Temperature, Liquid Water, Time and Habitability

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Key-parameters (among others) to describe habitability are:

* **Availability of liquid water**
  (transport of nutrients, waste and entropy)

* **Appropriate temperature range**
  (compatible to the presence of liquid water – or other liquids ?)

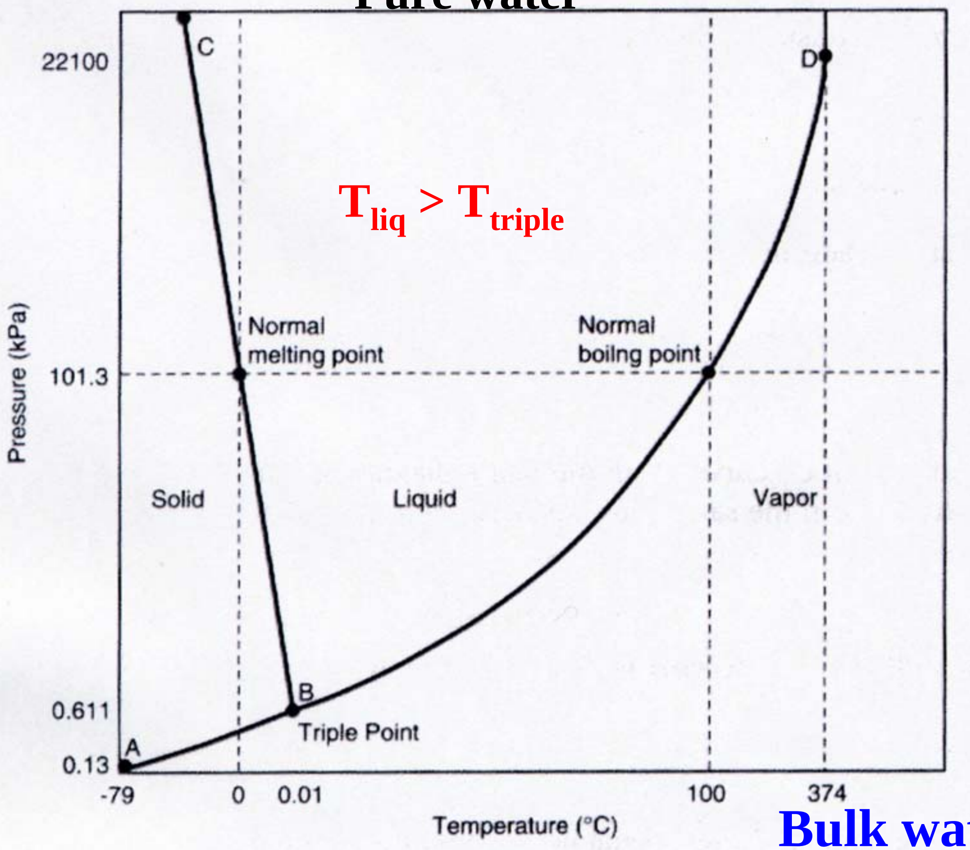
* **Time scale**
  (of bio-chemical processes compared to environmental variations)

Availability of liquid bulk water

Stable presence of liquid bulk water

(described by the phase diagram)

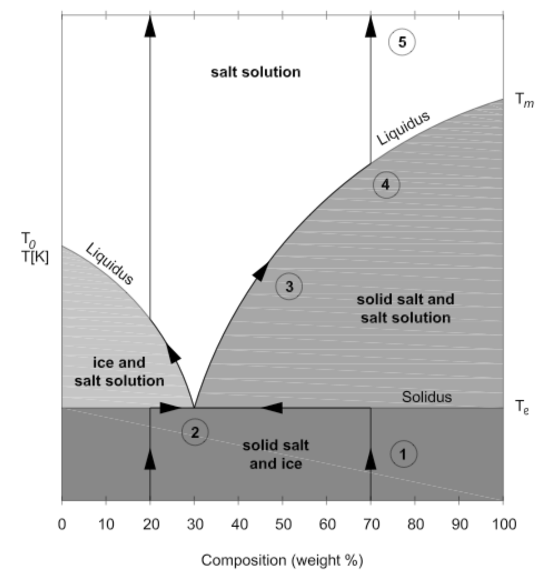
Pure water



$T_{liq} > T_{triple}$

Thus, T > 0° C

Aqueous salty solutions (brines)



$T_{liq} > T_{eut}$

Bulk water in cryo-brines can remain liquid at temperatures down to about -70° C

We are not limited to pure water only !

Availability of liquid bulk water

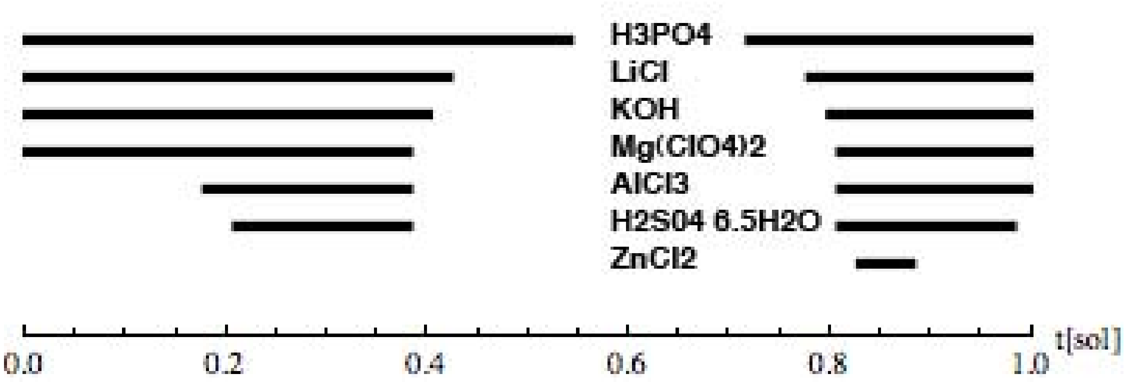
Liquid water in cryo-brines

Salt	Eutectic temperature [K]	DRH[%]
H_3PO_4	203	41
LiCl	206	48
KOH	210	50
$Mg(ClO_4)_2$	212	53
$AlCl_3$	214	53
$H_2SO_4 \cdot 6.5H_2O$	215	53
$ZnCl_2$	221	58
$CaCl_2$	226	60
$NiCl_2$	230	64

The liquid water in cryo-brines could overtake the biologically neccessary transport processes!

Deliquescence: Liquefaction of hygroscopic salts by accumulation of water vapour in case of sufficient relative humidity rh > DRH (threshold)

Condition for deliquescence: T > T_{eut} and rh > DRH simultaneously



Mars, 80° N, 0° E, shortly after northern spring (L_S = 90° - 120°). The condition rh(t) > DRH can be reached during evening, night and morning hours.

In presence of appropriate cryo-brines: Temporarily liquid bulk water is possible on an in the upper surface of present Mars

Availability of liquid „microscopic“ water

Interfacial and capillary water

Hydrophilic surfaces attract water atmospheric molecules, which get „adsorbed“ in nanometer-sized films.

This formation of „water-films“ may be amplified in interfaces between two solid surfaces towards 10 nm to 100 nm thicknesses.

Freezing point depression :

$$\Delta T = \frac{A\, T_m}{6\pi\rho_{ice} q d^3}$$

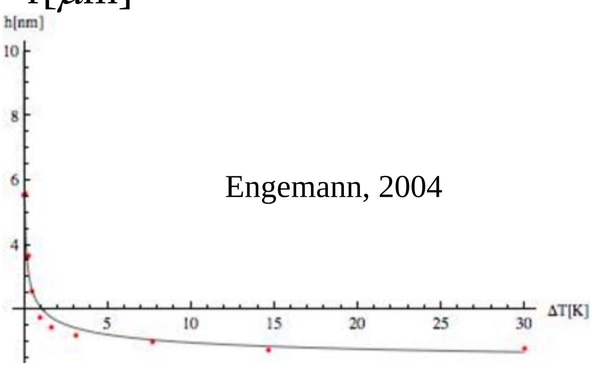
(experiments: down to – 130 °C)

In case of capillaries micrometers can be reached.

A freezing point depression of liquid capillary water:

$$\Delta T[K] = \frac{0.05}{r[\mu m]}$$

(i.e. ΔT = 50 K @ 1 nm)



Engemann, 2004

Number n of layers of water adsorption in dependence on water vapor pressure p (normalized to saturation pressure p_0) for different materials (Mikhail& Robens, 1983).

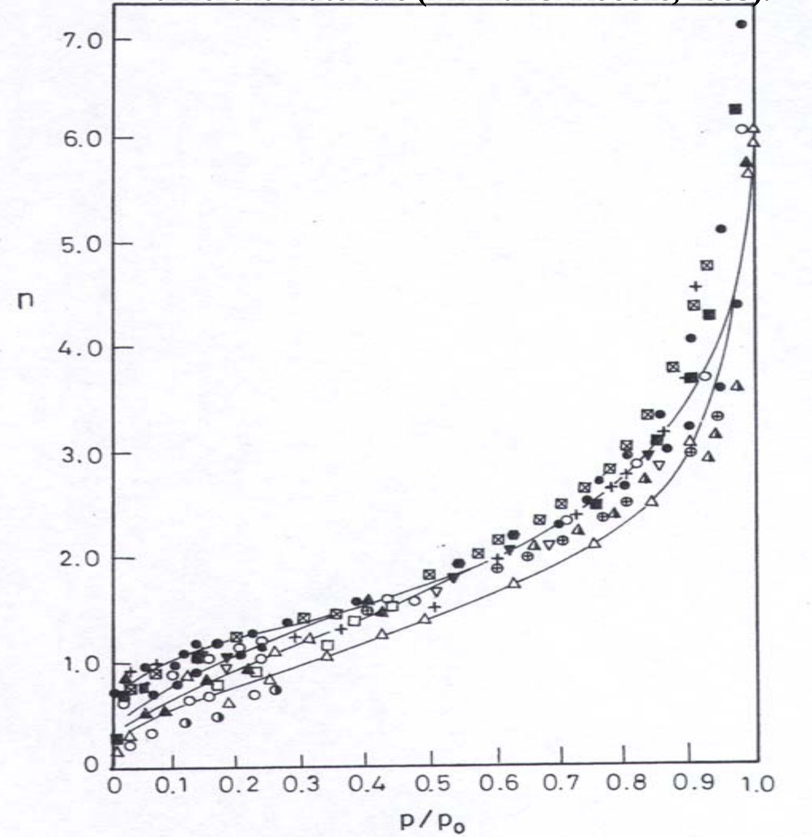
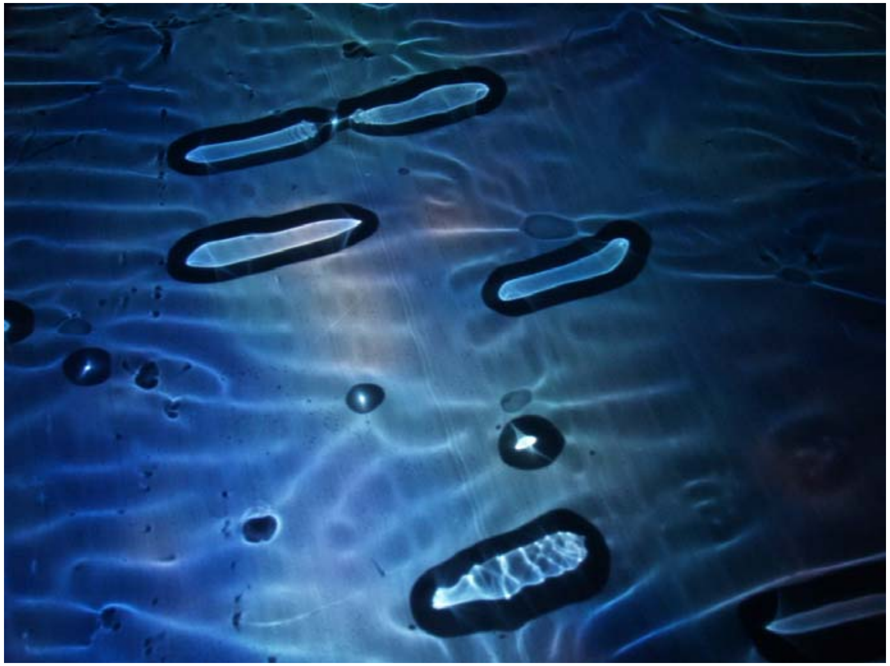


Fig. 2.31 *t*-Curves for pore structure analysis by water vapour adsorption[92]. The following symbols are used for the experimental points: zirconium silicate (*C* = 4.2) ◑ ◑; rutile (*C* = 5.2) △ △; silica (*C* = 7) ○ ○; silica gel, Davidson 81 (C = 10) □ □; zirconium silicate (*C* = 14.5) ▲ ▲; silica gel, Davidson 59 (C = 23) ▽ ▽; quartz (*C* = 23) ● ●; anatase (*C* about 50) ■ ■; anatase (*C* about 60) ⊕ ⊕; calcite (*C* about 70) ⊠ ⊠; barium sulphate (*C* about 120) ▼ ▼; barium sulphate (*C* about 160) ● ●; quartz (*C* about 200) + +

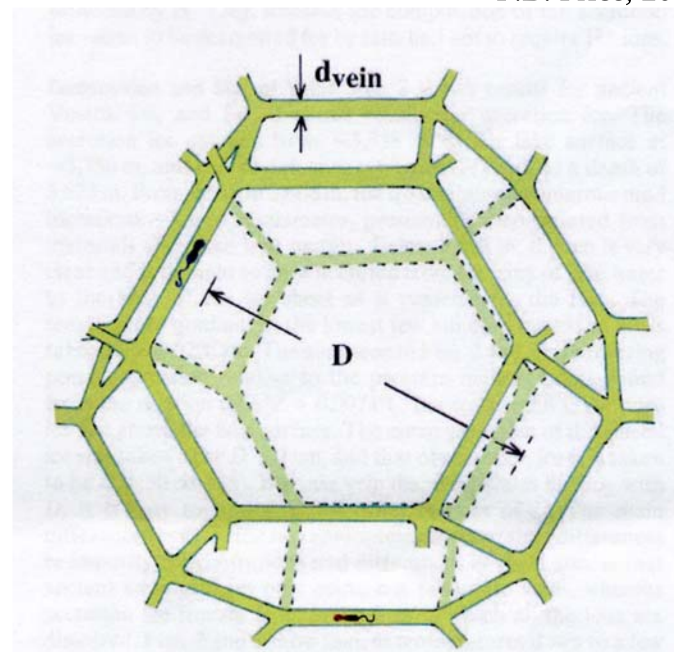
Life in microscopic capillaries (veins) with liquid water in water-ice and permafrost

P.B. Price, 2000



Nanometric water films on cell walls in ice are equivalent to an „infinite“ water environment (Möhlmann, 2009). Remember:

$$\Delta T[K] = \frac{0.05}{r[\mu m]}$$ **(i.e. 50 K @ 1 nm)**



Habitat of interconnected liquid veins along ice-grain boundaries (P.B. Price, 2000)

Dash et al., 2006: Premelting of ice can cause vein water to be liquid at temperaturs below but near the melting temperature

Life may exist in icy bodies at temperature below 0° C

A measure of the availability of water:

Water activity a_W (relative humidity of an atmosphere)

Equilibrium conditions: Water vapour pressure above a liquid or ice:

„Saturation pressure“ $p_S = a\, e^{-\frac{b}{T}}$

Real atmospheric partial water vapour pressure p_p

Water activity : $a_W = \frac{p_p}{p_S}$ **is a (standardized) measure of the atmospheric water content**

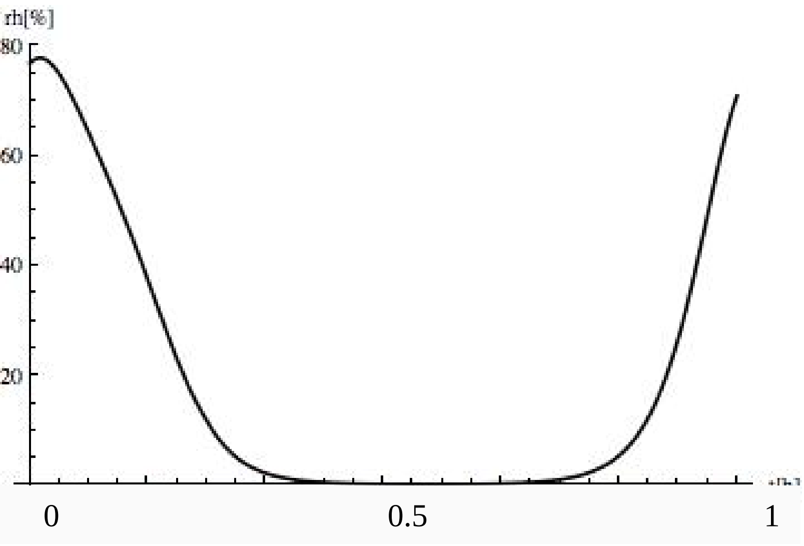
(alternatively, if measured in %: relative humidity rh[%] = 100 a_W)

The presence of water in an environment is often characterized by the water activity –

and often taken without caution as a bio-relevant parameter.

But, using only this one number for a_W can completely be misleading in case of time dependent (like diurnal) environmental conditions!

Water activity $a_W(t)$ - average and time variation



Diurnal variation of the atmospheric humidity ($rh[\%] = 100\ a_W$) for $L_s = 80°$, 68°N, long. 127.5 W (Phoenix landing site).

The diurnal humidity average is in this exemplary case

$$\bar{a}_W \geq 0.185$$

(there are about 5 hours of rh > 50% per sol).

many non-organic cryo-brines with a DRH < 50%

MEPAG (2006): Terrestrial organisms are not known to be able to reproduce at an a_W below 0.62. Recommendation for habitability-limits on Mars proposes to use a minimum water activity $a_W = 0.5$ for life to possibly exist there in “special regions” on Mars.

But simply using a constant value can completely be misleading in case of a diurnal variation $a_W(t)$!

Key-question: What is the minimum duration of water uptake by microbes (e.g.) to survive?

If a duration of 3 hours will be sufficient, then an average

$$\bar{a}_W < 0.2$$

seems to be possible !

Organisms could uptake liquid water from liquefied water (e.g. in brines) over several hours (also in case of $\bar{a}_W < 0.5$).

Availability of liquid water: Summary

Physics:

Liquid bulk water can exist in brines in the range between the eutectic temperature and boiling temperatures **-70° C < T**

Pure liquid water can exist in microscopic scales at temperatures down to about -50° C **-50° C < T**

Water activity a_W is an appropriate measure to characterize the availability of water under equilibrium conditions

Biology:

Average water activity $\bar{a}_W$ is to be used with care!
It is recommended to instead use the complete diurnal function $a_W(t)$

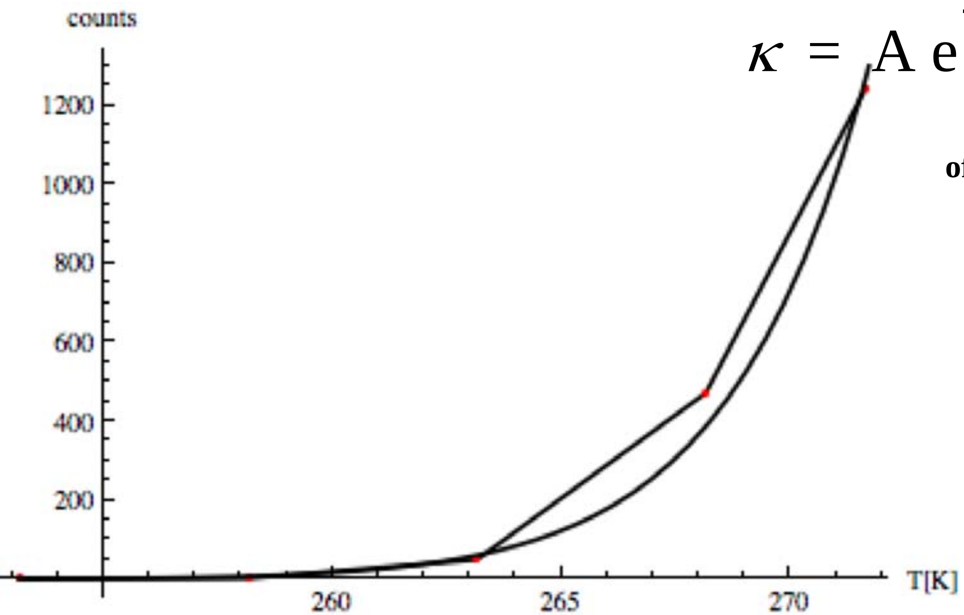
Key-question: What is the diurnal minimum duration for microbes to accumulate water to survive ?

Time-scales of bio-chemical processes

Arrhenius relation between reaction rates κ and temperature T[K]:

$$\kappa = A\, e^{-\frac{E_a}{k\,T}}$$

E_a – „Activation energy“
k – Boltzmann´s constant



Stepwise linear parts connect the counts of metabolism caused ^{14}C-labeled acetate incorporation into lipids over 550 days according to data of Rivkina et al. (2000) with an error limit 2σιγμα < 5%. The smooth curve describes the fitting according to the Arrhenius relation for an activation energy $E_a = 8\ 10^{-20}$ Ws.

Life is reported to actively exist on Earth down to temperatures of about -20° C., but there are indications of an active photosynthesis down to about – 50° C (Fig. 10 in de Vera et al., 2020)

Slow-down of reaction rates by a factor 117 in case of a temperature drop from 273 K to 223 K, and about 5 between 273 K and 253 K.

Enzymes can „catalytically“ reduce this slow-down by reducing the activation energy

Life at temperatures, which in the average are below 0° C, is not generally impossible due to low temperatures. Its possible existence has to be seen in time scales larger than those of the comparatively faster life on Earth.

Conclusions

Habitability has been defined as the potential of a planetary environment to support active (i.e. reproducing and metabolizing) life, and has often been coupled to the presence or absence of liquid water. Resulting limiting temperatures (of 0° C and 100°C) are used to postulate belts or zones of habitability around stars. But these belts may be only a part of really habitable zones around stars. Hoehler and Westall (2010) have described the need to introduce further relevant parameters to characterize habitability.

It is recommended to

*** extend the lower temperature limit to -50° C**
(the challenge: life in planetary ices)

*** use the time dependent function a_W (t)**
(instead of the misleading average water activity)

*** also take into account slow life processes**
(slower than on „hectic“ Earth)
- the problem: how to observe/measure that slow processes ?

*** Particularily take into account**
„Slow life in planetary icy bodies ?“

Conclusions

...and also have in mind

the impressive adaptation potential of life with respect to environmental changes

(also in view of changing Mars)

THANK YOU !