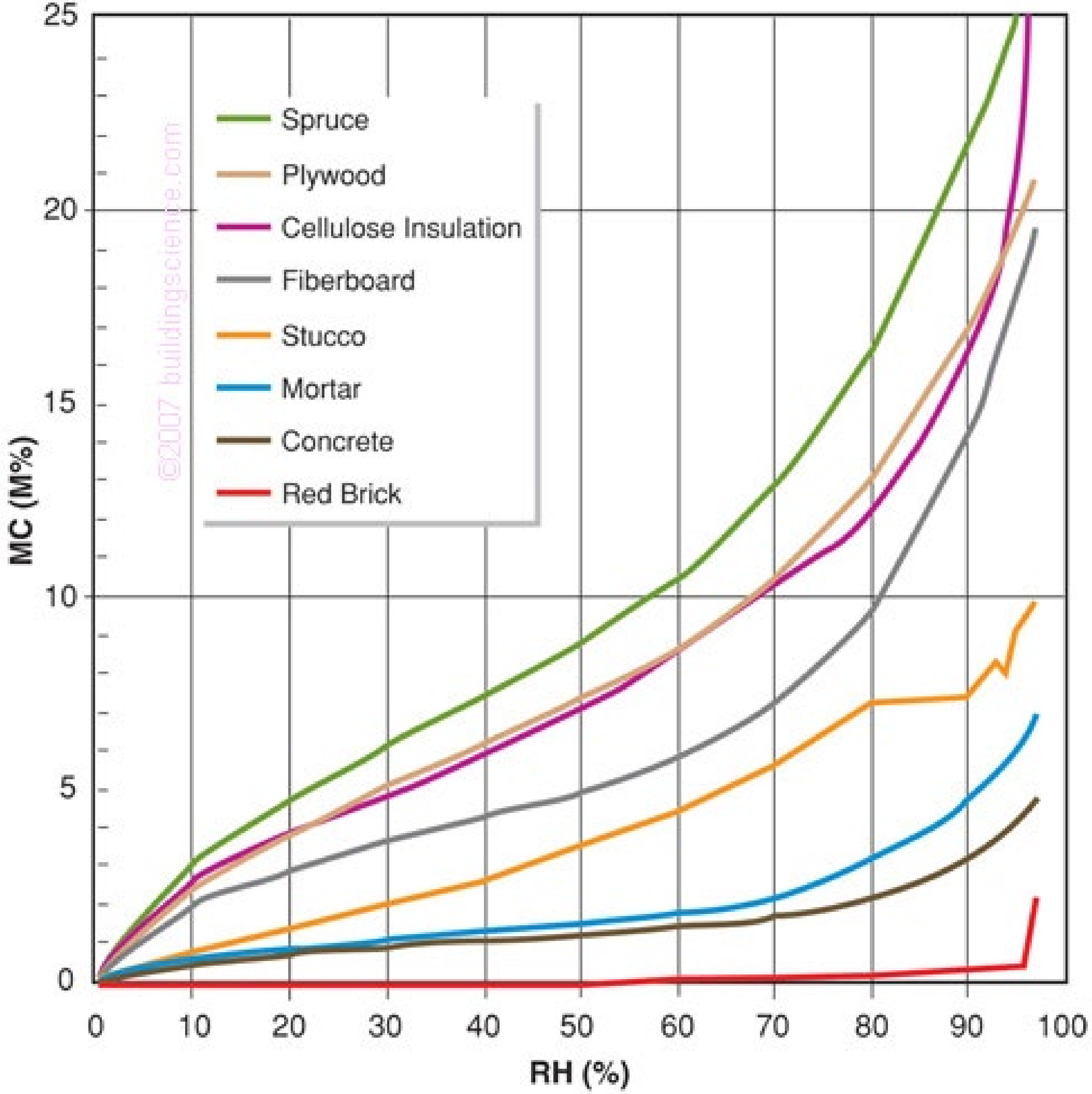
The equilibrium moisture content (emc) of a material is the mass of water contained in the material expressed as percentage of the dry mass of the material

$$emc = \frac{m - m_{dry}}{m_{dry}}$$

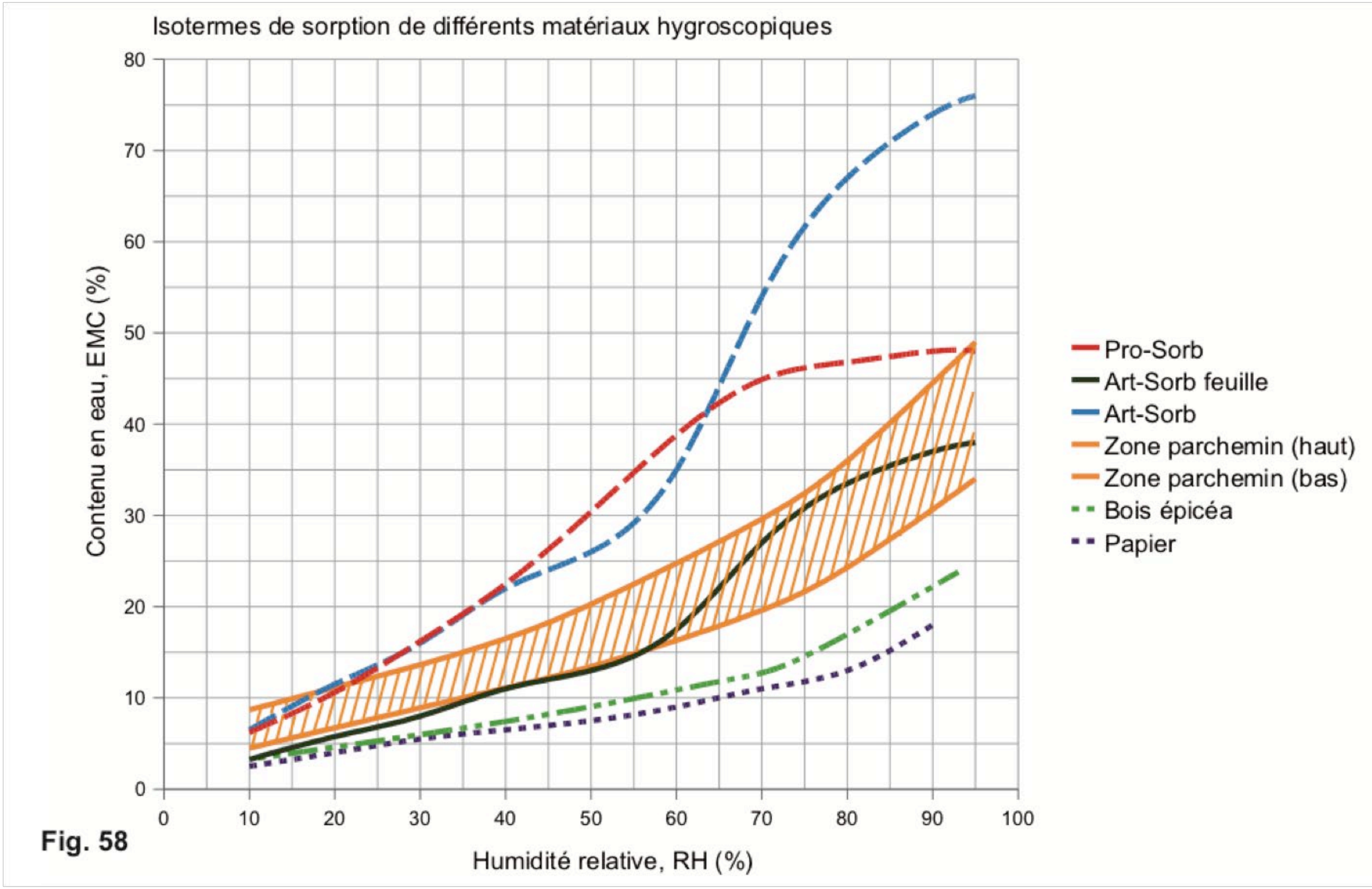
equilibrium= material in equilibrium with surrounding RH

- m_{dry} =100 g, m_{water}=20 g --> emc =
- m_{dry} =100 g, $m_{RH=50\%}$=105 g --> emc =
- m_{dry} =80 g, m_{water}=10 g --> emc =
- m_{dry} =80 g, $m_{RH=50\%}$=85 g --> emc =


mc (g water /100 g dry mat)
Equilibrium moisture content of different materials
30
25
20
15
10
5
wood
plywood
linen
paper
plaster
RH
0.2
0.4
0.6
0.8
1

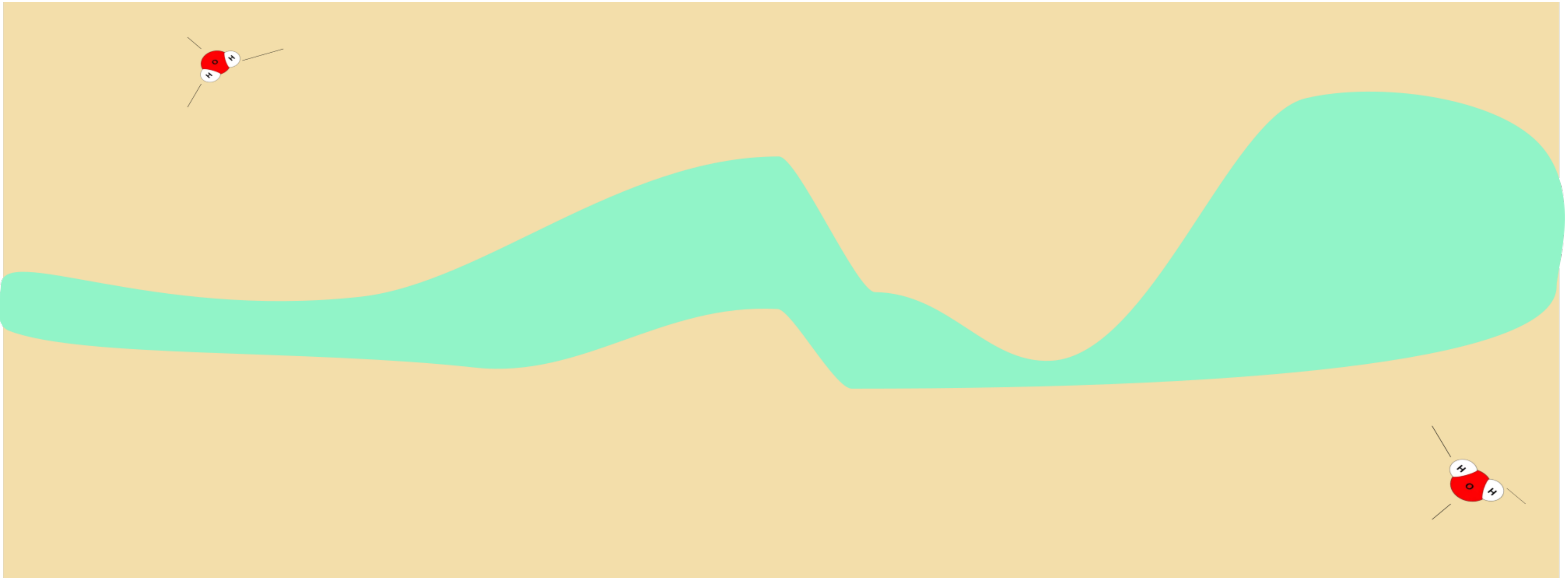


from https://www.buildingscience.com/documents/digests/bsd-138-moisture-and-materials

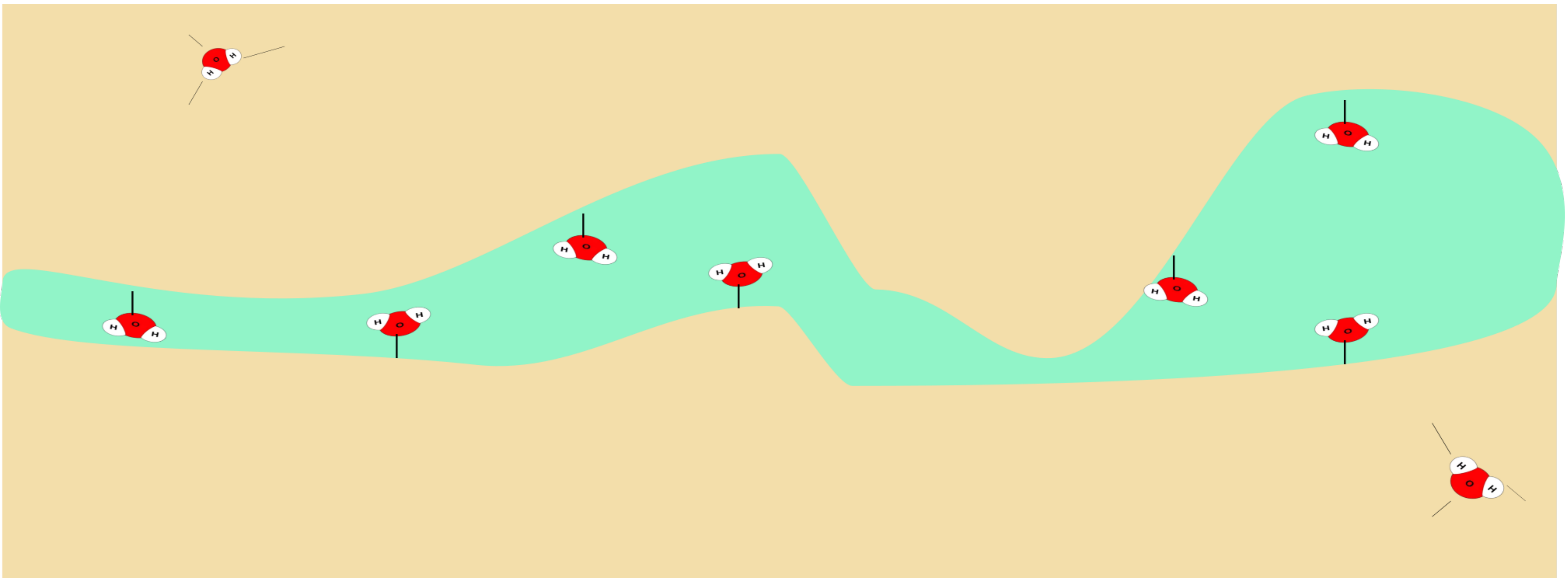


From Margaux Genton, 2015, BA Thesis, Hochschule der Künste Bern, Konservierung und Restaurierung

RH=0%

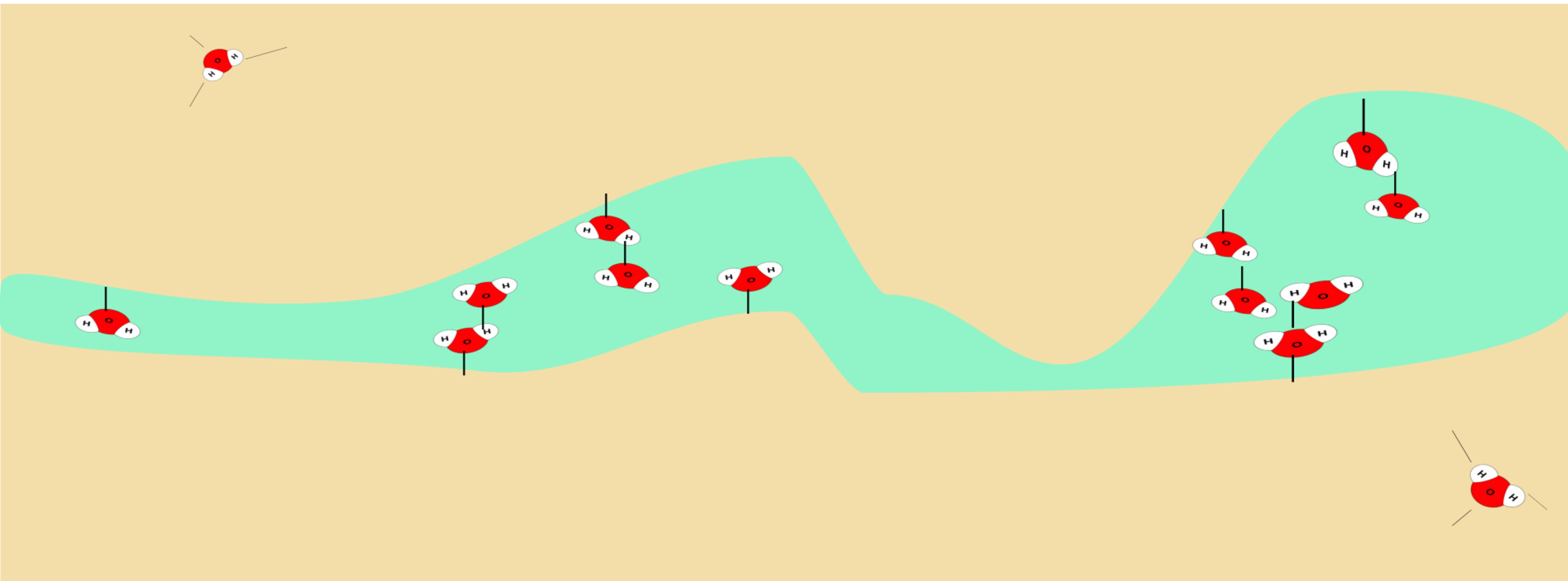


RH<20%



monomolecular layer

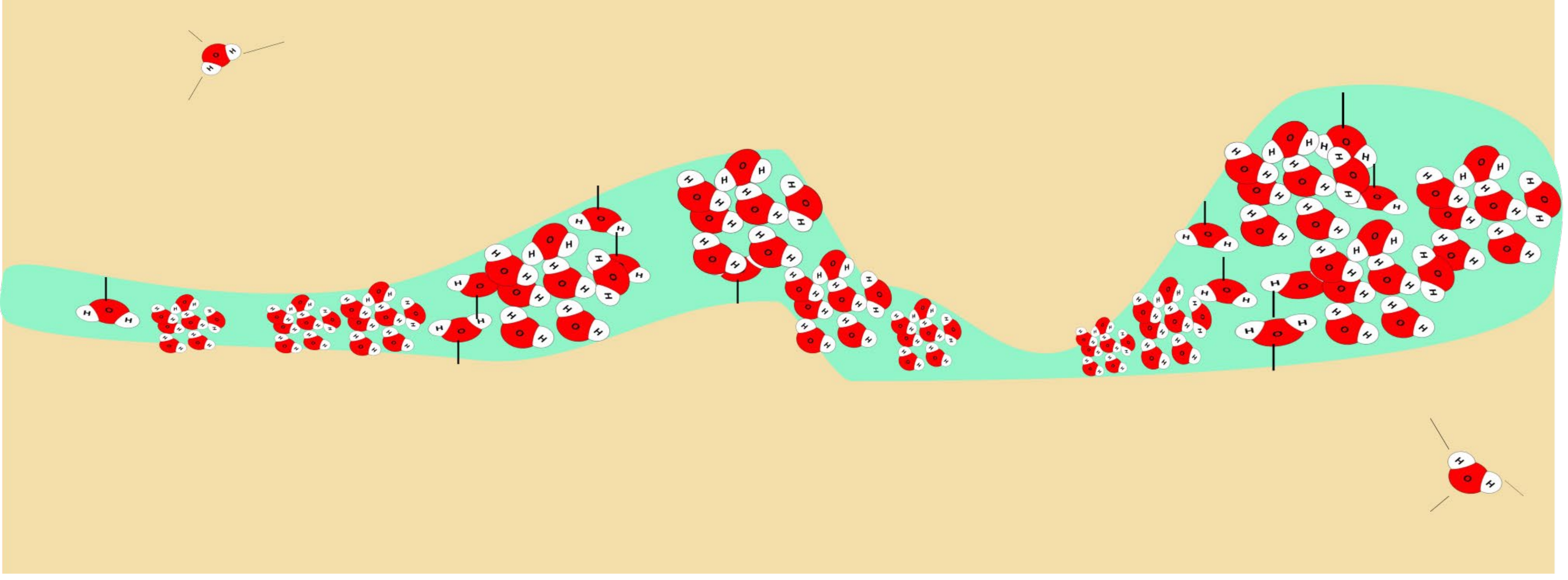
20%<RH<90%



further layers with less strong bonds, freezing temperature well below 0°C

swelling and shrinking depends on RH

RH>90%



capillary water, free water

Freezing temperature at 0°C

Capillary water has no influence on swelling and shrinking

Now we are equipped to look at the buffering effect of hygroscopic materials in 3 different situations:

- **closed systems undergoing temperature changes**
- **RH changes in a closed system after the insertion of hygroscopic materials**
- **semi-closed systems containing hygroscopic materials exposed to RH changes**

Closed system: no air exchange with the surrounding environment

semi-closed system: air exchange with the surrounding environment

The microclimate in packages, showcases, microclimate vitrines and backing board protected paintings

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Lesson 4

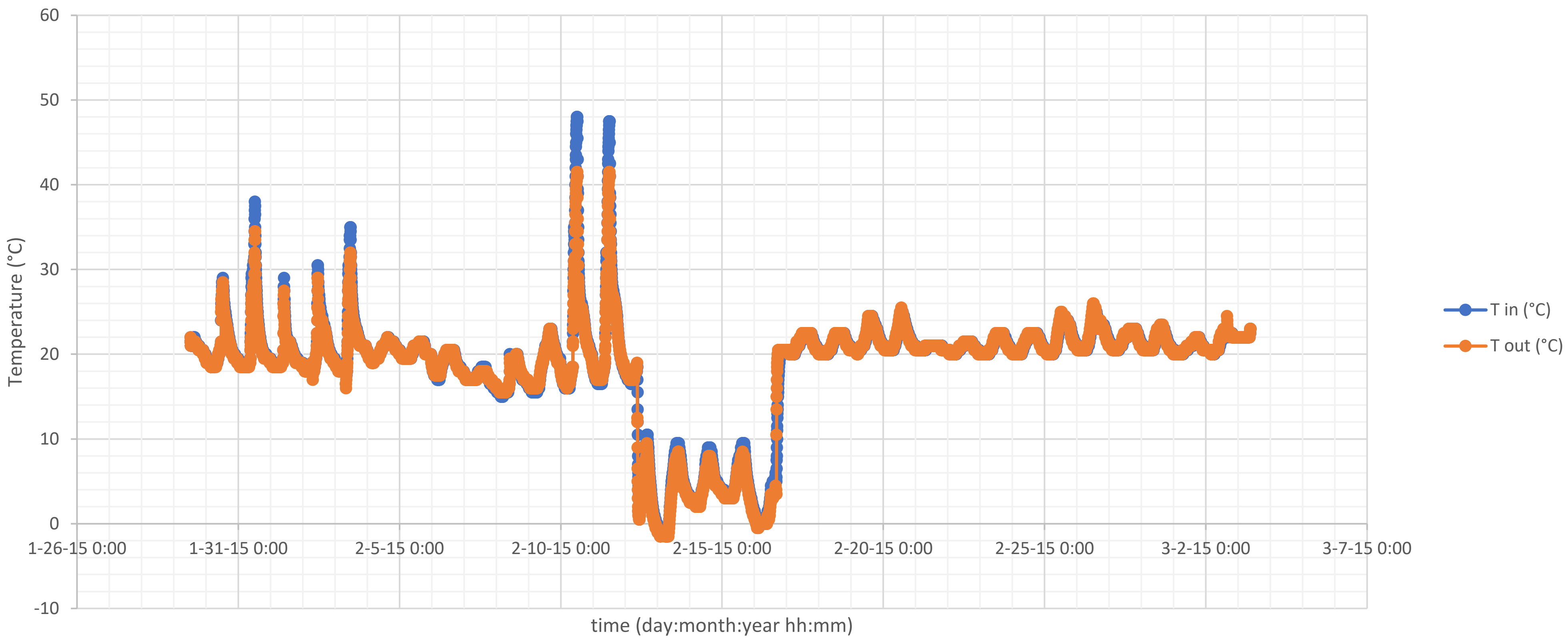
Buffering effect of hygroscopic materials against temperature changes in closed systems. Case study: microclimate vitrine

Design of the microclimate vitrine based on Sozzani, L. S. G. (1997). An economical design for a microclimate vitrine for painting using the picture frame as the primary housing. *Journal of the American Institute for Conservation*, *36*, 95–107.

Microclimate vitrines are built within the frame of a painting to stabilize the relative humidity. They consist of an impermeable backing board, a front glazing and careful lateral sealing with different types of tapes and gaskets to reduce as much as possible the air exchange

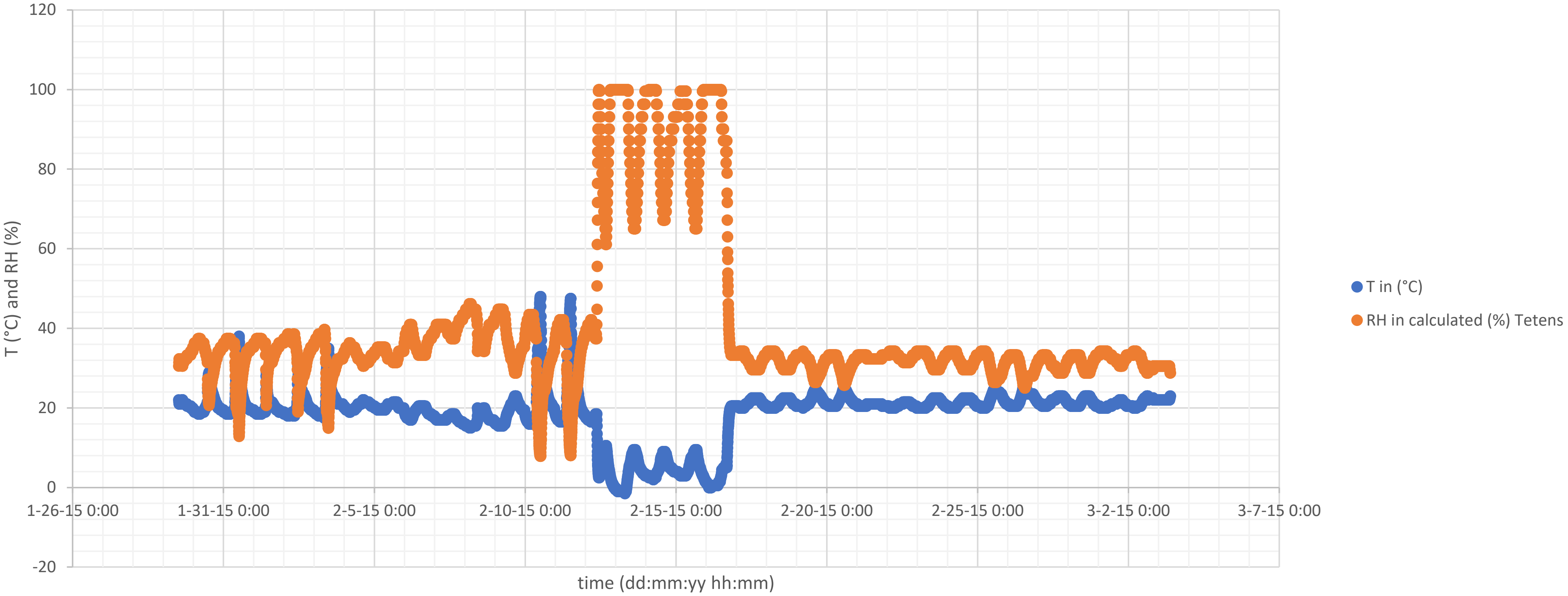
Dummy microclimate vitrine with space for a RF and T Datalogger

Temperature inside and outside the vitrine



Based on this temperature and on the fact that the initial measured AH in the system is 5.93 g/m3, which is the expected RH if the system would have been without hygroscopic materials? (data as Excel and csv file)

predicted RH if the vitrine would be empty, inert and closed



temperature decreases→RH increases (and viceversa)

condensation when T<dew point

Question: if the microclimate vitrine is closed and does not contain hygroscopic materials (it is inert) the AH:

- increases when the temperature increases
- decreases when the temperature increases
- is constant and independent from the temperature

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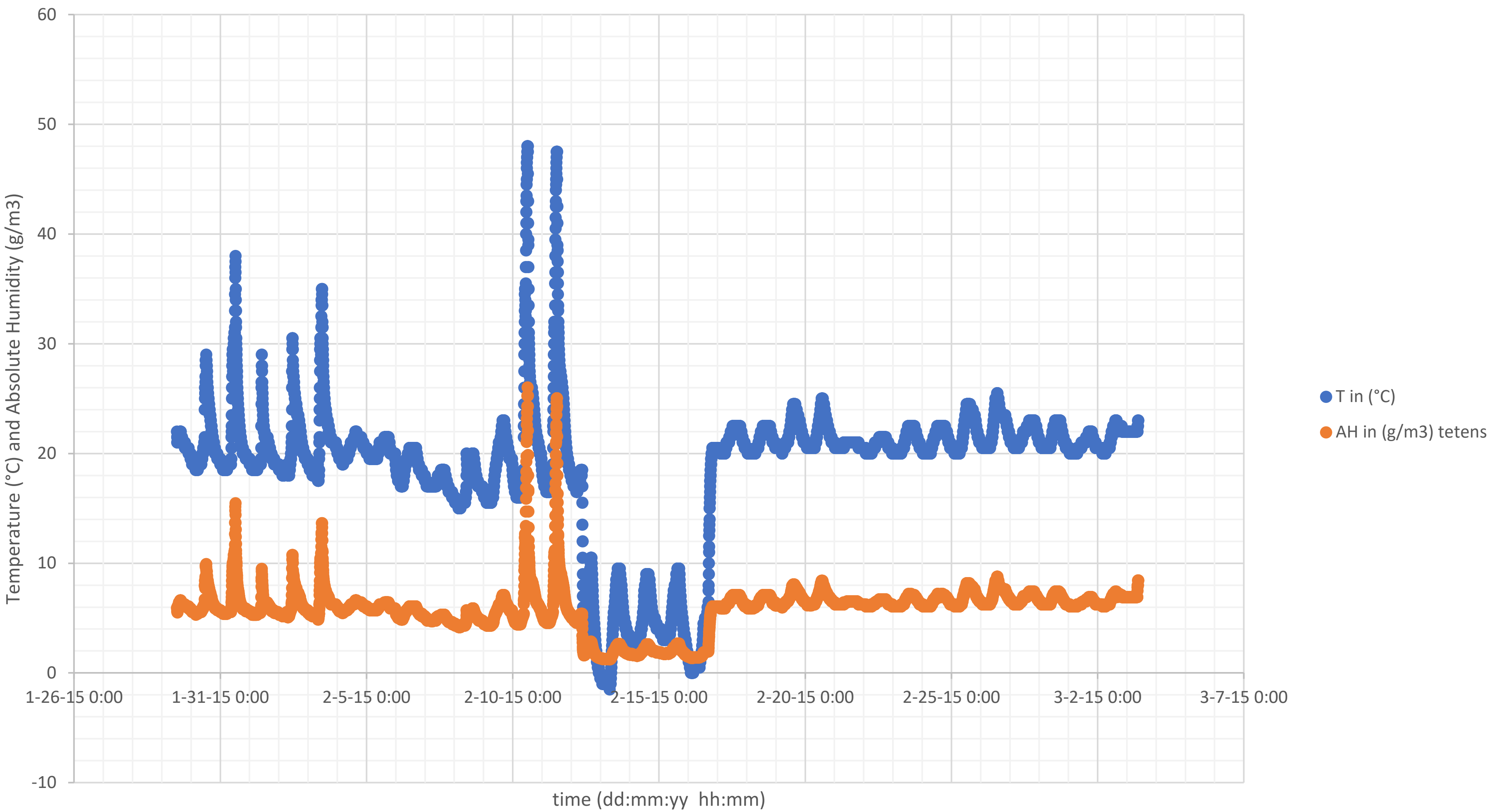
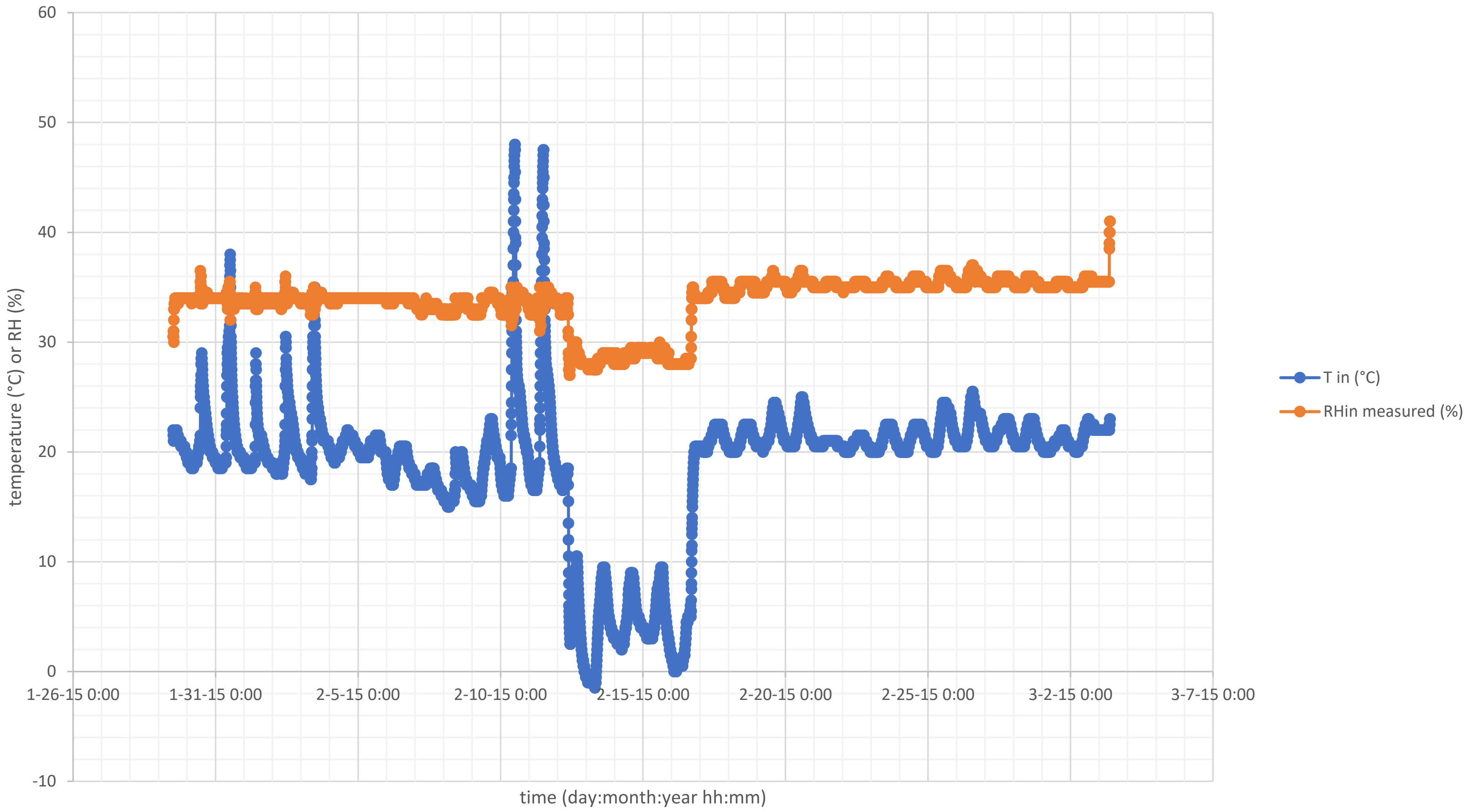
Measured AH: a temperature decrease leads to a decrease of the AH (and viceversa) despite the system is closed



Measured RH: a temperature decrease leads to a small decrease of the RH (and viceversa).



Formulate:

1. an hypothesis for the decrease of the absolute humidity when the T decreases = a description of the mechanism leading to the decrease of RH
2. a test experiment for your hypothesis
3. a prediction for the outcome of your test experiment

Quantitative estimation

Given that the free volume of the microclimate vitrine (volume not occupied by the panel and by the RH and T datalogger) is about 300 cm^3, estimate how many grams of water vapour are removed from the volume for the AH to decrease from 5.15 to 1.6 g/m3 when the temperature decreases from 18° to 0°C.

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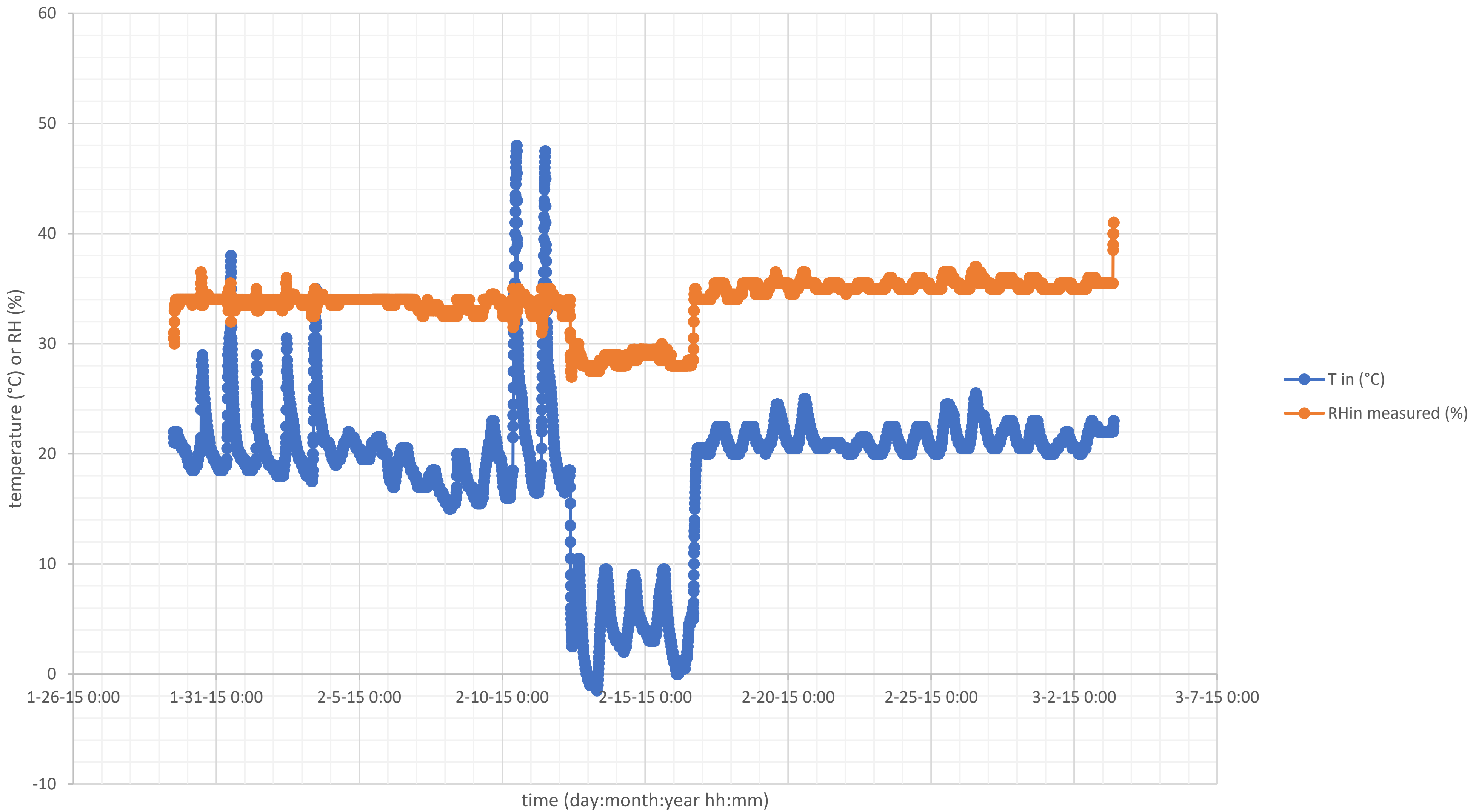
0.001 g!

The removal of a very small amount of water vapour is sufficient to lead to large changes in the absolute humidity and measureble changes in the relative humidity



large changes in T lead to small changes in RH, changes are in the same direction.

this is the so called **buffering effect of hygroscopic materials against T changes** in closed systems.

Unpacking the buffering effect of hygroscopic materials against T changes in closed systems:

1. hygroscopic materials contain much more water than the volume

2. the total amount of moisture in the system is constant

3. the emc of hygroscopic materials decreases by increasing temperature

1. Hygroscopic materials contain much more water than the volume

Comparison

Water vapour content of an empty volume (cube of size 5 cm) at 20°C und RH= 50% =

Emc of a cube of wood with size 5 cm at 20°C und RH= 50% (density of wood = 0.8g/cm3)

Water vapour content of an empty volume (cube of size 5 cm) at 20°C und RH= 50% ≅ 0.001 g

Emc of a cube of wood with size 5 cm at 20°C und RH= 50% (density of wood = 0.8g/cm3) ≅ 10 g

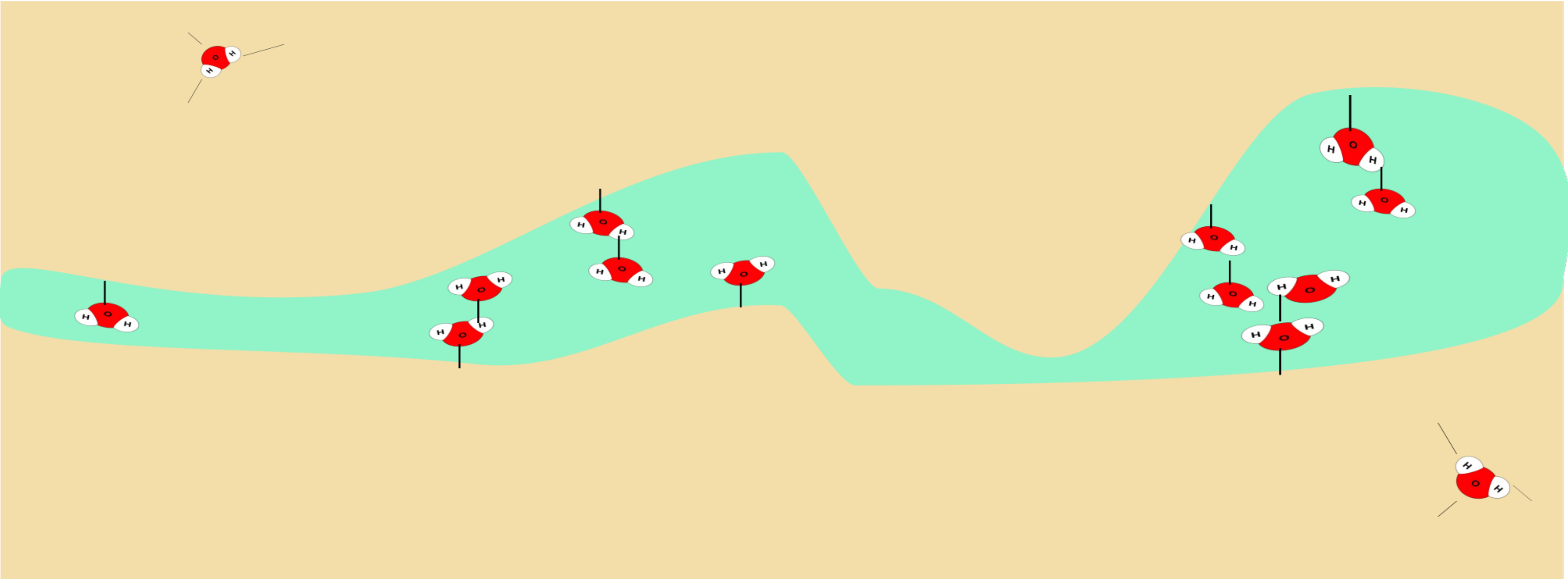
at the same volume hygroscopic materials contain much more water than air (up to 4 orders of magnitude more)

2. the total amount of moisture in the system is constant

System is closed-> The mass of water is constant in the system

but moisture can move between hygroscopic materials and volume

3. T dependency of the sorption isotherm



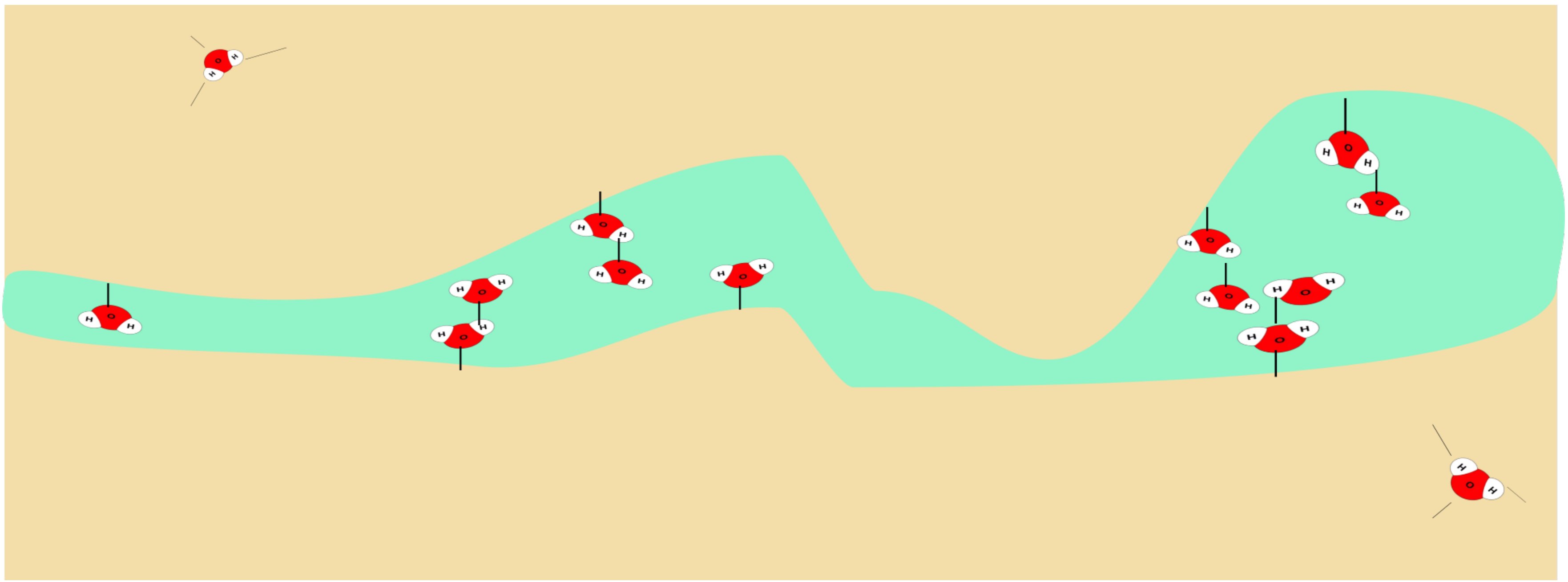
Question: T increases. The moisture content:

a. is constant

b. increases

c. decreases

3. T dependency of the sorption isotherm



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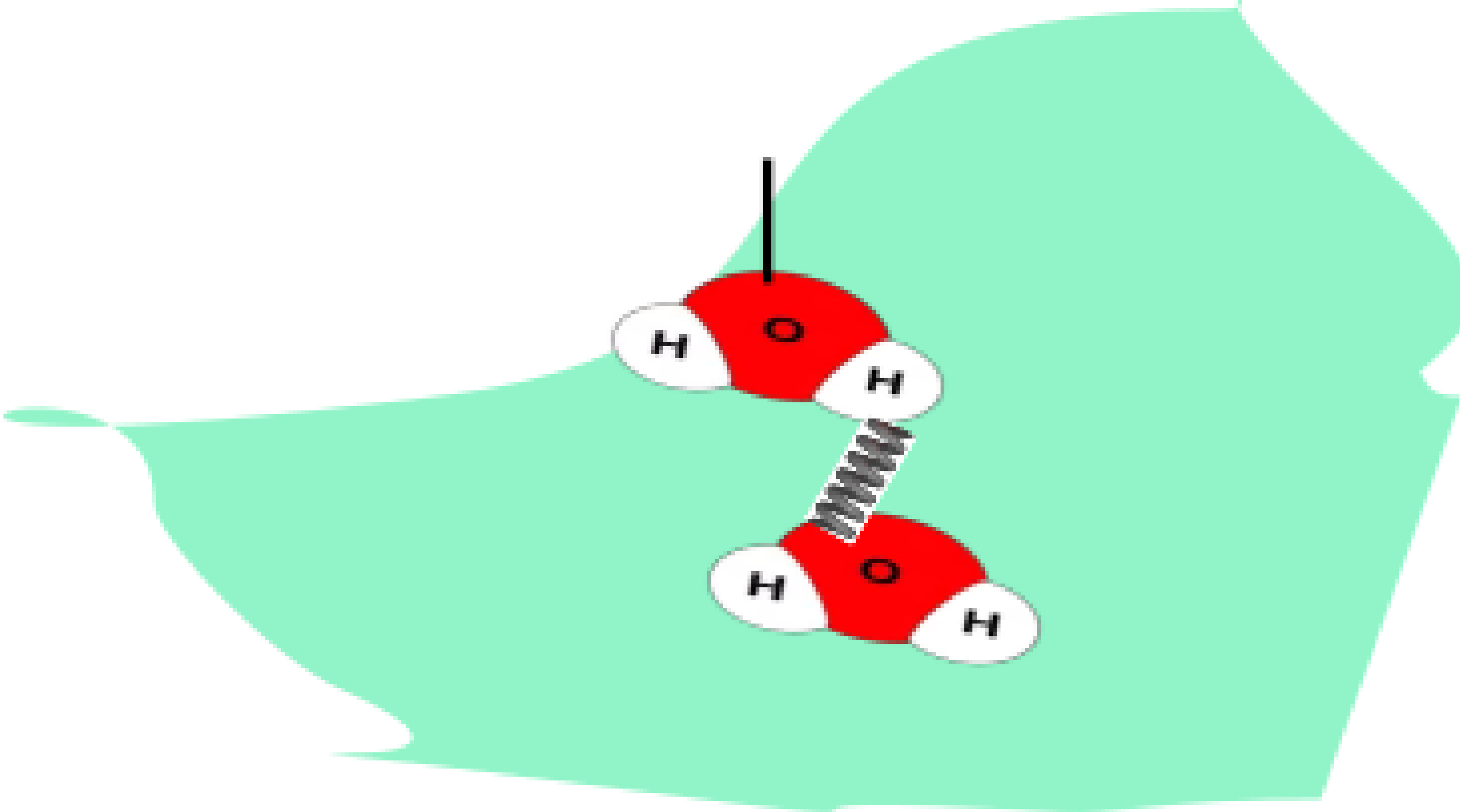
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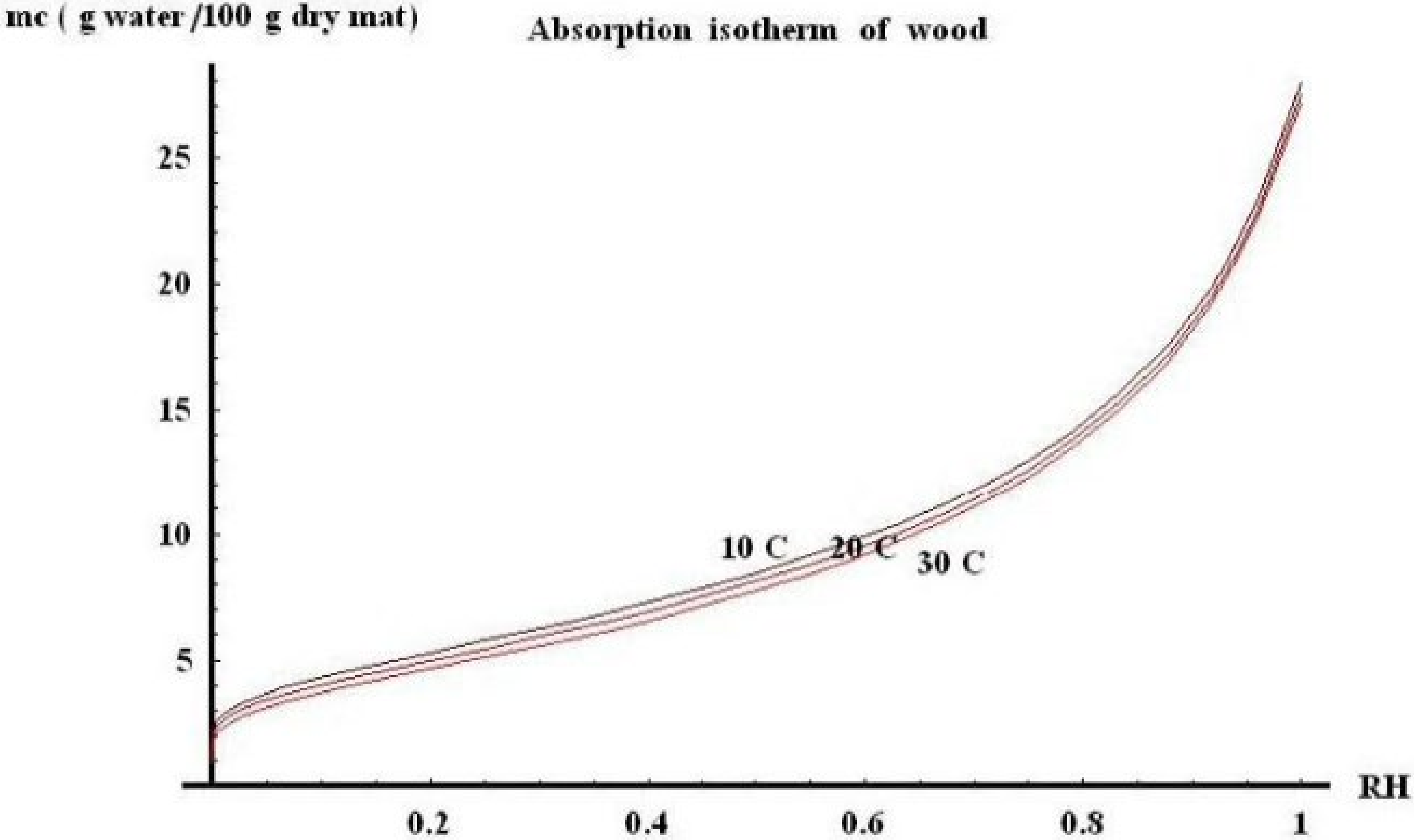
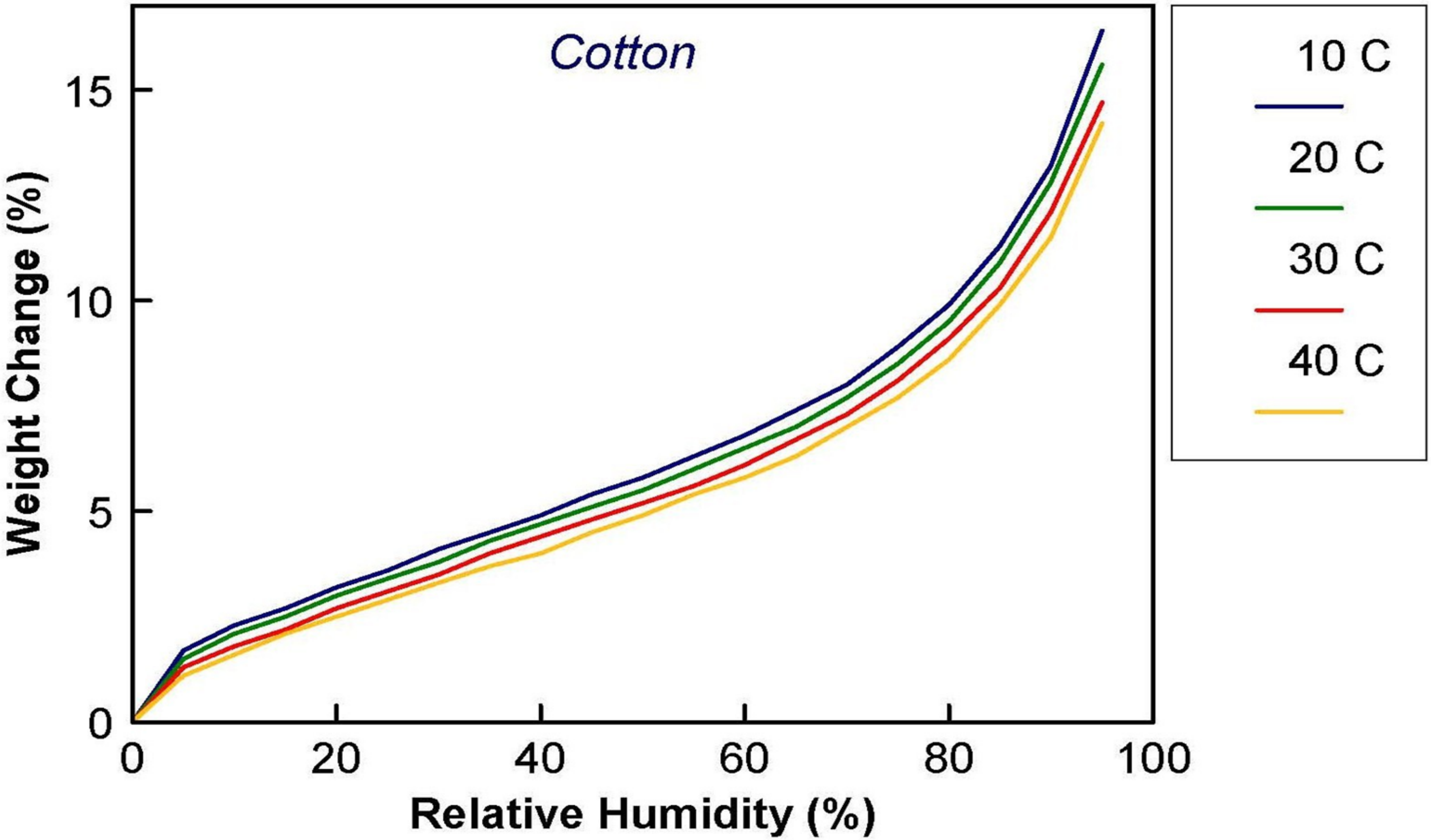
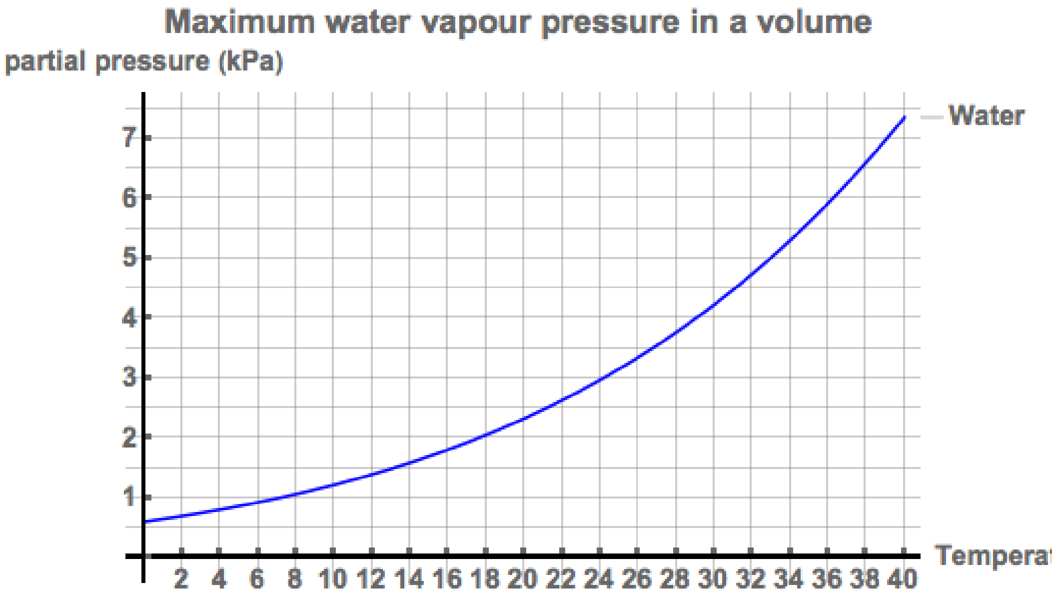


T increases → emc decreases



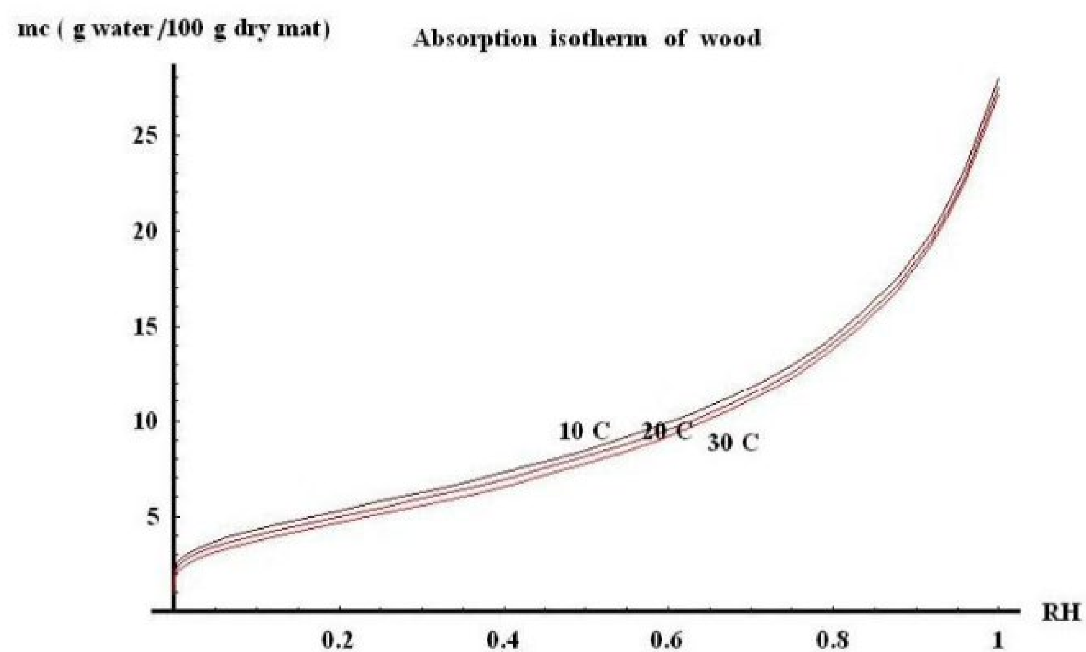
from: M. Mecklenburg, Course outline

Notice the difference!



Water content of air: increases with temperature

water content of a materials: decreases with temperature



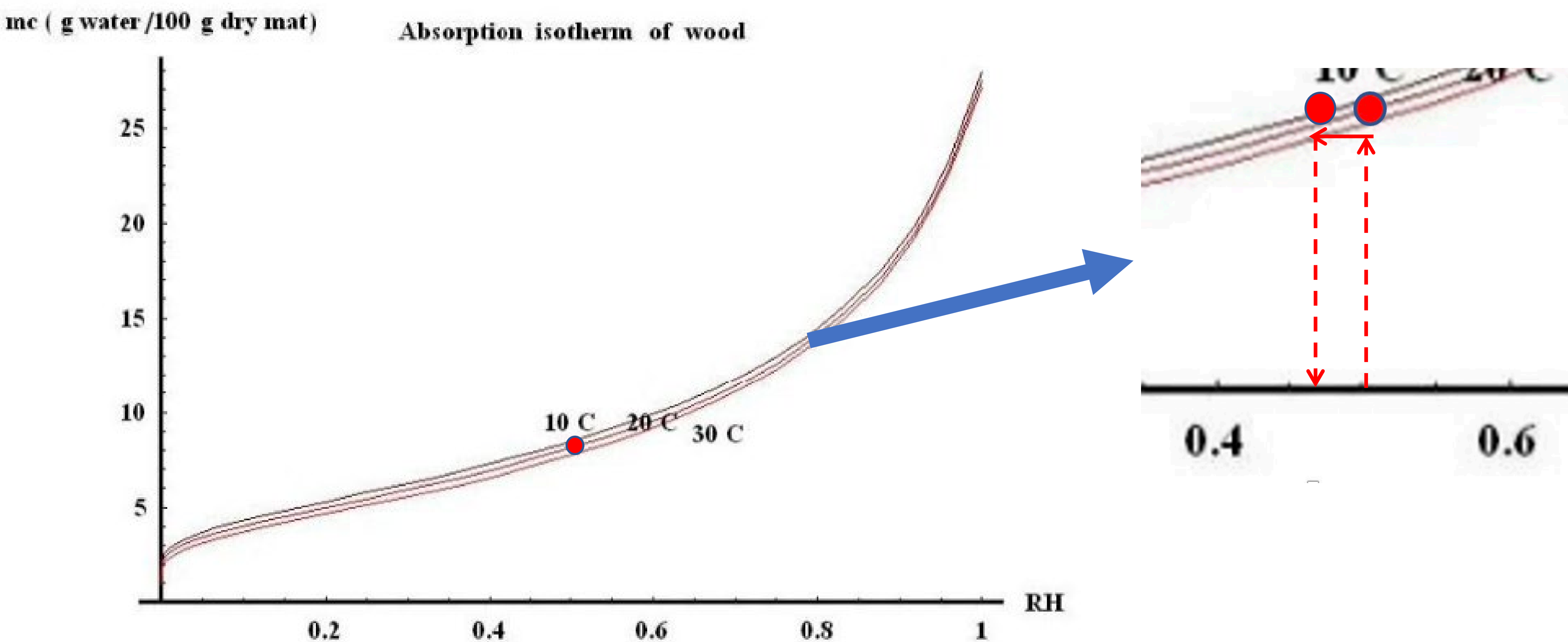
Unpacking the buffering effect of hygroscopic materials against T changes in closed systems:

1. hygroscopic materials contain much more water than the volume -> Mass of water in the system ≅ Mass of water in the hygroscopic material

2. the total amount of moisture in the system is constant -> Mass of water in the hygroscopic material is (approximately) constant

3. the emc of hygroscopic materials decreases by increasing temperature

Graphic solution to predict the RH change in the microclimate vitrine when the T changes :



The new RH can be red from the sorption isotherm at lower temperature. We move horizonntally because the mass of water in the hygroscopic materials is approximately constant. The final humidity will be slightly lower than the initial value.

Mathematical solution to predict the RH change in the microclimate vitrine when the T changes :

$$M_{water\ in\ system} = constant \tag{1}$$

$$M_{water\ in\ system} = M_{water\ in\ air} + M_{water\ in\ materials} \tag{2}$$

$$M_{water\ in\ material} >> M_{water\ in\ material} \Rightarrow M_{water\ in\ system} \approx M_{water\ in\ material} = constant \tag{3}$$

$$M_{water\ in\ material} \approx M_{material\ dry} \times (\alpha \times RH - \beta \times \Delta T) \tag{4}$$

$$M_{material\ dry} \times (\alpha \times RH_f - \beta \times \Delta T_f) = M_{material\ dry} \times (\alpha \times RH_i - \beta \times \Delta T_i) \tag{5}$$

$$RH_f \approx RH_i + \frac{\beta}{\alpha} \times (T_f - T_i) \tag{6}$$

$$RH_f(T_f) = RH_i(T_i) + \frac{\beta}{\alpha}(T_f - T_i)$$

$0<RH<1$

$\boldsymbol{\beta}=4 \times 10^{-4}$ ($°C^{-1}$)

$\boldsymbol{\alpha}=0.15$

Assumptions:

- system is closed
- moisture mass in the system is in the hygroscopic materials
- linear approximation of the sorption isotherm

In a closed system containing hygroscopic materials and subjected to T changes a decrease of T leads to a small decrease of the internal RH (and viceversa)

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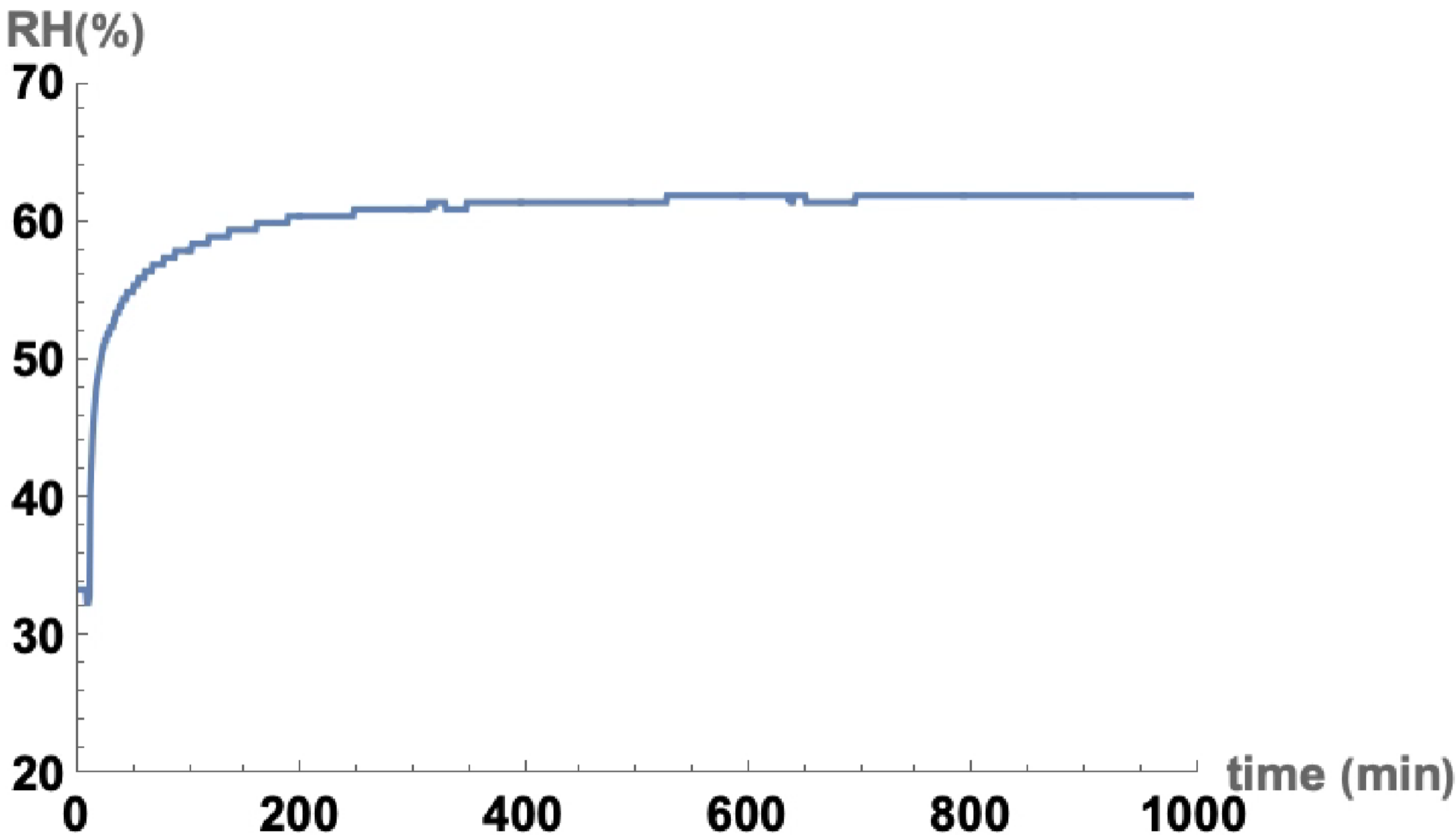
Lesson 5

closed systems: RH changes after the insertion of hygroscopic materials
semi closed systems: buffering effect against surrounding RH changes

closed system: RH changes after the insertion of hygroscopic materials

Situation:
newspapers freshly donated to a collection. The newspapers were previousy stored in a cellar and are possibly contaminated with moulds. They are sealed in plastic foils to avoid contamination in the museum. Which is the RH within the packages?

Experiment: measured RH in a closed system (bottle) initially at 30%RH, then filled with paper conditioned at 65% RH and closed



Animation 4. Measured RH in a Closed System (Bottle) Initially at 30%RH, then Filled with Paper Conditioned at 65% RH and Closed (please see "Animation" on Pressbooks for video).

Formulate:

1. an hypothesis for the increase of the RH
2. a test experiment for your hypothesis
3. a prediction for the outcome of your test experiment

Deductio ad absurdum:

possibility 1: RH stays 30% → emc in the paper= 3%→ Δemc= 3.5%, if the dry mass of the paper= 100g, the paper must loose 3.5 g of moisture. If this moisture goes in air, the RH becomes 100% →contraddiction!

Deductio ad absurdum:

possibility 2: 30<RH<65, e.g. RH=50% → emc in the paper= 5%→

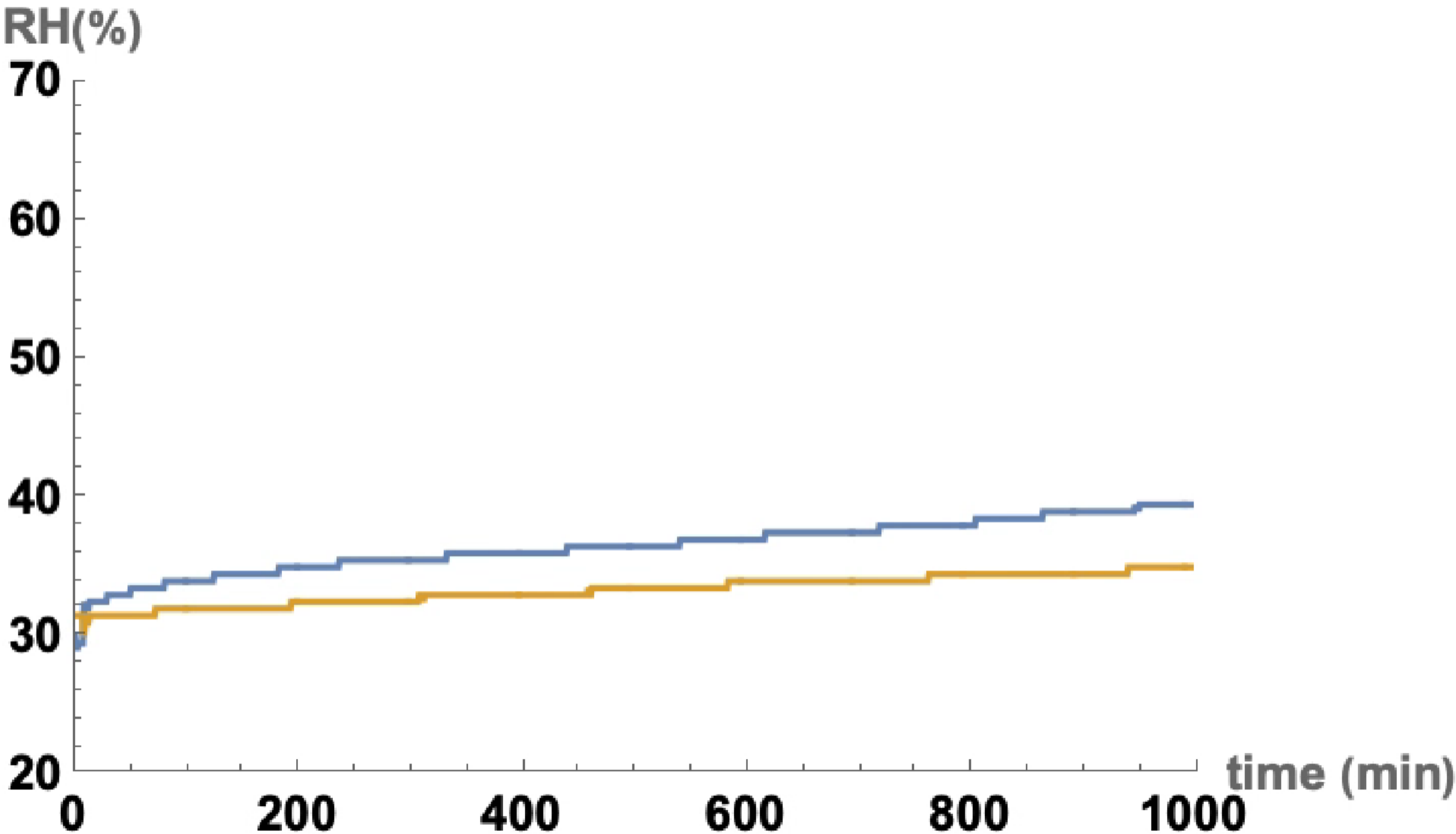
Δemc= 1.5%, if the dry mass of the paper= 100g, the paper must loose 1.5 g of moisture. If this moisture goes in air, the RH becomes 100% →contraddiction!

Deductio ad absurdum:

Only remaining possibility : RH=65%, the value at which the paper was initially conditioned

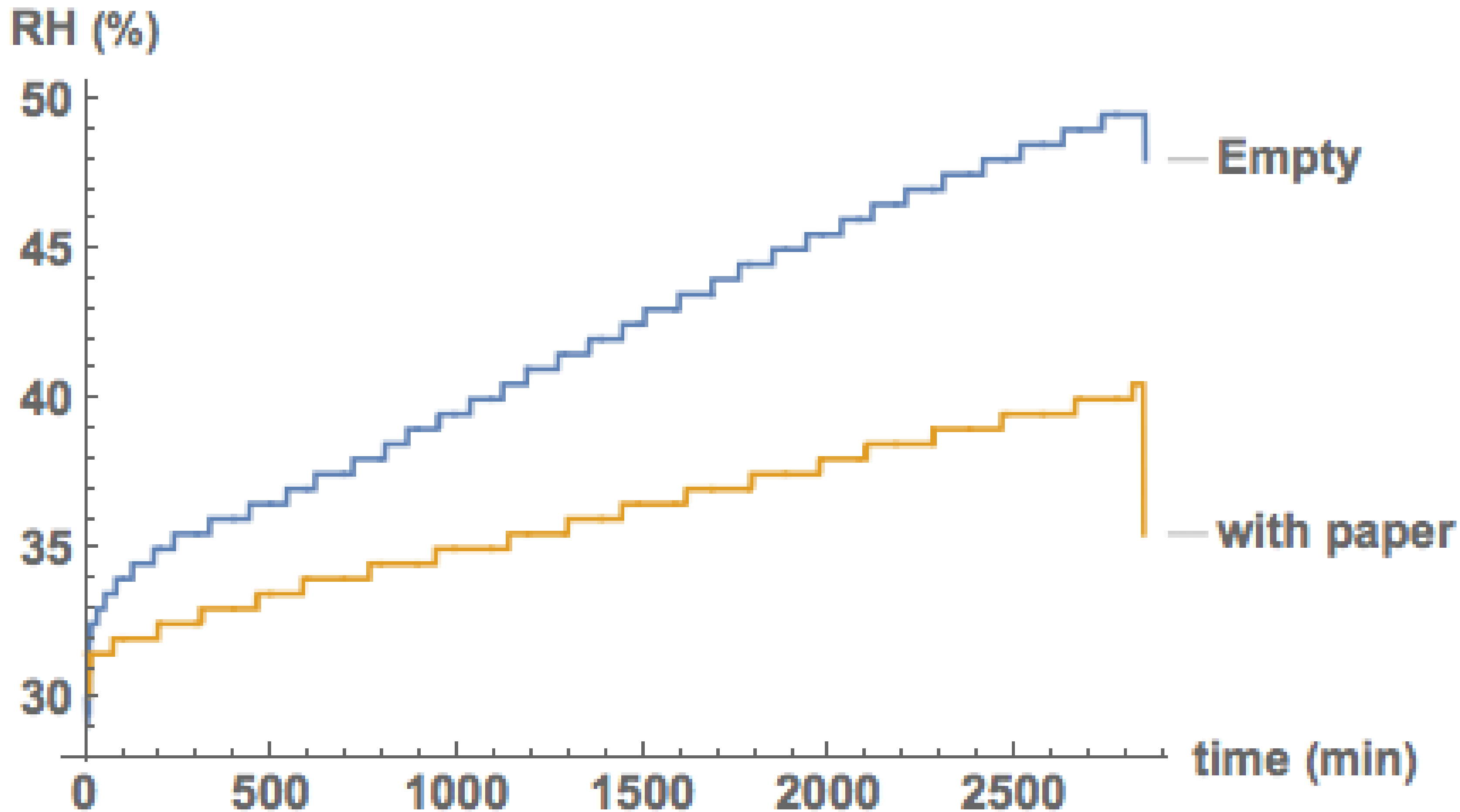
In closed system the moisture content of the hygroscopic materials determine the RH and not viceversa!

Situation:
newspapers freshly donated to a collection. The newspapers were previsouly stored in a cellar and are possibly contaminated with moulds. They are packed in a semi-closed package to avoid contamination in the museum. Which is the RH within the packages?

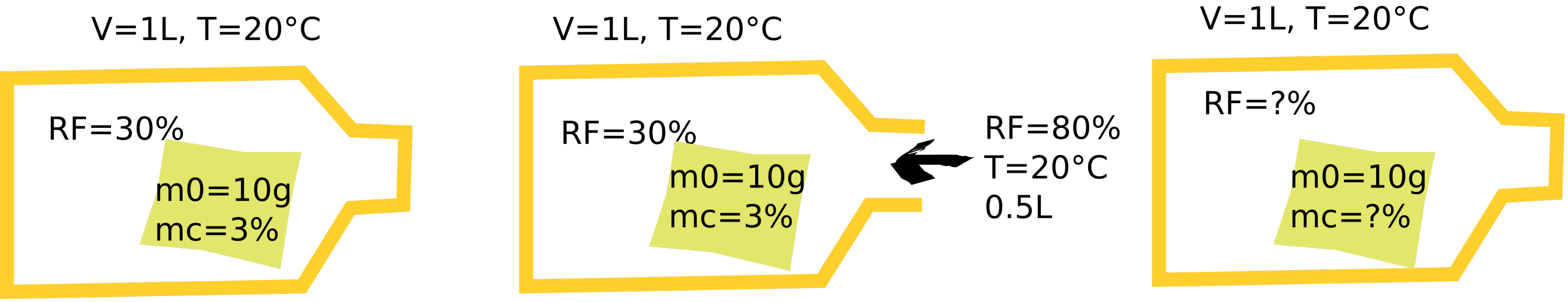


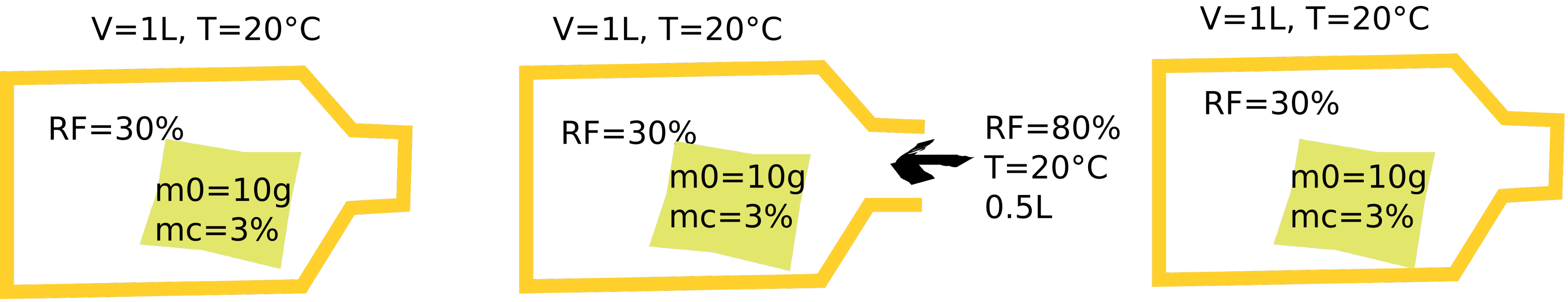
Animation 5. RH in Semi-Open Bottles Exposed to High RH (please see "Animation" on Pressbooks for video).

RH in bottles initially at 30% and then closed and exposed to 80% R



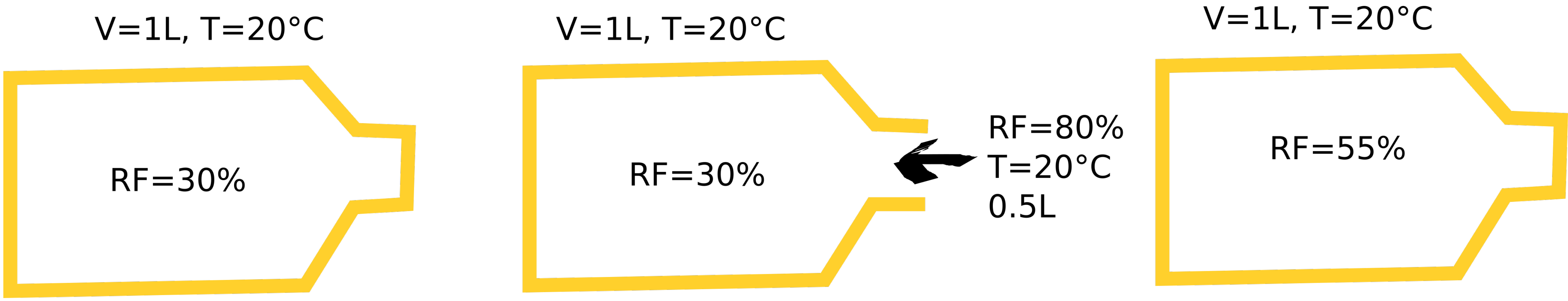
Bottle with hygroscopic materials



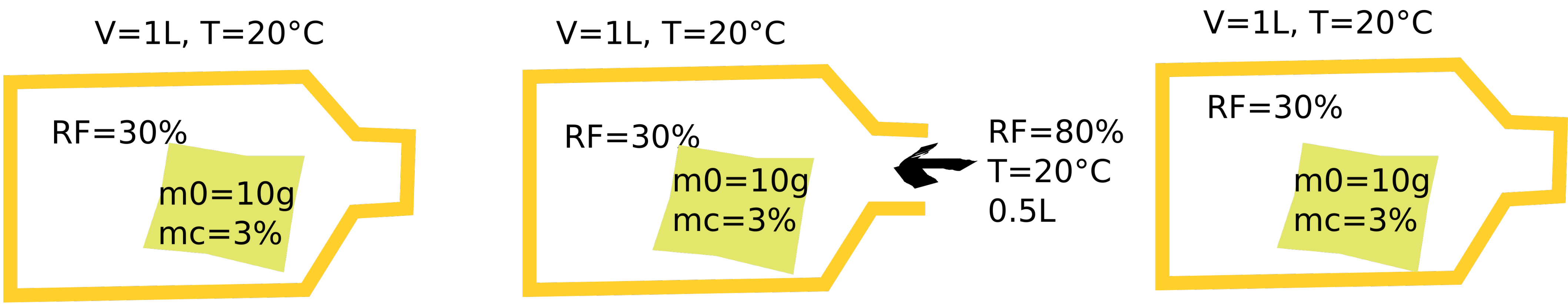


V=1L, T=20°C
RF=30%
m0=10g
mc=3%
V=1L, T=20°C
RF=30%
m0=10g
mc=3%
RF=80%
T=20°C
0.5L
V=1L, T=20°C
RF=30%
m0=10g
mc=3%

Empty bottle



bottle with an hygroscopic material



This is the buffering effect of hygroscopic materials in semi-closed systems against RH changes

Experiments (in preventive conservation):

- prepare different type of packages (bags, boxes, with materials of different permeabilities) and measure the RH within the package after inserting newspapers that were previously conditioned at 80% RH

- prepare different types of well-sealed boxes , insert hygroscopic materials and measure the internal RH wile exposing them to different temperatures.