Report

Water - its significance in science, in nature and culture, in world religions and in the universe

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Publication Date:
2011

Permanent Link:
https://doi.org/10.3929/ethz-a-006647391

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W A T E R

Its Significance in Science,
in Nature and Culture,
in World Religions
and in the Universe

Peter Brüesch
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„Water constitutes the principle of all things“

„That from (water) which is everything that exists and from which it first becomes and into which it is rendered at last, its substance remaining under it, but transforming in qualities, that they say is the element and principle of things that are“.

Thales of Miletus: ~ 624 BC to 548 BC

„The wise find pleasure in water.“

Confucius, 551 BC to 479 BC.
**Western Hemisphere:**
- Europe (west of London)
- Western part of Africa
- Atlantic Ocean
- And a large part of the Pacific

**Eastern Hemisphere:**
- Europe (east of London)
- Eastern part of Africa
- Asia
- Australia
- Indian part of Ocean
- And some part of the Pacific

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**Water, Ice, Snow and Clouds**

Iceberg floating in Lago Argentina broken off from the Perrito – Marino Glacier.

H₂O is the only chemical substance which exists at normal conditions in all three phases, liquid, solid, and gas.

My own Lectures have been kindly complemented by colleagues from several Universities and Industries by contributions about related theoretical and practical topics. I am indebted to them for obtaining many precious additional knowledge of this vast subject.

In 2000 I wrote an extended study for the ABB Research Center with the title: “Potential Technological Applications of Water – based Dielectric Liquids: Physical and Chemical Basis”.

In addition to these activities I gave a series of Lectures about the general topics of “Water”. During this time the main goal was to acquire and to convey a broad survey of the different aspects of water.

Since water is of central importance for human beings and survival as well as for nature as a whole, I have decided to establish a comprehensive Review of the whole large subject which is summarized in ten Chapters. They contain the most important aspects of water in a form as simple as possible for a large community of readers. A large and detailed list of References provides a survey about the broad topics treated in this work.

As a basis of this vast domain I have used my Lectures and Seminars as well as many detailed and helpful discussions with colleagues. The whole work is condensed in the form of a “Power–Point” and a PDF presentation. A considerable number of explaining texts serves to elucidate the graphs and pictures. Each Chapter contains a list of general and special References.

Peter Brüesch  October 2011
I should like to express deep thanks to the following friends and colleagues:

For contributions to my Lectures at the EPFL in Lausanne:

Professor J. Dubochet (Univ. of Lausanne); Professors F. Rotzinger, H. Girault, and H. Vogel (EPFL); Professor W. F. van Gunsteren (ETHZ); Professor P. Bochsler (University of Bern). Dr. O. Buser (Swiss Federal Institute of Snow and Avalanche Research (SLF), Weissfluhjoch – Davos); Dr. M. Carlen (ABB Research Center, Dättwil); and Dr. S. Truffer (Service des Eaux de Lausanne). Some of their contributions have been incorporated in this work.

I should like to thank the Professors M. Boller, U. von Gunten, and A. Zehnder of the Swiss Federal Institute of Aquatic Science and Technology (Eawag) in Dübendorf for their Lectures in the ABB-Research Center in Baden - Dättwil. In addition, I am indebted to Professor Thomas Stocker from the University of Bern for precious information and interesting discussions about the most important role of water vapour for the Global Climate.

I must express very grateful thanks to the theologian Hans Domenig of Chur for his support concerning the significance of water in Christianity. In addition, I thank Dr. Walter Schneider for his continuous support concerning the latest literature about water.

I am also indebted to Dr. H.R. Zeller and Kirkor Arsik for their help in data handling and PC-support. In addition, I thank Dr. Zeller for his critical comments about the ascent of water in tall trees.

Finally, I should like to thank my dear wife for her interest as well as for her support and patience during the long period of preparation of this work.

Peter Brüesch: Scientific Career

1934 Born in Schuls – Graubünden - Switzerland
1948 – 1954 Gymnasium in Chur, Switzerland
1954–1960 Study of Experimental Physics at the ETHZ in Zürich
1960 – 1965 PhD at the Laboratory of „Physical Chemistry“ at the ETHZ
1965 – 1967 Postdoctoral Fellowship at the Chemistry Department, Oregon State University, USA
1967 – 2002 Scientific collaborator and Project Leader at the ABB Research Center – Switzerland
   Studies of „Solid State Physics“, resulting in 72 Publications in refereed Journals
1975 Nominated „Private Dozent“ at the Physics Department of the EPFL in Lausanne
1987 Nominated „Professeur Titulaire“ at the Physics Department of the EPFL
1998 – 2000 Consultant at the ABB Research Center related to „Water Technology“
2000 – 2011 Studies and Research about „Water and Aqueous Solutions“ and its role in Nature
   - Since 1997: Lectures about „Solid State Physics“ and about „Water“ at the EPFL in Lausanne
      This formed the basis of the following extended Work in German and English:
      „Wasser: Seine Bedeutung in der Wissenschaft, in der Natur und Kultur, in den Weltreligionen und im Universum“
      „Water: Its Significance in Science, in Nature and Culture, in World Religions and in the Universe“

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1. Prologue

From the Big–Bang to the Water in the Earth
1.1 The Big Bang

The physical laws of the Big Bang are not known.

There exist only elementary particles: protons (p), neutrons (n) and electrons (e).

Cooling down and expansion

Radiation - or Light Area

Formation of hydrogen (H, H₂) and Helium (He)

Age of present Universe: ~ 13.7 billions of years
Remarks about the Big Bang Concept

From: Evidence for the Big Bang
By Björn Feuerbacher and Ryan Scranton
Copyright @ 2006

(Remarks concerning our Figure at p. 3)

„Contrary to the common perception, the Big Bang Theory (BBT) is not a theory about the origin of the Universe. Rather it describes the development of the Universe over time. This process is often called „cosmic evolution“ or „cosmological evolution“..."

The Figure at page 3 is popular but might be misleading:

- „The BBT is not about the origin of the Universe. Rather, its primary focus is the development of the Universe over time“.
- „BBT does not imply that the Universe was ever point-like“.
- „The origin of the Universe was not an explosion of matter into already existing space..."

The famous cosmologist P.J.E. Peebles stated this succinctly in the January 2001 edition of Scientific American: „That the Universe is expanding and cooling is the essence of the Big Bang theory. You will notice I have said nothing about an „explosion“ - the Big Bang theory describes how our Universe is evolving, not how it began“. The cosmologist Rudolf Kippenhahn states in his book „Kosmologie für die Westentasche“ („Cosmology for the pocket“): „There is also the widespread mistaken belief that, according to Hubble's law, the Big Bang began at one certain point in space. For example: At one point, an explosion happened, and from that an explosion cloud travelled into empty space, like an explosion on Earth, and the matter in it thins out into greater areas of space more and more. No, Hubble's law only says that matter was more dense everywhere at an earlier time, and that it thins out over time because everything flows away from each other“. In a footnote he added: „In popular science presentations, often early phases of the Universe are mentioned as, at the time when the Universe was as big as an apple‘ or „as a pea“. What is meant there is in general the epoch in which not the whole, but only the part of the Universe which is observable today had these sizes“.

Evidence for the Big Bang

The hypothesis of the Big Bang is able to explain the following properties of the present Universe:

- Expansion of the Universe as observed by Hubble.

  → Reversal of expansion: Density and temperature increase rapidly → Contraction to a small region!

- The Big Bang generated a “radiation flash of lightning“ as predicted by Gamov. This radiation is called today “Cosmic Background Radiation" (3 K - Radiation) in the microwave region.

- The initial distribution of the lightest elements, Hydrogen (H) and Helium (He), in the oldest stars strongly suggest the existence of a hot original state in the Universe: The observed ratio of H and He is consistent with the predictions obtained from the Theory of the Big Bang as a result of thermonuclear reactions within the first three minutes.
1.2 Galaxies, Stars, and Planets

The Andromeda Galaxy is the nearest larger neighbour Galaxy to our Milky Way Galaxy. It contains billions of stars with planets.

The distance between the Milky Way Galaxy and the Andromeda Galaxy is inconceivably large, about 2.4 to 2.7 millions of light-years (about 25 trillions km).
In the hot centers of the stars such as in our sun, giant quantities of energy are generated by nuclear fusion.

Within the stars, the pressure and temperatures are extremely high such that hydrogen atoms (H) are fused to produce Helium (He).

Since the mass of a He-atom is smaller than that of the two H-atoms from which they are produced, the Einstein relation \( E = \Delta m c^2 \) predicts that a huge amount of energy \( E \) is produced. (Here, \( c \) is the velocity of light, and \( \Delta m \) is the mass defect).

90% of the lifetime of a star are used to fuse hydrogen atoms into helium atoms.

If hydrogen is used up, fusion of helium starts, and as one of the by-products also Oxygen (O) is formed!

Depending on the mass of the stars, all the elements up to iron (Fe) are formed by successive nuclear fusion. This process is also called nucleosynthesis.

After the formation of iron, the star collapses, leading to a supernova explosion.

All elements generated by this explosion are scattered away into the Galaxy. This leads to the formation of giant interstellar clouds and to the formation of new stars and planets.
From the Big Bang to Water on the Planet Earth

Generation of atomic Hydrogen (H) at the Big Bang → molecular Hydrogen $H_2$

Generation of atomic Oxygen (O) by nuclear fusion in the stars leading to their explosion → molecular Oxygen $O_2$

Water is generated by the violent reaction

$$2H_2 + O_2 \rightarrow 2H_2O$$

→ Water is expected to be widespread in the Universe!

Important restriction: Liquid water exists only at pressures and temperatures as are present at our Earth!!

“Life Zone” in the Solar System

Due to the simultaneous existence of Water in its gaseous, liquid and solid state, the Earth is the only planet which is located in the habitable „Life Zone“ of the Solar System! (s. p. 447)
1.2 The Planet Earth and the Role of Water

About 70% of the surface is covered with water!

Hemisphere of the Earth covered completely with clouds.
On the average, 60-70% of the terrestrial sky is permanently covered with clouds!
Water is the only chemical compound which exists on the Earth at natural conditions in all three states of matter (liquid, solid and vapor).

The role of Water for Evolution

Evolution is the change of heritable features of a population of living organisms from one generation to the next generation. These characteristics are coded in the form of genes, which are copied during reproduction to the next generation. As a result of mutations, different variations of these genes are formed, which can give rise to different and new characteristics.

The evolution started in water (see: $H_2O$: P. Ball, Chapter 8)

Water and the Origin of Life

Life, as we know it, requires water as a universal solvent and as a transport medium. According to accepted scientific knowledge it possesses properties which are crucial for the generation of life. It is, however, possible that life can develop and exist without the existence of water. But many scientists strongly believe that the presence of liquid water (in a certain region or on a specific planet such as the Earth) not only makes life possible, but is even a necessary condition for its formation.
Possible Origin of Terrestrial Water

a) One part of water is believed to originate from magma of early volcanos; this water therefore stems from the interior of the Earth.

b) A further part of water is probably due to collisions of comets and/or asteroids rich in water and possessing the correct isotopic ratio of D/H.

Geysirs in the “Black Rock Desert” of Nevada

Sometimes the heat of volcanic rocks causes the water to boil and to evaporate. As a consequence of the high steam pressure, a hot water stream is ejected like an explosion: a Geysir is formed.

Within the reservoir of the Geysir the water is overheated, i.e. it remains liquid, although its temperature is considerably higher than that of the boiling point.
Only one tenth of an iceberg is visible; 90% are hidden below the surface of the sea.

The icebergs consist essentially of fresh-water!

Clouds are Heralds of the Sun and of Water!
The Global Water Cycle

The numbers indicate the water transport in 1000 km$^3$ per year.

Without Water no Life!!

A human being survives:

- 3 weeks without food
- only 3 days without water!
- 3 minutes without air
Healing Power of watering places

Mechanical effects, buoyancy - friction - hydrostatic pressure  

Movements free of pain, massage, …

Thermal effects: pain relieving, anti-inflammatory, relaxation of muscles

Chemical effects: Minerals and trace elements ➔ better blood circulation

Non-specific stimulations: ➔ Stimulation Therapy ➔ positive influence of the vegetative nervous system (Tonus)

Destructive Power of Water: Tsunami wave

A Tsunami wave, which destroyed a coastal town in South–Eastern Asia at December 2004; such waves can be as high as 35 m!

Most massive Earthquake of magnitude 9.0 triggered a giant Tsunami and a serious nuclear catastrophe in Japan at March 11, 2011!!
1.1 Hypothesis and Evidence for the Big Bang

R.1.1.1 A SHORT HISTORY OF THE UNIVERSE
J. Silk
New York : Scientific American Library (1994)

R.1.1.2 DAS SCHICKSAL DES UNIVERSUMS
Eine Reise vom Anfang zum Ende
Günter Hasinger
Wilhelm Goldmann Verlag, München
Taschenausgabe April 2009

R.1.1.3 BIG BANG
Simon Singh
The most Important Scientific Discovery of All Time and Why Your Need to Know About It
Fourth Estate, London / New York 2004
© 2005 der deutschen Ausgabe : Carl Hanser Verlag München Wien

R.1.1.4 ZURUECK VOR DEN URKNALL
Die ganze Geschichte des Universums
Martin Bojowald
4. Auflage Juni 2009
S. Fischer Verlag GmbH, Frankfurt am Main 2009

The physicist Martin Bojowald has generated much interest because he was able by using a series of equations to get closer to the Big Bang as before; he obtained even information as to the properties and development of the Universe before the Big Bang. At these negative times with reversed space-time, the Universe was contracting before it expanded after the Big Bang.
1.2 Galaxies and Stars

R.1.2.1 Stars and Galaxies
Ron Miller
Twenty-First Century Books , 2006
ISBN 0761334661, 9780761334668
96 pages

R.1.2.2 Stars and Stellar Evolution
Klass de Boer et Wilhelm Seggewiss (2008)

R.1.2.3 Cycles of fire : Stars, Galaxies, and the wonder of deep space
William K. Hartmann , Ron Miller

R.1.2.4 p. 7. The Andromeda Galaxy
s. Internet : „Andromeda Galaxie“ → Images

R.1.2.5 p. 11 : The Life Zone in the Solar System
Habitable Zone – Wikipedia
www.de.wikipedia.org/wiki/Habitable_Zone

1.3 The „Blue Planet“

R.1.3.1 H₂O : A BIOGRAPHY OF WATER :
Philip Ball , Weidenfeld & Nicolson (London ,1999)

R.1.3.2 THE BLUE PLANET
( UK Import)
DVD ~ David Attenborough
DVD - Erscheinungstermin : 3 . Dezember 2001 ; Amazone.de
R.1.3.3  "Planet Earth" (2006), TV series
With David Attenborough and Sirgoumey Weaver
www.imdb.com/title/tt0795176/

R.1.3.4 WATER IN BIOLOGY, CHEMISTRY AND PHYSICS
G. Wilse Robinson, Sheng–Bai Zhu, Surjit Singh, and Myron W. Evans

R.1.3.5 WATER FROM HEAVEN: Robert Kandel; Columbia University Press (2003)

R.1.3.6 H₂O - THE MYSTEREY, ART, AND SCIENCE OF WATER
Chris Witcombe and Sang Hwang
Sweet Briar College
http://witcombe.sbc.edu/water/

R.1.3.7 THE STRANGEST LIQUID
"Why water is so so weird"


R.1.3.9 THE STRUCTURE AND PROPERTIE OF WATER

R.1.3.10 THE WATER ENCYCLOPEDIA
2nd Ed. (Lewis Publishers: Chelsea, MI, 1990)

R.1.3.11 DE L’EAU
Paul Caro
"Questions de science", Hachette Livre (1995)

R.1.3.12 PLANETE EAU
Guy Leray
EXPLORA – Collection dirigée par Dominique Blaizot
La Cité - Presses Pocket


R.1.3.14 LE GRAND LIBRE DE L’EAU
Editions La Manufacture (1995)

R.1.3.15 L’AVENIR DE L’EAU
Eric Orsenna
Editions Fayard
Octobre 2008 (broché ou poche)

R.1.3.16 WASSER: Welten zwischen Himmel und Erde
Art Wolfe und Michelle A. Gliders (Weltbild)

R.1.3.17 WASSER: Das Meer und die Brunnen, die Flüsse und der Regen

R.1.3.18 WASSERBUCH: Natur Mensch Mythos

(Ein phantastisches Buch über die Bedeutung des Wassers und der Luft !)

R.1.3.20 DAS GREENPEACE BUCH VOM WASSER
Klaus Lanz
Naturbuchverlag
Deutsche Ausgabe 1995, Weltbild Verlag GmbH, Augsburg

R.1.3.21 H₂O : A Gentle Introduction to Water and its Structure
Simon Fraser University, USA
http://www.chem1.com/acad/sol/aboutwater.html

1 – 14
R.1.3.22  
WASSER
Juraj Tögyessy and Milan Pliatnik
Verlag Die Witschaft Berlin, 1990

R.1.3.23  
p. 11 : Our Solar System : The Earth is the only Planet which lies in the so-called
Life – zone .
Figure from NASA : modified by P. Brüesch
Copyright @2011, Astrobio.net

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right : Complete coverage of a hemisphere with clouds:
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R.1.3.25  
p. 14 : Iceberg with hole near sanderson hope south of Upernavik, Greenland
En. Wikipedia.org/.../File:Iceberg_with_hole_near_sanderson_hope_July 27 , 2007 :

R.1.3.26  
p. 16 : Origin of Water on the Earth
Terrestrial origin :
Exterrestrial origin :

R.1.3.27  
p. 17 : Geysirs :
s. Internet : „Geysire in the Black Rock Desert of Nevada .

R.1.4.28  
p. 18 : Giant Iceberg
von : „Tagesanzeiger“ (TA) der Schweiz , WISSEN – 27. 1 . 2005

R.1.4.29  
p. 19 : Clouds are Herald of the Sun and of Water
Aus : Das GREENPEACE Buch vom WASSER
Klaus Lanz ; p. 11
Augsburg : Naturbuchverlag , 1995

R.1.4.30  
p. 20 : The global Water Cycle
http://www.der-brunnen.de/wasser/allgasser/allgwasser.htm

R.1.4.31  
p. 23 : Destructive Power of Water : Tsunami
http://people.cornellcollege.edu/E-McNeil/images/Tsunami%20Wave.jpg

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1 - 15
2. Physical and Chemical Properties of Water
2.1 Phase Diagram, Water molecule, heavy Water and Clusters

H₂O molecules in the gaseous state (water vapour) at low gas pressures. The molecules are moving freely in space exhibiting translational- and rotational motions.

“Structure” of water molecules in liquid water: the molecules are linked by hydrogen bonds and are essentially disordered. The molecules exhibit hindered translational and rotational motions and at the same time the H–bridges are constantly broken and reformed.

In “normal” hexagonal ice Ih, the oxygen atoms form an ordered hexagonal lattice, while the hydrogen atoms are distributed statistically. The identity of the molecules is, however, conserved (molecular crystal). The molecules are linked together by hydrogen bonds.
$T_p$: triple point at $T_p = 0.01 \, ^oC$ and $P_p = 611.657 \, Pa = 6.116 \times 10^{-3} \, \text{bar}$

$T_c$: critical point at $T_c = 374.12 \, ^oC$ and $P_c = 221.2 \, \text{bar}$

The numbers I, VI, VII and VIII denote different modifications of ice.
2.2 The Water Vapour

Water vapour: Water in the gaseous state

Clouds are water droplets

Water vapour in the air

Liquid water

$T_2 > T_1$

$P_2 > P_1$
Water molecules in the vapour

Individual molecules are flying in all directions with different velocities \( v \); the higher the temperature, the larger is the mean velocity \( \langle v \rangle \). (Figure prepared by P. Brüesch).

The \( \text{H}_2\text{O} \)-molecule

Nuclear distance or bond length: \( d(\text{O} - \text{H}) \):
about 1 Ångström = 1 Å
1 Å = 0.000'000'1 mm

Molar mass: \( \approx \) 18 g

\( \text{O} - \text{H} \) bond: strong electron pair-binding

\( \text{H}_2\text{O} \) and \( \text{D}_2\text{O} \) are polar molecules: the centers of gravity of the negative and positive charges are separated!
\( \rightarrow \) Dipole moment \( \mu \) (polar molecule)
\( \mu = 1.854 \text{ D} \); 1 D = 1 Debye = 3.3356 \( \times \) \( 10^{-30} \) C m

\( \Rightarrow \) liquid \( \text{H}_2\text{O} \) is an excellent solvent for a large number of substances!
The $\text{D}_2\text{O}$ molecule of heavy water

In heavy water or deuterium oxide, $\text{D}_2\text{O}$, both hydrogen atoms are replaced by deuterium D. The nucleus of a D-atom contains one proton and one neutron. 

- **Molar mass**: $m = 20$ g
- **Freezing point**: $T = 3.82 \, \text{°C}$
- **Boiling point**: $T = 101.42 \, \text{°C}$
- **Density at 20 °C**: $1.105 \, \text{g/cm}^3$
- **(largest density)**: $1.107 \, \text{g/cm}^3$ at $11.6 \, \text{°C}$
- **pH**: $7.43$

Heavy water is produced by electrolysis of natural water which contains about $0.015\%$ deuterium; in the residue of the electrolyte, heavy water can be enriched up to more than $98\%$. Pure heavy water is strongly poisonous. Because of its moderating power and small absorption for neutrons, heavy water is used as a moderator for nuclear reactions → production of slow neutrons!

In addition to $\text{D}_2\text{O}$ there exists also deuterium protium oxide, $\text{HDO}$, which sometimes is also called heavy water; in pure form it is unstable.

**Tritium oxide: $\text{T}_2\text{O}$**

Tritium T is the heaviest isotope of hydrogen: The nucleus of a T-atom is composed of one proton p and of two neutrons n. For this reason the molar mass of Tritium oxide, $\text{T}_2\text{O}$, is $m = 22$ g.

- **Freezing point**: $4.48 \, \text{°C}$
- **Boiling point**: $101.51 \, \text{°C}$
- **Density**: $1.2138 \, \text{g/cm}^3$
- **pH**: $7.61$

Since T-atoms are unstable and decompose gradually into helium atoms (half-life: 12.32 years), $\text{T}_2\text{O}$ is radioactive. Due to its high diffusivity, $\text{T}_2\text{O}$ in its gaseous state is particularly dangerous for living beings. This is because exposition causes all organs uniformly with radioactive radiation.
The isotopes $H$, $D$ and $T$

$H = ^{1}H$  
$D = ^{2}H$  
$T = ^{3}H$

Hydrogen  Deuterium  Tritium

$e$ : electron, $p$ : proton; $n$ : neutron; $H$, $D$, and $T$ possess 1, 2 and 3 nucleons, respectively, in their nuclei.

Water, “intermediate heavy water” and “heavy water”

charges: $e$ : $-q$, $p$ : $+q$, $n$ : 0

masses: $m_p = m_n$ >> $m_e$

The abundance of $D$ in natural hydrogen $H$ is very small, about 0.015%. 

$H = ^{1}H$  
$D = ^{2}H$  
$T = ^{3}H$

$M = 18$  
$M = 19$  
$M = 20$

light water  intermediate heavy water  heavy water

$H$  $D$  $D$
Molecular orbitals of the H₂O molecule

For the calculation of the electronic structure of molecules, quantum mechanics must be used (the electron is an elementary particle having a very small mass: \( m_e = 0.9107 \times 10^{-27} \) g (!))

Result: 4 club-shaped “molecular orbitals” are formed where each of which is occupied by 2 electrons; they indicate the residence probability of the 4 electron pairs.

\[ \rightarrow \text{The electronic structure is not plaine but rather 3-dimensional and the end points of the clubs form a tetradron (!)} \]

Thermal Motion of a H₂O - Molecule

The atoms O and H fluctuate randomly about their equilibrium positions; this leads to small changes of the bond lengths and of the bond angle.

Approximate decomposition of thermal motion into three normal vibrations:

The normal modes of vibrations can be observed by Infrared and / or Raman spectroscopy.

In reality, the amplitudes of the atomic displacements are much smaller than illustrated; exception: Water vapour on the Umbra of the Sun at temperatures between 3000 and 3500 °C (s. p. 443).
Infrared Vibration – Rotation Spectrum of Water Vapour
Important for global warming !!

The fine-structure absorptions which are grouped around the fundamental vibrations originate from the rotational motions of the whole molecules.

From an exact analysis of the spectra it is possible to deduce the geometry of the molecules!

(Spectrum measured by P. Brüesch)

1 THz = 10^{12} Hz = 1 Billion Hz; 1 Hz = 1 vibration / second

The Water Dimer and the Hydrogen Bond

The positively charged proton H\(^+\) links the negatively charged O\(_1\) of the left hand sided molecule with the negatively charged atom O\(_2\) of the molecule at the right hand side.

O\(_1\) - H ----- O\(_2\) is the hydrogen bond

The hydrogen bond (H–bridge) is nearly linear and d(O\(_1\) - H ---- O\(_2\)) is about 3 Å.

The water dimer (H\(_2\)O\(_2\)) is polar: its experimentally determined static dipol moment is large, namely \(\mu = 2.6\) D.

{The dipole moment of the monomer H\(_2\)O is 1.854 D}. 
[1 D = 1 Debye = 3.3356 \times 10^{-30} \text{ C m}].
Remarks about Hydrogen Bonds

Hydrogen Bonds: General:

Hydrogen bonds (H–bonds) are chemical bonds of mainly electrostatic nature. In general, their bond strengths are distinctly lower than that of covalent or ionic bonds. The H–bonds are responsible for the fact that water molecules usually cluster to form larger groups. For this reason also warm water remains a liquid with a relatively high boiling point. This fact is a necessary prerequisite for most living beings. In proteins H–bonds glue the atoms together, thereby maintaining the three-dimensional structure of the molecules. H–bonds also keep together the individual ropes to form the characteristic double helix (s. pp 199–201; 4-A-5-1).

Hydrogen Bonds in Water:

H–bonds are responsible for a number of important properties of water! Examples are the liquid state at normal conditions, the large cohesion, the high boiling point and the density anomaly at 4 °C (pp 69, 73, 74). The typical bond length H–O of H–bonds in water is 0.18 nm and the total O–H–O bond is nearly linear and its length is about 0.3 nm (1 nm = 10⁻⁹ m = 10 Å (Angstrom)) (see pp 26, 39, 41).

In liquid water, preferentially 4 water molecules are linked together with a central molecule (s. pp 60, 61). During vaporization these H–bonds must be broken; this also explains the relatively high vaporization energy at 100 °C.

It has been found by means of Compton scattering that the covalent O–H bonds of a water molecule partly extend into the weak H–O bonds. Therefore, although the H–bonds are essentially ionic they possess a small covalent contribution.

Cluster of H₂O: 1) Dimer and Trimer

The formation of H–bonds in water is co-operative: The formation of a first H–bond triggers a change of the charge distribution of the molecules in such a way that the formation of a second H–bond is favoured. This leads to the formation of clusters.

Compton scattering (blue and red curved flashes) from an ice crystal show that there is a substantial probability that the two shared electrons (two small spheres) of the O-H bond spread out into the hydrogen bonds. This is a purely quantum mechanical effect known as electron delocalization. Electrons seek the lowest possible energy state, and for the covalent bonding pairs in water, the lowest energy state extends into the hydrogen bond. The hydrogen bonds in ice (and water) are therefore partly ionic and partly covalent.
In contrast to the dimer, the clusters with $n > 2$ are only weakly polar or even non-polar, such that the permanent dipole moments $m$ are small or even zero. The oxygen atoms of the cyclic structures are not arranged in one plane, i.e. the clusters are not planar.

Clusters of $\text{H}_2\text{O}$: 2) Trimer, Tetramer, Pentamer, und Hexamer

- $n = 3$: cyclic trimer
- $n = 4$: cyclic tetramer
- $n = 5$: cyclic pentamer
- $n = 6$: cyclic hexamer

The Water Hexamer: $(\text{H}_2\text{O})_6$

As shown in the model, the six-sided ring is not plane!

The water hexamer is the smallest particle of the hexagonal ice.
Clusters of H$_2$O: Cyclic and Tetrahedral Pentamers (H$_2$O)$_5$

Examples: $n = 5$: Pentamer (H$_2$O)$_5$

General: a (H$_2$O)$_n$-cluster is a group of $n$ water molecules, which are linked together by hydrogen bonds.

Two other compounds with Hydrogen bonding

H$_2$F$_2$

Ammonia Hydrogen Bonding

Hydrogen fluoride is composed of HF - molecules. Because of the difference in electronegativity between H and F, a hydrogen bond occurs between the hydrogen atom of a molecule and the fluorine atom of a neighbouring molecule. The acid is an extremely corrosive liquid and is a strong poison.

Liquid Ammonia, NH$_3$, is a very good solvent and exhibits similar properties as H$_2$O; it is, however, considered a high health hazard. N and H of neighbouring molecules are linked by H–bonds.
2.3 The Ices of Water

Depending on temperature and pressure as well as on the preparation conditions, there exist a large number (at least 13) of stable and metastable crystalline ices.

- Structural building stone: tetrahedral coordination with hydrogen bonds between the molecules.
- The phase diagram is determined by the Clapeyron equation:
  \[ \frac{dP}{dT} = \frac{\Delta H_m}{T \Delta V_m} \]

The temperature and pressure regimes associated with most of the 13 known crystalline phases are indicated here. When hexagonal ice at 77 K is subjected to increasing pressure, so-called amorphous ice forms: at 1 GPa (blue circle), high-density amorphous ice forms; if the temperature is then raised, very-high-density amorphous ice forms (red circle).
Modifications of Ice - 1

Ices at low temperatures

1. "Normal" hexagonal ice (ice Ih) with proton disordering
2. Ordered hexagonal ice XI
3. Cubic ice Ic
4. Glassy and/or amorphous ice

Ices at intermediate temperatures

5) ice II: a structure with ordered protons
6) metastable ice III and proton-ordered structure ice IX
7) metastable ice IV and monoclinic ice V
8) tetragonal ice XII

Ices at high pressures

9) ice VI: tetragonal unit cell; density = 1.31 g/cm³ (-175°C, 1 bar)
10) ice VII: bcc – lattice of O– atoms; H– atoms disordered; density = 1.599 g/cm³
11) ice VIII: is formed by cooling of ice VII; protons are ordered; density = 1.626 g/cm³.
12) ice X: is formed from ice VII by increasing the pressure to 165 GPa = 1.65 Megabar!
Here, the protons are located midway between two neighbouring oxygen atoms! This
means that ice ceases to be a molecular crystal ➔ atomic crystal (s. p. 56)!

Modifications of Ice - 2

• Depending on temperature and pressure, there exist different modifications of ice, which differ in their structures, i.e. in their spatial distributions of the H₂O–molecules.

• up to now there are at least 13 modifications: ice Ih, ...... ice XII

  • our “natural” ice: ice Ih (h = hexagonal)

  • “metastable” ice: such as ice XII (about -40°C, 4000 bar)

• exotic “glowing” ice: such as ice VII, ice X (about 500°C, 100’000 bar)
(see glowing ice in Jupiter (p. 475) and in Saturn (p. 480).

• Superionic conducting ice (very high mobility of the protons!)

• metallic ice?
Hexagonal structure of ice Ih:
each $\text{H}_2\text{O}$-molecule is surrounded by 4 nearest $\text{H}_2\text{O}$-molecules (●).
red line: $\text{H}$-bonds

Head with potbelly: $\text{O}$-atom
hands: $\text{H}$-atom
lags with feed: H–bridges;
note the 6–fold ring of $\text{O}$–atoms

Philip Ball: "$\text{H}_2\text{O}$: A Biography of Water"
Weidenfeld & Nicolson (1999), p. 159

The corresponding spectrum of liquid water is shown at pp 114 and 115.
There exist two low-frequency "external" vibrations of the whole molecules and 3 high-frequency "internal" vibrations $\nu_1, \nu_2, \nu_3$ of the atoms within the molecules.
Snow crystals are art works!

Note the approximate hexagonal symmetry of the crystals! (s. p. 176-178 and Ref. R.4.3.6)

The seven basic forms of snow crystals, each of which possesses hexagonal symmetry (s. p. 176)
Phase diagrams of the two high-pressure modifications of ice VII and ice VIII:

Their phase boundaries have been detected by means of Raman scattering (empty squares: H₂O, full squares: D₂O).

The oxygen atoms are green, the hydrogen atoms are red.

The structure of ice VIII is hexagonal with ordered protons; by heating, it transforms into the cubic form ice VII with disordered protons.

In cubic ice VII each oxygen atom is tetrahedrally surrounded by four hydrogen atoms and the molecules are linked by O–H–O bonds.

If the pressure is increased up to 165 MPa, there is evidence for the formation of a new structure in which the hydrogen bonds disappear. In this structure, ice X, the mean positions of the hydrogen atoms are in the centers between the two oxygen atoms. This means that in ice X there exist “symmetrical” O–H–O bonds which implies that we are dealing with an atomic crystal rather than with a molecular crystal.
At extremely high pressures, a fundamental change of the structure of normal water–ice occurs: A particularly dense ice is formed, in which the strong covalent bonds within a water molecule and the weak hydrogen bonds between the water molecules become equivalent. The pressure at which this occurs as well as the detailed formation of this process has been studied by an international research team guided by Prof. Dominik Marx (Lehrstuhl für Theoretische Chemie der Ruhr – Universität Bochum (RUB)) by means of theoretical model calculations (see Ref. R.2.3.9).

Sophisticated quantum mechanical computer simulations of the experiments at room temperature are able to show in detail of how molecular ice is transformed into ice X, demonstrating the transition of hydrogen bonds and covalent bonds into atomic bonds as a result of high external pressures. This occurs via a form of ice, in which the hydrogen atoms have essentially lost their memory as to which of the two oxygen atoms they belong with the consequence that they are permanently oscillating between their two oxygen neighbors. This corresponds to a very dynamical form of ice, which does not obey anymore the famous „ice – rules“ of Linus Pauling as proposed around 1930.

Other scientists have speculated, that these unconventional forms of „hydrogen bonds“ which are formed in ice at high pressures, could play an important role in processes such as in enzyme catalysis in which hydrogen bonds and transfer mechanisms from H - O-----H to H – O – H bonds play an important role in biochemical processes.
2.4 Liquid Water: Structure and Dynamics

“Random Network” Model of liquid water

“Groundstate”: totally interconnected “Random Network” having an open tetrahedral structure; realized in supercooled water.

“Excited state”: macroscopically interconnected “Random Network” containing many deformed and broken bonds; continuous topological reorganization; realized in the stable state of water.

Anomalous properties: as a result of the competition between “open” water (as in ice) and more compact regions with deformed and broken hydrogen bonds.


“Random Network Model” with tetrahedral coordination (only the O– atoms are shown). Originally, the model has been constructed for Si and Ge. F. Wooten and D. Weaire in: Solid State Physics 40, pp 1 - 42 (1987).
Mean instantaneous configuration of a water molecule

The \( \text{O} \cdots \text{H} - \text{O} \) hydrogen bonds are usually bent or broken but are reformed continuously and quickly.

The lifetime of a hydrogen bond is very short, only about a billion of a second, i.e. about \( 10^{-12} \) seconds; this is a time in the pico-second (ps) range or less.

More compact and much more dynamic structure as in ice!!

Ballet of \( \text{H}_2\text{O} \) – Molecules in Liquid Water

Water molecules—with hands re-presenting lone pairs of electrons—perform a wild dance that involves grabbing neighbours by the ankles. These clasps, due to hydrogen bonding, lead to a tetrahedral arrangement of neighbours around each molecule.

This is the central motif of the structure of water, and the key to all its anomalous properties.

Liquid water has a very large specific heat:

1 cal / (g °C) ! ➔ buffer for stabilization of clima!!

Figure and text by: Philip Ball: “A Biography of Water”, p. 159;

The Figure has been slightly modified by P. Brüesch by adding the blue and green arrows indicating the exchanges and rotations of the molecules.
In ice, the molecules execute small vibrations around their equilibrium positions located at a regular lattice.

For the calculation of the molecular dynamics, realistic interaction forces between the molecules are introduced which simulate the nature of hydrogen bonds.

**Result:** In liquid water the molecules execute a wild dance. They are still loosely connected by hydrogen bonds but these bonds are no longer straight lines as in ice but are rather strongly tilted and break very easily.

As a consequence, partners exchange very wildly and rapidly with a mean residence time of the order of billionths of seconds!

In a rough first approximation, this irregular motion can be decomposed into several fundamental vibrational and librational motions (see pp 64, 65).

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**Local structure of liquid water**

Disordered structure of liquid water: a snapshot from a molecular dynamics study (s. p. 62)

- The dashed white lines indicate the hydrogen bonds between neighbouring water molecules.
Absorption spectrum in the Far–Infrared of the intermolecular vibrations of liquid water at 27 °C. In a rough approximation, the wild dance of the water molecules (pp 61-62) can be decomposed into two fundamental vibrations. These absorptions can be observed as two broad absorption bands at 675 cm⁻¹ (about 20 THz) and near 200 cm⁻¹ (about 5 THz). The broad and intensive band near 675 cm⁻¹ can be assigned to the „hindered“ rotational motion of the H₂O–molecules, while the band near 200 cm⁻¹ is due to the „hindered“ translational motion of the H₂O–molecules. The extremely large widths of these absorption bands are due to the complex interactions between the H₂O–molecules (distribution of absorption frequencies!). The two „external“ normal vibrations are illustrated at page 64 and the complete infrared spectrum is shown at page 114. (The above Figure has been composed by P. Brüesch).
2.5 Liquid Water: Anomalies

- Liquid water is about 9% heavier than ice!
- The density maximum of water is not at the freezing point at 0°C but lies at about 4°C!
- The melting temperature decreases with increasing pressure!
- Compared with other substances, the heat capacity, the surface tension and the thermal conductivity are unusually large!
Anomalies: General - 2

- For a large number of substances, water is an excellent solvent (s. pp. 127-135).

- Pure liquid water can be supercooled down to as low as -37 °C without freezing!

- If supercooled and cold liquid water is heated up until 4 °C it exhibits a contraction!

Note: both, supercooled and superheated water are very important in nature!
(Example: metastable superheated water present in the xylem conduits of tall trees (pp 215, 216; 220, 221)

Four additional anomalies of liquid water

Temperature dependences of a) the density $\rho$; b) the thermal expansion coefficient $\alpha_T$; c) the isothermal compressibility $\kappa_T$, and d) the isobaric specific heat $C_p$ at 1 bar = 0.1 MPa. The red curves indicate the experimental data for Water (s. Ref. R.2.0.17, R.2.5.3). The blue lines indicate the behaviour for simple liquids (Annotation of axis redrawn)
With increasing pressure the melting temperature increases.

With increasing pressure the melting temperature decreases!
2.6 Density and specific heat

Densities of Water and Ice at 1 bar

At the transition from water to ice the density decreases by about 9%!!

Anomaly: ice is lighter than water !!!
The Density Maximum of Water is at 4 °C!

Anomaly: by cooling below 4 °C the density decreases again!

For nearly all other liquids (except Bismuth (Bi)) the density increases with decreasing temperature down to the melting point.

Note: As for H₂O (p. 72) the density of liquid Bi is larger than the density of its solid phase: Bi expands 3.32% on solidification; its melting point is just above 271 °C. See: Bismuth – Wikipedia, the free encyclopedia: en.wikipedia.org/wiki/Bismuth
Specific heats $C_p$ : Comparison with liquid water

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Specific heat (cal/°C g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100</td>
<td>0.4</td>
</tr>
<tr>
<td>-50</td>
<td>0.6</td>
</tr>
<tr>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>50</td>
<td>1.0</td>
</tr>
</tbody>
</table>

$C_p$ of liquid water: about two times larger than that of ice Ih at $T_S$ and than that of vapour at $T_D$. Reason: deformation and/or dissociation of hydrogen bonds which give rise to a large and strongly temperature dependent configurational energy.

At $T_S$ and $T_D$, energy is used for melting and evaporation, respectively, leading to sharp “lambda – anomalies” of $C_p$ ($\lambda$ – anomalies at $\uparrow$).

(Figure composed by P. Brüesch from several experimental Data)
Remarks about the anomalies of the temperature dependence of the specific heat \( C_p(T) \), of the thermal expansion \( \alpha(T) \) and of the isothermal compressibility \( \kappa(T) \) of liquid water.

For typical liquids, \( C_p \) decreases slowly with decreasing temperature and this is also the case for liquid water but only down to 35 °C. At 35 °C the specific heat of water passes through a minimum and increases again with decreasing temperature (p. 77).

In the supercooled state, below 0 °C, \( C_p \) increases strongly with decreasing temperature (p. 77).

Anomalous behaviours are also observed for the thermal expansion \( \alpha(T) \) (pp. 69 and 81) as well as for the isothermal compressibility \( \kappa(T) \) (pp. 69 and 82).

All three quantities, \( C_p(T) \), \( \kappa(T) \) und \( \alpha(T) \), behave in such a way as to suggest the existence of a singularity at low temperatures (below about -40 °C), but there is no proof for this conjecture. Although there exist a large number of theoretical models for the very unusual properties of water, these and many other anomalies remain essentially a puzzle.

Although it is often possible to explain one of the anomalies with an appropriate theoretical model, most other anomalies can not be explained with the same model. There exists no universal theory of liquid water!

It can, however, taken for granted that for the explanation of all anomalies, the complicate nature of the hydrogen bonds plays a central role.
Reason and Relevance of water’s high specific heat

Between 0°C and 100°C the specific heat of water is about 1 cal/(g °C). Compared with most other substances, the specific heat of water is therefore unusually high (see pp 75 and 77).

We can trace water’s high specific heat, like many of its other properties, to hydrogen bonding. Heat must be absorbed in order to break hydrogen bonds, and heat is released when hydrogen bonds form. A calorie of heat causes a relatively small change in the temperature because most of the heat energy is used to disrupt hydrogen bonds before the water molecules can begin moving faster. And when the temperature of water drops slightly, many additional hydrogen bonds form, releasing a considerable amount of energy in the form of heat.

What is the relevance of water’s high specific heat to life on Earth? By warming up only a few degrees, a large body of water can absorb and store a huge amount of heat from the sun in the daytime and during summer. At night and during winter, the slow cooling down of water stabilizes the temperature of the air. Thus because of its specific heat, the water that covers most of the planet Earth keeps temperature fluctuations within limits that permit life. Also, because organisms are made primarily of water, they are more able to resist changes in their own temperatures than they were made of a liquid with a lower specific heat.
2.7 Various physical quantities and properties

Expansion coefficient $\alpha(T)$ of liquid water in its whole range of existence at 1 bar

Isothermal compressibility $\kappa(T)$ of liquid water in its range of existence at $P = 1$ bar

\[ \kappa = -\frac{1}{V} \left( \frac{\partial V}{\partial P} \right)_T \]

![Graph showing isothermal compressibility](image)


(Figure compiled by P. Brüesch)

---

**Thermal conductivity of Ice, Water and Vapour**

![Graph showing thermal conductivity](image)

At the transition from water to ice, the thermal conductivity increases by about a factor of 3.6; however, going from water to its vapour at the boiling point, the thermal conductivity decreases by about a factor of 27.

(Figure compiled by P. Brüesch)
At constant pressure, the viscosity decreases almost exponentially with increasing temperature; this behaviour is also found in the supercooled state.

The temperature dependence of the viscosity $\eta$ can be approximated by

$$\eta(T) = \eta_0 \exp \left( \frac{\Delta E_h}{R T} \right).$$

$\Delta E_h$ is the Arrhenius activation energy for viscous flow; at 0 °C, $\Delta E_h$ is about 5 kcal/mol. For water, the temperature dependence of $\Delta E_h$ is considerably stronger than for most other liquids.

For most liquids, $\eta$ increases strongly with increasing pressure $P$. This is also the case for water above 30 °C. Below 30 °C, however, the viscosity of water first decreases with increasing pressure, then passes through a minimum between $P = 1000$ to 1500 kg/cm², and only at higher temperatures it increases again.

In contrast to many other properties of water (such as the density, expansion, compressibility and specific heat), the surface tension does not show any obvious anomaly by cooling down into the supercooled state. In particular, no drastic increase is observed in the deeply supercooled state, i.e. no indication of an anomaly is observed by approaching -45 °C.

If the surface tension is not measured at 1 atm but rather along the boiling point curve, (s. pp 99 - 101), it decreases continuously and disappears at the critical point $P_k$ (354.15 °C and 221.2 bar). In other words, the miniscus of water in a glass capillary disappears at the critical point $P_k$.

One anomaly of water is the fact that it has the highest surface tension of all non-metallic liquids! This is due to the strong cohesion between water molecules as a result of hydrogen bonding.
Water striders (Wasserläufer) are walking on water. Due to the very high surface tension of water (s. p. 85), the water surface acts like an elastic film that resists deformation when a small weight is placed on it. In the present picture, two Water striders are mating on the Water surface, thereby producing a mirror reflection.

The “Water - ions” $H_3O^+$ and $HO^-$ in ultrapure Water

Example: the dimer

Self - dissociation or self - ionization of pure water

In pure water at 25 °C there will exist about one $H_3O^+$ ion and one $OH^-$ ion in 550 millions of $H_2O$ molecules $\Rightarrow$ $pH = 7$

\[ pH \approx - \log [ H_3O^+] \]
\[ [ H_3O^+] \text{ in mol} / \text{dm}^3 \]

$\Rightarrow$ very seldom process!

exchange of the $O-H$ bond with the $H--------O$ bond

Considering a given $H_2O$ - molecule, a $H_3O^+$ - ion is formed after about 11 h.

Hydronium - ion $H_3O^+$

Hydroxide - ion $OH^-$
Formation and Hydration of Hydronium ions $H_3O^+$

Mechanism of formation of a hydronium ion $H_3O^+$ and of a hydroxide ion $OH^-$ (schematic representation of a proton transfer)

In a dilute acidic solution, the small $H_3O^+$ ion is strongly hydrated: it is hydrogen bonded to three $H_2O$ molecules forming a $(H_9O_4)^+$ ion complex. A similar complex exists for the $OH^-$ ion.

$2H_2O \rightarrow H_3O^+ + OH^-$

pH of pure water and $H_3O^+$ ion concentrations as a function of temperature

With increasing temperature the pH decreases, i.e. the self-ionization $2H_2O \rightarrow H_3O^+ + OH^-$ increases strongly as shown in the Table below.

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>pH</th>
<th>$[H_3O^+]$ in $10^{-7}$ mol/L</th>
<th>number of $H_3O^+$ ions number of $H_2O$ molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.49</td>
<td>0.32</td>
<td>5.75 x 10^{-10}</td>
</tr>
<tr>
<td>10</td>
<td>7.27</td>
<td>0.54</td>
<td>9.70 x 10^{-10}</td>
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<tr>
<td>20</td>
<td>7.08</td>
<td>0.83</td>
<td>14.9 x 10^{-10}</td>
</tr>
<tr>
<td>25</td>
<td>7.00</td>
<td>1.00</td>
<td>18.0 x 10^{-10}</td>
</tr>
<tr>
<td>30</td>
<td>6.92</td>
<td>1.20</td>
<td>21.6 x 10^{-10}</td>
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<td>40</td>
<td>6.77</td>
<td>1.70</td>
<td>30.6 x 10^{-10}</td>
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<tr>
<td>50</td>
<td>6.63</td>
<td>2.34</td>
<td>42.2 x 10^{-10}</td>
</tr>
<tr>
<td>100</td>
<td>6.14</td>
<td>7.24</td>
<td>130.4 x 10^{-10}</td>
</tr>
</tbody>
</table>
**pH and normalized hydronium ion concentration as a function of T**

With increasing temperature, the pH-value of pure water decreases. This does not mean that water becomes more acidic as the temperature increases; this decrease is rather due to the fact that with increasing temperature the self-dissociation of H₂O-molecules:

$$2 \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{OH}^-,$$

increases which results in a higher concentration of water ions.

Note that at 25 °C the pH = 7.

The Figure shows the ratio of the concentrations of H₃O⁺-ions and of water molecules in pure water as a function of temperature T, $r_+(T) = \frac{[\text{H}_3\text{O}^+]}{[\text{H}_2\text{O}]}$. $r_+$ increases with increasing T as does the ratio $r_-(T) = \frac{[\text{OH}^-]}{[\text{H}_2\text{O}]}$ of the hydroxide ions OH⁻. Since $r_+(T) = r_-(T)$, water remains neutral.

At 25 °C, $r_+ = r_- = 10^{-7} \text{ (mol/L) / 55.5 (mol/L)} = (10^3 / 55.5) \times 10^{-10} = 18 \times 10^{-10}$; [one mole of water has a mass of ≈ 18 g].

---

**Mobilities of H₂O⁺- and OH⁻-ions as a function of temperature**

$$u = u(\text{H}_3\text{O}^+) + u(\text{OH}^-) = \frac{\sigma}{(F \times c)}; \quad \sigma = \text{measured conductivity (s . p 92)}; \quad F = \text{Faraday – constant}, \quad c = \text{concentration of H}_3\text{O}^+ - \text{ions (or OH}^-\text{-ions)}, \quad \text{which are obtained from the observed ion product} \ K_w \text{ of pure water at room temperature. Assumption:}$$

$$u(\text{H}_3\text{O}^+) = 0.64 \times u; \quad u(\text{OH}^-) = 0.36 \times u \text{ independent on temperature. The factor 0.64 has been deduced from the known mobilities} \ u(\text{H}_3\text{O}^+) \text{ and } u(\text{OH}^-) \text{ at 25 °C.}$$

(Figure prepared by P. Brüesch from different Data)
Temperature dependence of ionic conductivity $\sigma_{\text{DC}}(T) = q c u(T)$ of ultrapure water at 1 bar. $u(T)$ is the total ionic mobility (s. p. 91).

Conductivity of ultrapure Water

$q$: ionic charge
$c(T)$: ion concentration
$u(T)$: sum of ionic mobilities

At 25 °C chemically pure water has a pH-value of 7 and an extremely small specific resistance of $14.09 \times 10^6$ Ω cm which corresponds to a specific conductivity of about $70 \times 10^{-9}$ (Ω cm)$^{-1}$ (s. p. 92). This very high resistivity results from the very small concentration of the $\text{H}_2\text{O}^+$- and $\text{OH}^-$ ions (about 1.5 ppb at 25 °C).
**Pressure dependence of the ionic conductivity of pure water**

The values have been normalized to the known conductivity values at 1 atm. Note the anomalous increase of the conductivity with increasing pressure!

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**The electric double layer at a metal electrode in pure water**

Peter Brüesch and Thomas Christen: J. Applied Physics, 95, No 5, 2004, p. 2846 - 2856

Pure water is a weak electrolyte that dissociates into hydronium ions and hydroxide ions. In contact with a charged electrode, a double layer forms for which neither experimental nor theoretical studies exist, in contrast to electrolytes containing extrinsic ions like acids, bases, and solute salts. Starting from a self-consistent solution of the one-dimensional modified Poisson – Boltzmann equation, which takes into account activity coefficients of point-like ions, we explore the properties of the electric double layer by successive incorporation of various correction terms like finite ion size, polarization, image charge, and field dissociation. We also discuss the effect of the usual approximation of the average potential as required for the one-dimensional Poisson-Boltzmann equation, and conclude that the one-dimensional approximation underestimates the ion density. We calculate the electric potential, the ion distributions, the pH-values, the ion-size corrected activity coefficients, and the dissociation constants close to the electric double layer and compare the results for the various model corrections.
2.8 Phase diagram of Water

Phases of a single substance

Depending on temperature $T$ and pressure $P$ it is possible that:

- a compound can exist in the solid, liquid or gaseous state
- two or three states can coexist:
  - solid $\leftrightarrow$ liquid: melting curve
  - solid $\leftrightarrow$ vapour: sublimation curve
  - liquid $\leftrightarrow$ vapour: vapour pressure curve
  - solid $\leftrightarrow$ liquid $\leftrightarrow$ gas: triple point
Phases of a single substance - 2

- Two coexisting states are said to be in dynamical equilibrium if an equal number of molecules is transferred from state 1 into state 2 per unit time.

Solid ↔ liquid ↔ vapour ↔ : triple point

- The vapour pressure curve extends from the triple point up the critical point.

- Above the critical point it is no longer possible to distinguish between the liquid and gaseous state.

- Liquid water can be supercooled!

- Liquid water can be superheated!

Phase diagram of H₂O (schematic)
Phase diagram of water

- **melting curve**
- **melting point or freezing point at 1 atm and 0 °C**
- **triple point:**
  - \( T_v = 0.098 \, ^\circ C \)
  - \( P_v = 0.006 \, \text{bar} \)
- **sublimation curve**
- **boiling point curve**
- **boiling point at 1 atm and 100 °C**
- **critical point:**
  - \( T_c = 374 \, ^\circ C \)
  - \( P_c = 221 \, \text{bar} \)

Boiling point curve of water

- **critical point:**
  - \( (374 \, ^\circ C, 221 \, \text{bar}) \)
- **triple point:**
  - \( T_v = 0.01 \, ^\circ C \)
  - \( P_v = 611.73 \, \text{Pa} \)
- **supercritical vapour**
- **ice**
- **liquid**
- **vapour**
For each gas there exists a well-defined temperature, above which it is impossible to liquify it at arbitrary high pressures. This temperature is known as the critical temperature $T_c$ of the gas. If the gas is cooled down to this temperature, it is possible to liquify it by application of a sufficiently high pressure. At the critical temperature $T_c$ a certain pressure is necessary, which is called the critical pressure $P_c$. For water, the critical point is at $T_c = 374°C$ and $P_c = 221$ bar.

Water above the critical point is called supercritical water (s. p. 99). Above the critical point, the densities of water vapour and liquid water are indistinguishable; for this reason, this state is called „supercritical“. Chemically, supercritical water is particularly active. For this reason, experiments have been performed to neutralize strongly harmful substances with the help of supercritical water. Examples include the hydrolytical decomposition of Dioxins and PCBs which are highly toxic chemicals.
**Example: Pressure cooker**

- **Pressure gauge:**
  - 0 to 1.6 bar
  - Excess pressure

- **Thermometer:**
  - 0 to 150 °C

**Example:**
- Cooking temperature = 120 °C
  - Excess pressure = 1 bar

**Rule of Thumb:**
- ΔT = 10 °C
  - Cooking time is 2 to 3 times shorter!

**Temperature (°C) vs. Total Pressure (bar):**

**Example:**
- Cooking temperature = 120 °C
  - Excess pressure = 1 bar

**Pressure dependence of melting and boiling point**

a) Water defines the temperature scale of Celsius

The Celsius scale is a temperature scale, defined such that (at normal pressure of 1013.25 hPa = 1 atm) water freezes at 0 °C and boils at 100 °C.

b) The melting point or freezing point of pure water is 0 °C. The melting point depends only very weakly on pressure. A prominent anomaly of water is, however, the fact that as the pressure increases, the melting point decreases (s. Figures at pp 70 and 99); at a pressure of 2000 bar, water freezes at a temperature as low as -22 °C.

c) The boiling point of a substance is the temperature, at which the vapour pressure is equal to the pressure of the surrounding atmosphere. At a pressure of $p_a = 1013.25$ hPa, water boils at 100 °C. The boiling point of water depends strongly on the external pressure (s. pp. pp 70, 99 - 101) and hence at the Earth from the altitude $H$ above the Sea level (see left-hand Figure): the boiling point decreases about 3 °C for every 1000 m increase in height. At the Sea level, $p_a = 1$ bar and on top of the Mount Everest with $H = 8850$ m (right-hand Figure), the Boltzmann barometric equation gives the result that the air pressure decreases according to the exponential law $p(H) = p_a \cdot \exp(-H / 7990 \text{ m}) = 0.335 \text{ bar}$.
Schematic representation of the phases of water at different temperatures and atmospheric pressure

- Superheated water
- Boiling point
- Stable (normal) water
- Melting point
- Supercooled water
- Ultraviscous water
- Glassy water

Here, water is stable only in its solid crystalline phase

P–T Phase diagram of water

(s. p. 106 for atmospheric pressure)

Supercooled water:
Is obtained by careful cooling of very pure water.

„No man’s land“:
Here, no liquid phase but only a solid crystalline phase exists (s. also p. 106)

„Glassy water“:
If liquid water is very rapidly cooled down, a glassy amorphous ice is formed.
LDA: „Low-Density Amorphous“ ice
HDA: „High-Density Amorphous“ ice

Deeply undercooled liquid water:
If LDA at atmospheric pressure (≈ 0.1013 MPa = 1013 hPa) is heated above -137 °C, then a highly supercooled liquid water is produced: deeply supercooled liquid water. This ultraviscous water has a caramell-like consistency.

The metastable phase diagram shown above is tentative: it is based on the presently available data.
Superheated water: (p. 106): If pure water in the absence of foreign particles is heated in a smooth and homogeneous container, i.e. in the absence of condensation nuclei, then it is possible to superheat the water up to at least 110 ºC without transforming it into the gaseous phase.

This is a metastable state which can eventually be dangerous, since a small mechanical shock can provoke a large gas bubble within a very short time which escapes the vessel explosively: as a result, the liquid itself can escape very rapidly, a reaction which occurs most often in narrow and large vessels.

In many cases, persons have been injured by boiling of water in the microwave heater for preparing beverages. Such water can easily be superheated and at certain conditions (i.e. by dipping a spoon into the water or by adding granular grains of coffee to it) it can provoke violent boiling or even dangerous explosions.

The colder water in the upper part of the Geysir exerts a pressure onto the underlying hot water and acts as a vessel pressure cooker. In this way the boiling water becomes superheated, i.e. it remains liquid above 100 ºC.

Vapour bubbles which splash through the openings, cause a reduction of the pressure in the inner part of the Geysir. The superheated water transforms violently to vapour and seeths upwards, where it splashes as a vapour - or water fountain.

Supercooled water: (s. pp 99, 106, 107). Water contains usually condensation nuclei (such as ice crystals, impurities or irregularities at the surface of the vessel), it freezes at 0 ºC. In our normal environment such nuclei exist almost always, such that the freezing (of still water) takes indeed place at 0 ºC.

In the laboratory it was, however, possible to keep very pure and still water in the liquid state down to -70 ºC by very slow cooling! Thus supercooled water is metastable: it freezes at once if condensation nuclei are added.

The supercooled water in the bottle is poured into a vessel which contains natural condensation nuclei.
As a result, the supercooled water freezes instantaneously to ice.

In the atmosphere, supercooled water is present very frequently. At temperatures between 0 and -12 ºC, the concentration of supercooled water droplets is even higher than that of ice crystals but by decreasing the temperature further, the number of ice crystals continuously increases. At a temperature of -20 ºC the ratio of supercooled water droplets and ice crystals is 1:1. At still lower temperatures, the concentration of ice crystal becomes larger than that of supercooled water. Supercooled water droplets exist in the atmosphere down to temperatures of -40 ºC (see Chapter 4: Appendix 4_A_3_1).
2.9 Colours and Spectra of Water

Colours and spectra of H₂O and D₂O

H₂O: very weak absorptions in the red and yellow spectral range, but transparent in the blue region → in large depths it appears blue!

D₂O: no absorption in the red and yellow range → colourless!

Light water (H₂O) and light ice are the only chemical substances known until now, for which the colours are due only to molecular vibrations (overtones - and combinations of the fundamental vibrations, see pp 112 - 114)!

The colours of most other substances originate from light-induced electronic excitations [Example: red colour of copper].
Spectrum of liquid water from the UV to the FIR

Infrared (IR) - Far Infrared (FIR)

Absorption of water and ice from the Far–Infrared (FIR) to the Ultraviolet (UV) spectral range

The weak absorptions in the Near Infrared (NIR) are overtones and combinations of the normal vibrations (fundamentals) in the IR and FIR. They are produced by anharmonic coupling of the fundamental vibrations!

Absorption coefficient $\alpha$ (cm$^{-1}$) vs. THz

$1$ THz (Terahertz) = $1$ Trillion Hertz = $10^{12}$ Hz
The assignment of the absorption bands is illustrated at p. 114.

As shown in the Figure, the absorption bands of ice are located at slightly displaced frequencies with respect to the corresponding bands of water.
In the Micro-Wave (MW):
Reorientation of the permanent dipole moments of the Water molecules: „Dipolar Relaxation“

In the Infraret (IR):
Molecular vibrations: (internal and external);
In the Near Infrared (NIR) to the visible region (VIS):
Overtones and combinations

In the Ultraviolet (UV):
Plasma absorption

Optical constants:
Refractive index $n(\nu)$ and absorption coefficient $\alpha(\nu)$ of liquid water

Complex dielectric constant $\varepsilon(\nu) = \varepsilon_1(\nu) + i \varepsilon_2(\nu)$

Dispersion and absorption of liquid water

• In the microwave range: directional changes of the permanent dipole moments of the water molecules: „Dipolar Relaxation“

• In the infrared range: molecular vibrations: (internal and external)
• in the Near Infrared (NIR) up to the Visible range (VIS): overtones and combinations

• In the UV: electronic plasma absorptions
There exist several analytical and MD models. The most popular model is the Onsager-Kirkwood-Fröhlich model which gives

$$
\varepsilon_g(T) = \varepsilon_\infty + 2\pi N \frac{m^2}{k_B T} g
$$

$\varepsilon_\infty \approx 4.2$ : contributions of molecular vibrations and electronic polarization.

$N$ = number of molecules per unit volume.

$m$ = permanent dipole moment of a water molecule in liquid water ($m = 3.0$ Debye).

$g$ = correlation factor of Kirkwood; $g$ is a measure for the orientational correlation between a "central" molecule and its surrounding molecules ($g = 2.6$ at $0^\circ C$ and $g = 2.46$ at $83^\circ C$).

The factor $k_B T$ in the denominator takes into account the thermal motion of the water molecules, which counteracts the alignment of the dipole moments in the electric field.

⇒ According to Kirkwood, the high dielectric constant of water is not only due to the strong polarity of the individual water molecules (large $m$) but also by the correlated motion of the molecules which gives rise to a large $g$ – factor.

(For a derivation of $\varepsilon_g(T)$ see Ref. R.2.9.7, R.2.9.8)
The strongly inhomogeneous field $\Delta E$, which emerges from the tip of the pen, partially aligns the dipole moments of the water molecules and exerts a force onto the polar liquid causing a deflection of the jet of water. The force is proportional to $F = \frac{\Delta E}{\Delta x}$; $\Delta x =$ diameter of the jet of water; $\Delta E =$ change of $E$ across $\Delta x$. 
Generation of a "water bridge" by a high electric field

Here, water is subjected to a tension!

Centrifugal – method for the generation of a very large stress (negative pressure) in water

J.M. Briggs (NBS): the water column contained in a horizontally rotating capillary tube breaks apart only at very high negative pressures; at about 10 °C the negative pressure reaches a maximum value of about -277 bar (!) and decreases by about 22% as the temperature is increased to 50 °C.

Rupture as a result of loss of inner cohesion of the liquid and/or by the loss of adhesion at the walls of the capillary?

Between 0 °C and 10 °C, the limiting pressure undergoes an enormous increase of more than 90%! It presents another anomaly in the behavior of water in this interesting region.
„Setting to music“ the Infrared spectrum of liquid water (p. 114) by transformation into the audible acoustic range (Concerning „Water in Music“ s. Chapter 8, Section 4) (P. Brüesch, 28. 1. 2009)
Remarks concerning the „setting to music“ of the infrared spectrum of water:

The spectrum of Figure 124 has been generated from the infrared spectrum (IR) of water shown in Figure 114 by reducing each frequency by the factor $2^{36.5}$: this corresponds to a reduction of each IR frequency by 36.5 octaves, thereby transforming it into the audible acoustic range. The reduction factor has been chosen in such a way that the frequency of the hindered rotation at 20 THz (Figure 114) is set to the sound frequency at 220 Hz. The concert pitch a' is fixed at 440 Hz.

The spectrum shown at p. 124 comprises more than 8 octaves each having 12 semitones; in the Figure the semitones are indicated by the small red circles. In the linear frequency scale of this spectrum, the individual semitones are distributed very densely at low frequencies, but their distances increase strongly with increasing frequency. The frequency $f_n$ and their distances are given by

$$f_n = 2^{(n/12)} \cdot f_0,$$
$$\Delta f_n = f_{n+1} - f_n = (2^{1/12} - 1) \cdot f_n = 0.05946 \cdot f_n,$$

where $n = 0, 1, 2, …, 101$, and $f_0$ has been chosen to be 4.33 Hz. For music, the 6 important octaves are:

``c' - c ; c' - c ; c - c' ; c' - c'' ; c'' - c'''' ; und c''' - c'''``

where ``c = 32.7 Hz and c''' = 2092 Hz, which corresponds approximately to the register of the piano. Some important sounds are indicated in the Figure. For a „setting to music“ it would probably be necessary to take into account the large widths of the IR-absorption bands: transformed into music, the broad and asymmetric band at 220 Hz, for example, should be decomposed into two or three bands at lower frequencies.

---

Relative intensity as a function of $g_n = \log_2(f_n / f_0) = n / 12$

$$f_n = f_0 \cdot 2^{(n/12)}$$

$(n = 0, 1, 2, …, 101)$
Appendix – Chapter 2

Part of the pure rotational spectrum of water vapour in the far–infrared region

Very detailed information about the geometry of the water molecule (bond–length and bond angle) is obtained from spectroscopic measurements in the infrared and microwave region. In the microwave and Far–Infrared Region (FIR), the rotational motions of the molecule are observed. From the observed rotational spectra and the theoretical expressions for the rotational energies, the moments of inertia can be evaluated. The total energy of the molecule is given by $E(r,v) = E_r + E_v + E_{rv}$, where $E_r$ is the rotational energy, $E_v$ the vibrational energy and $E_{rv}$ the coupling between the rotational and vibrational motions (Coriolis energy or Coriolis coupling).

The observed superposition of the spectrum due to the vibrational motions (pp 37, 140) and the rotational spectrum of water vapour is shown at p. 38. (For more details see References R.2.0.1 and R.2.0.2).
Since the water molecules in ice are more strongly bound than in liquid water, the water vapour pressure over the ice is smaller than over the supercooled water. If, however, we are not considering bulk ice and bulk water but rather water droplets and snow crystals in clouds (s. Chapter 4, p. 4-A-3-1), a maximum vapor pressure difference is observed at about -15 °C but below about -50 °C the vapor pressure curves are again practically identical (Bergeron – Findeisen – Process).
2. Physical and chemical properties

From the Figures contained in this Chapter more than one half of them have been prepared, completed and suitably arranged by the present author. If ever possible, I have cited the original Literature but in other cases it was only possible to quote the corresponding Internet citation. In general, the Literature given here contains the general aspects and information of this extremely vast subject. In addition, a lot of information stems from Lectures given by the author (Reference R.2.0.1 and R.2.0.2 below).

2.0 General References

R.2.0.1 WATER: PHYSICAL PROPERTIES AND IMPLICATIONS FOR NATURE
P. Brüesch: Lectures given in the "Troisième Cycle du Département de Physique de l’EPFL; Sémestre d’Eté (1998), and References cited therein.

R.2.0.2 POTENTIAL TECHNOLOGICAL APPLICATIONS OF WATER-BASED DIELECTRIC LIQUIDS: PHYSICAL AND CHEMICAL PROPERTIES
P. Brüesch. ABB Report, 09-00 V4 TN (3. 2. 2000) and References given therein.

R.2.0.3 PHYSICAL CHEMISTRY

R.2.0.4 PHYSICAL CHEMISTRY

R.2.0.5 PHYSIK
R.2.0.6 MOLECULAR ORBITAL THEORY
C.J. Ballhausen and H.B. Gray (W.A. Benjamin, Inc. New York (1965))
(Molecular Orbitals; s. Figure at p. 36 in present Chapter)

R.2.0.7 MOLECULAR VIBRATIONS
The Theory of Infrared and Raman Vibrational Spectra
E.B. Wilson, Jr., J.C. Decius, and P.C. Cross
(Normal modes of vibrations of the water molecule; s. Figure at p. 37 in present Chapter)

R.2.0.8 THE HYDROGEN BOND : Recent Developments in Theory and Experiments
Eds.: P. Schuster, G. Zundel, C. Sandorfy
North-Holland Publishing Company (1976)
(Hydrogen bonds in clusters and in liquid water; s. pp 39 - 45; 50; 55, 56; 59; 61, 62; 76; 78; 87, 88 in present Chapter)

R.2.0.9 WOLKENGUCKEN ("Looking at Clouds")

R.2.0.10 DIE ERFINDUNG DER WOLKEN ("The invention of Clouds")

R.2.0.11 PHYSICS OF ICE

R.2.0.12 PHYSICS AND CHEMISTRY OF ICE

R.2.0.13 THE CHEMICAL PHYSICS OF ICE

2.1 Phase diagrams and basic facts

R.2.1.1 H₂O: A BIOGRAPHY OF WATER:
Philip Ball, Weidenfeld & Nicolson (London, 1999), pp 146, 147

R.2.1.2 Phase diagram of water: s. Reference R.2.0.3: pp 246 - 247

R.2.1.3 Phase diagram of water: s. Reference R.2.0.4: pp 186 - 187
2.2 Water vapour, Molecules, Hydrogen bonds and Clusters

R.2.2.1 About the „Thermal motion of Water molecules“:
Ref. R.2.0.1, p. 19; Ref. R.2.0.2, p. 4; Ref. R.2.0.3, p. 599; Ref. R.2.0.4, p. 580.

R.2.2.2 The infrared spectrum of water vapour (p. 38) has been measured by P. Brüesch.

R.2.2.3 THE HYDROGEN BOND: Recent Developments in Theory and Experiments
Eds.: P. Schuster, G. Zundel, C. Sandorfy
North-Holland Publishing Company (1976)
(Hydrogen bonds in clusters and in liquid water: s. pp 39–45; 50; 55, 56; 59; 61, 62; 76; 78; 87, 88 in present Chapter)

R.2.2.4 p. 45: HF: www.chem.berkeley.edu/hydrogenbonding

2.3 The Ices of Water

R.2.3.1 PHYSICS OF ICE

R.2.3.2 PHYSICS AND CHEMISTRY OF ICE
Proceedings of the International Symposium on the Physics and Chemistry of Ice, held in Sapporo, Japan, 1–6 September 1991

R.2.3.3 p. 47: „Condensed – matter physics . Dense ice in detail“

R.2.3.4 The Figure at p. 55 is contained in: ESRF Highlights 1995/96

R.2.3.5 p. 56: Structure of Ice X: Magari Benoit, Dominik Marx and Michele Parrinello

R.2.3.6 A comprehensive and updated list of the modifications of the ices of water is contained in Reference R.2.0.1, p. 205

2.4 Liquid Water: Structure and Properties

R.2.4.1 pp 52, 53: Snow crystals: s. also pp 176–182 and References R.4.3.6 – R.4.3.7

R.2.4.2 Figure from p. 55 from: ESRF Highlights 1995/96; pp 55-57: References R.2.0.11 – R.2.0.13

R.2.4.3 p. 56: Struktur of Ice X: Magari Benoit, Dominik Marx and Michele Parrinello

R.2.4.4 A comprehensive and updated list of the Ices of Water is contained in the Reference R.2.0.1, p. 205.

2.5 Anomalien des Wassers

R.2.5.1 An extensive List of the anomalies is given in Ref. R.2.0.1, Section 1.4., pp VI – IX.


R.2.5.3 p. 69: For other anomalies: s. Reference R.2.0.17.
2.6 Density and specific heat

R.2.6.1 p. 73: Density as a function of temperature in the range 0°C und 10°C

R.2.6.2 Density of liquid water:
Figure at p. 74 adapted and designed by P. Brüesch in Reference R.2.0.2, p. 33

R.2.6.3 Specific heat \( C_p \): Figures 76 and 77:
Figures adapted and designed by P. Brüesch in Reference R.2.0.2, p. 35

R.2.6.4 Reason and significance of the large specific heat of water:
http://www.sciencebyjones.com/specific_heat1.htm

2.7 Various physical Properties and Experiments

R.2.7.1 The Figures at pp 81-85 have been prepared and designed by P. Brüesch.
As far as possible, the relevant References are quoted.
see P. Brüesch: Reference R.2.0.2, pp 34-38

R.2.7.2 p. 85: Water has the highest surface tension of all non-metallic liquids!
http://en.wikipedia.org/wiki/Properties_of_water; see also Ref. R.2.0.2: p. 36

R.2.7.3 p. 86: Water strider walking on water due to high surface tension
see: de.academic.ru/dic.nsf/1491187 and: en.wikipedia.org/wiki/Gerridae

2.8 Phase Diagrams of pure Water

R.2.8.1 pp 99 – 107: Phase diagrams of Water: the Figure at p. 92 shows superheated water (meta-stable), both, by overheating at constant pressure as well as by reduction of pressure at constant temperature.

R.2.8.2 p. 105: Melting point and boiling point:
http://www.zeno.org/Meyers-1905/A/H%C3%B6henmessung
Mount Everest:
http://wikipedia.org/wiki/Mount_Everest

R.2.8.3 p. 106: Phase diagram of water, p. 245 in Reference R.2.0.3

R.2.8.4 p. 107: Phase diagram of water, p. 187 in Reference R.2.0.4
2.9 Colours and Spectra of Water

R.2.9.1  p. 111: Absorption of H$_2$O and D$_2$O: from [www.webexhibits.org/causesofcolor/5B.html]


R.2.9.3  p. 113: The spectra of ice and water have been collected from different Literatur – data by P. Brüesch.

R.2.9.4  p. 114: The infrared spectrum has been composed by P. Brüesch, using data from H.D. Downing and D. Williams (J. of Geophysical Research 80, 1656 (1975)).

R.2.9.5  p. 115: Infrared absorption spectra of liquid water and ice
Figure composed by P. Brüesch from different Literature data

R.2.9.6  p. 116: Refractive index n(ν) and absorption coefficient α(ν) of pure water:
Figure from: J.D. Jackson: Classical Electrodynamics, John Wiley & Sons, p. 291 (1975)
Explanation to the Figure from P. Brüesch:
above: Index of refraction; below: absorption coefficient a of pure water at N.T.P. conditions.
The small vertical arrows indicate the energy scale in units of eV and the vertical small dashes indicate the wavelength scale. The visible range of the spectrum is illustrated by the two vertical dashed lines. Note the logarithmic scale in both direction.

R.2.9.7  p. 117: Complex dielectric constant $\varepsilon_r(\nu) = \varepsilon_\infty + \varepsilon_i(\nu)$ of H$_2$O as a function of frequency s. Referenz R.2.0.1

\section{2.10 Various Topics}

R.2.10.1  p. 120: Dielectrophoresis

R.2.10.2  p. 121: Explanations to experimental details for „Floating Water Bridges“


R.2.10.4  p. 122: The Life and Scientific Contributions of Lyman J. Briggs
Soil Science Society of America Journal by: Edward R. Landa and John R. Nimmo

R.2.10.5 Probing water under tension – Physics Update
Physics Today, December 2, 2010
blogs.physicstoday.org/update/2010/.../ist-easy-to-think.html
R.2.10.6 pp 123 - 126:
Transformation of the Infrared Spectrum of liquid Water into the Audio–Acoustic Frequency Range
(Proposed by P. Brüesch for the basis of a „Water Music“)

R.2.10.7 p. 2_A_8-1: Satturation vapour pressure over water and ice
in: Ice Properties - Caltech
www.lts.caltech.edu/~atomic/snowcrystals/ice/ice.htm
3. Water as a Solvent and in Electrochemistry
3.1 Water as a Solvent: General

Absolutely pure Water does not exist in Nature!

Hydrophilic and hydrophobic substances

- Pure water does not exist in nature:
- For a large majority of compounds water is an excellent solvent!
  - Reason: the H₂O-molecule has a large dipole moment (strongly polar molecule ➔ polar liquid).
  - Many substances, i.e. sodium chloride (NaCl), sulfates, carbonates, urea are hydrophilic substances or “water friendly”.
    (An exception: Barium sulfate, BaSO₄, is not water-soluble!)
  - Certain gases are strongly soluble in water: i.e. nitrogen (N₂), oxygen (O₂), carbon dioxide (CO₂).
  - Compounds which are not soluble in water are called hydrophobic compounds (water hostile), i.e. carbon, synthetic materials.
Since the water molecules possess a large dipole moment, water is a polar solvent. In addition, the water molecules are linked together via hydrogen bonds.

Therefore, water is an excellent solvent for substances composed of polar molecules or for compounds containing hydrogen-bonded molecules (i.e., for sugar).

The ions of dissolved salts strongly attract water molecules.
Example: NaCl in water \( \rightarrow \) Na\(^+\)(H\(_2\)O)\(_m\) + Cl\(^-\)(H\(_2\)O)\(_n\) (see p. 131)

\[ \text{Water is a very “hungry” liquid !!} \]

Dissolution of sodium chloride in water

- In the lattice of sodium chloride the ions Na\(^+\) and Cl\(^-\) execute small vibrations around their equilibrium positions (lattice vibrations)
- Agglomeration of H\(_2\)O to NaCl \( \rightarrow \) formation of Hydration-Energy (HE)
- The HE increases the vibrational amplitudes of Na\(^+\) and Cl\(^-\) ions in NaCl \( \rightarrow \) loosening of the bonds in the crystal lattice of sodium chloride
- If the amplitudes of the ions are sufficiently large, the ions break apart from the NaCl surface \( \rightarrow \) dissolution of sodium chloride \( \rightarrow \) hydration of NaCl
Clustering and orientation of $\text{H}_2\text{O}$–molecules around the $\text{Na}^+$- and $\text{Cl}^-$- ions of NaCl (sodium chloride): Hydration of ions

The positively charged protons (hydrogen – ions $\text{H}^+$) orient themselves around the negatively charged $\text{Cl}^-$ ions.

- Hydration shell of $\text{Cl}^-$
- $\text{Cl}^-(\text{H}_2\text{O})_5$ - cluster

The negatively charged oxygen ions $\text{O}^2-$ orient themselves around the positively charged $\text{Na}^+$-ions.

- Hydration shell of $\text{Na}^+$
- $\text{Na}^+(\text{H}_2\text{O})_5$ - cluster

The hydrated ions $\text{Na}^+(\text{H}_2\text{O})_n$ and $\text{Cl}^-(\text{H}_2\text{O})_m$ are moving in opposite directions in an external electric field; here, we have chosen $n = m = 5$.

- ionic conductivity (s. p. 92) !.

Structure of NaCl- solution in water

Instantaneous configuration of a 1.791 molar aqueous NaCl solution.

The $\text{Cl}^-$- ions are represented by the two yellow spheres.

The $\text{Na}^+$- ions are the (partly hidden) smaller green spheres.

Water molecules:
- Blue spheres for oxygen (O),
- red small spheres for hydrogen (H).
**Solubility of non-ionic compounds**

**Example: Sugar**

The water molecules are hydrogen-bonded with the polar groups (OH-groups), thereby separating the sugar molecules from the solid sugar in the solution.

**Insoluble (non-polar) substances in water**

**Examples: Fats, oils, synthetic materials, silicon**

Non-polar molecules do not dissolve in water, since for the water molecules it is energetically more favourable to form hydrogen bonds among themselves rather than forming Van der Waals bonds with the non-polar molecules → formation of emulsions; Example: water-in-oil emulsion.

---

**Solubility of Glucose, Sucrose, etc. In water**

Organic molecules such as Glucose, Sucrose (Rohrzucker) and Vitamin C (ascorbic acid) are soluble in water since they possess hydroxile (OH-) side chains; together with the water molecules, they form hydrogen bonds:

\[ \text{H} - \text{O} - \text{H} \]

An emulsion contains two liquids in which one of them is dispersed in the other; an example is oil in the form of droplets (red) dispersed in water (blue).

An emulsion is thermodynamically unstable since the droplets tend to coagulate; in order to avoid this coagulation, the droplets are coated with a suitable surfactant which prevents the droplets from sticking together.

**Emulsion of oil in water**

3 – 4
With increasing concentration of sodium chloride (NaCl) in water the freezing point decreases; sea water freezes at -2.8 °C. The saturated NaCl–solution freezes only at -22.5 °C.

(Figure prepared and designed from different sources by P. Brüesch)

Phase diagrams of water and dilute aqueous solutions:

Boiling point elevation and freezing point depression

At a given temperature, the vapor pressure $p$ of a solution is smaller than that of the pure solvent because the water molecules are bound to the ions of the dissolved compound (e.g. Na$^+$ and Cl$^-$ ions in a NaCl–solution). As shown in the left-hand Figure, a decrease of vapor pressure causes a boiling point elevation by the amount of $\Delta T_{bp} = T_{bp}^* - T_{bp}$ (a liquid is boiling if its vapor pressure is equal to the ambient pressure, $p_{ambient}$). This is, however, only the case if the gas above the solution does not contain ions, atoms or molecules of the dissolved material.

The right-hand Figure shows that a decrease in vapor pressure causes a freezing point depression, $\Delta T_{fp} = T_{fp}^* - T_{fp}$. This is, however, only the case if pure solvent crystallizes. For dilute solutions the temperature changes are proportional to the pressure changes: $\Delta T \sim \Delta p$. 

3 – 5
At time $t_1$, water starts to boil and the temperature ($T_1 = 100^\circ C$) remains constant until all water is vaporized. At time $t_2$, the salt water boils at $T_2 > T_1$. With increasing vaporization of water, the salt concentration and the boiling point increase. If all water is vaporized, the salt is completely crystallized.
3.2 Sea Water

General Remarks and Facts

1. The largest part of the surface of the earth (about 70 %) consists of water.

2. About 97 % of the water on the earth is Sea Water.

3. In Sea Water at least 72 different chemical elements have been observed, most of them in extremely small concentrations.

4. Salinity is the total salt concentration in Sea Water.

5. A salinity of 35 ‰ (= 3.5 %) corresponds to 35 g of dissolved salt in 1000 g Sea Water.

6. 1000 g Sea Water contains about 10.7 g sodium ions and 19.25 g chloride ions; the largest part of it is NaCl (sodium chloride); about 85 % of the dissolved salts is NaCl. This explains the salty taste of Sea Water which is not drinkable.

6. The largest part of salt in the Sea has been generated by eruption of volcanic rocks, the Earth's crust, the disintegration and erosion of mountains in the Sea, as well as by the transport of minerals by rivers into the Sea.

7. In the remaining liquid water, the salinity is increased by evaporation and condensation (evaporated and frozen water are free of salts!). The salinity is decreased by rain or by melting of ice.

8. The salinity of the landlocked „Dead Sea“ is up to 33.7 %, in the average about 28 %; (compare this with the „Middle Sea“, the salinity of which is only about 3 %). Note, however, that the „Dead Sea“ is an „inland water“ and as such belongs to „Limnology“ (s. p. 183).
Seawater: Facts and Explanations

• The average salinity of seawater is about 3.5 mass percent. On the other hand, the salt content of the Baltic Sea is about 0.2 to 2% while the salt content of the Dead Sea is about 30%.

• The principle salts are the chlorides, where sodium chloride (NaCl) plays the dominant role. Magnesium chloride, magnesium sulfate, calcium sulfate, potassium chloride, and calcium carbonate together constitute less than 1 mass %.

• For an average salt concentration of 3.5% the melting or freezing point is -1.9 °C (s. p. 137).

• The salts are washed out permanently from stones and rocks by rain and melting water. By evaporation of fresh-water the originally very diluted salt water is concentrated and salty Sea Water is produced. By this effect, the salt concentration in the Sea would slowly but continuously increase, if at the same time salt would not be removed from the sea.

• The loss of salt is firstly due by drying out of seas whereby the salt accumulates at the soil. This salt is often found in salt mines. Secondly, Sea Water can be captured in the crevices of sediments of the sea bed and in this way the salt is withdrawn from the water.

• The very high salt concentration of the Dead Sea is due to the fact that firstly the water from the Jordan continuously runs into it thereby enriching it always by minerals. Secondly, and even more important, the Dead Sea has no drainage.

• In addition to the salts, Sea Water contains dissolved gases such as carbon dioxide (CO₂), oxygen (O₂), nitrogen (N₂) and other atmospheric gases.
Typical depth profiles of temperature in different climatic zones of Sea Water

![Graph showing temperature profiles]

The thermocline is the transition layer between the mixed layer at the surface and the deep water layer. The definition of these layers is based on the temperature variation $T(h)$.

Remarks about the temperature distribution in the salt water of the oceans

- The latitude gives the location of a place on Earth north or south of the equator.
- High latitudes: in the regions of the north- or south pole.
- With decreasing temperature, the density of Sea Water continuously increases up to the freezing point; therefore, the temperature of maximum density is identical with the freezing point $T_{fp}$, which depends on the salt concentration (salinity). For a salinity of 34 g/L (3.5 mass %) $T_{fp} = -1.94 ^\circ C$.
- The water with maximum density sinks down to large depths; below a depth of about 2000 m the temperature is therefore $T_{fp}$.
- At high latitudes (north- and south pole) $T = T_{fp}$ and below this regions, $T(h) = T_{fp}$, independent on the height $h$. 
The densest water is deep water and has the temperature $T_{fp}$ of the freezing point.

The temperature therefore decreases with increasing depth; the formation of the thermocline (transition layer between deep and surface water) results in the first place by the variation of the density with temperature in the water layer.

If the surface of the salt water freezes at $T_{fp}$, then the resulting ice is free of salts and its density is equal to the density of ice obtained by cooling of fresh-water.

This ice is swimming on the salt water and the “frozen-out” salt increases the density of the Sea Water just below the ice. This process is called “brine rejection”.

The pycnocline is a layer or zone of changing density in lakes or oceans.

The pycnocline is a layer or zone of changing density in lakes or oceans.

A black smoker or sea vent, is a type of hydrothermal vent found on the ocean floor.

They are formed in fields hundreds of meters wide when superheated water from below the Earth’s crust penetrates the ocean’s floor, (critical point at 374 °C and 221 bar (s. pp 99 –101); (superheated water : s. pp 103 and 108)

This water is rich in dissolved minerals from the crust, most notably sulfides. When it comes in contact with cold ocean water, many minerals precipitate, forming a black chimney-like structure around each vent.

At a depth of 3000 m the temperature is about 400 °C, but does not usually boil at the seafloor, because the water pressure at that depth (about 300 bar) exceeds the vapour pressure of the aqueous solution.

The water is also extremely acidic, often having a pH value as low as 2.8 – approximately that of vinegar!

Each year $1.4 \times 10^{14}$ kg of water is passed through black smokers.
3.3 Water in Electrochemistry

Electrolysis: General

With the help of two electrodes, a direct current is passed through an electrolyte containing positive cations and negative anions. As a result of electrolysis, reaction products are formed from the ions contained in the electrolyte.

The solution between the electrodes contains an electrolyte with positive and negative ions. By application of an electric field, the positively charged cations migrate to the negatively charged cathode. At the cathode they accept one or several electrons and are reduced to atoms. On the other hand, at the anode, the opposite process takes place: there, the negatively charged anions give up electrons and get oxidized.

The minimum voltage which must be applied for the electrolysis, is called the decomposition voltage \( U_z \). For the electrolysis of pure water, \( U_z \) is 1.23 V; in practice, however, the unavoidable overvoltage requires a voltage of at least 2 V.
Electrolysis of pure Water

Self-Dissociation: \(2 \text{H}_2\text{O} \leftrightarrow \text{H}_3\text{O}^+ + \text{OH}^-\) (s. pp 87, 88 in Chapter 2)

Electrolysis of pure water is very slow, and can only occur due to the extremely small concentrations of the "water ions" \(\text{H}_3\text{O}^+\) and \(\text{OH}^-\) (s. pp 87-93).

Reactions:

Cathode:

\[4 \text{H}_3\text{O}^+(\text{aq}) + 4 \text{e}^- \rightarrow 2 \text{H}_2(\text{g}) + 4 \text{H}_2\text{O}\]

Anode:

\[4 \text{OH}^-(\text{aq}) \rightarrow \text{O}_2(\text{g}) + 2 \text{H}_2\text{O} + 4 \text{e}^-\]

Total reaction:

\[2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})\]

Technical Water Electrolysis

Net reaction: \(2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})\)

The electrodes are emerged into water which is made weakly conductive by adding sum sulfuric acid, i.e. \(\text{H}_2\text{SO}_4\) or Potassium Hydroxide, KOH.

Cathode reaction: In the electric field, the positively charged \(\text{H}_3\text{O}^+\) - ions migrate to the negatively charged cathode, where they accepts an electron. In this process, hydrogen atoms, \(\text{H}\), are produced; they combine to form \(\text{H}_2\) molecules, which escape in the form of \(\text{H}_2\) - gas. As a result, \(\text{H}_2\text{O}\) - molecules remain: \(2 \text{H}_3\text{O}^+ + 2 \text{e}^- \rightarrow \text{H}_2(\text{g}) + 2 \text{H}_2\text{O}\), (or: \(2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{H}_2(\text{g})\)).

Anode reaction: The negatively charged hydroxide ions, \(\text{OH}^-\), migrate towards the positively charged anode. Each \(\text{OH}^-\) - ion gives away an electron to the positive pole, such that oxygen atoms are produced, which combine to \(\text{O}_2\) - molecules. The remaining \(\text{H}^+\) - ions are immediately neutralized by hydroxide ions \(\text{OH}^-\) to produce \(\text{H}_2\text{O}\) - molecules: \(4 \text{OH}^- \rightarrow \text{O}_2(\text{g}) + 2 \text{H}_2\text{O} + 4 \text{e}^-\).

New development: Use of SPE (Solid Polymer Elektrolyte) as proton conductors, using Pt - catalyzers → reduction of power consumption as compared with the traditional KOH - technology.
Water decomposition according to Hoffmann

The water decomposition device of Hoffman allows the electrolytic decomposition of aqueous solutions.

It allows the demonstration of the electrolytic decomposition, for example of water as shown in the Figure. In this case, the device is filled with diluted sulfuric acid or potassium hydroxide because pure water does not possess a sufficient electric conductivity. After the application of a direct voltage at the platinum electrodes, a gas development takes place at the cathode and at the anode.

In this reaction, water is decomposed into Oxygen and Hydrogen.

At the cathode, the $\text{H}_3\text{O}^+$-ions which have been generated by protolysis are reduced to $\text{H}_2$ and at the anode water is oxidized to $\text{O}_2$.

Cathode reaction: $4 \text{H}_3\text{O}^+ + 4 e^- \rightarrow 2 \text{H}_2 + 4 \text{H}_2\text{O}$
Anode reaction: $6 \text{H}_2\text{O} \rightarrow 4 \text{H}_3\text{O}^+ + \text{O}_2 + 4 e^-$

Net reaction: $2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2$

Current – voltage characteristics of Electrolysis

In an aqueous electrolyte (e.g. a 1 M $\text{H}_2\text{SO}_4$ solution or a 6–8 M KOH solution), the formation of $\text{H}_2$-gas at the cathode and of $\text{O}_2$-gas at the anode sets in only if the voltage has reached a certain value, the so-called decomposition voltage.
• First, all the three chambers are filled with an electrolyte (i.e. with a NaCl-solution).
• Then, a large DC voltage (400–500 V) is applied. The cations migrate through the Cation Exchange Membrane (CEM) into the cation space while the anions migrate through the Anion Exchange Membrane (AEM) into the anode space until the middle chamber (desalination chamber) is free of salts.
**Principle and Applications of Bipolar Electrodialysis**

**Principle**

In analogy to the conventional electrolysis (pp 148-150), the repeating membrane unit contained in the membrane module is composed of two Bipolar Membranes (BM), on a Cation Exchange Membrane (CEM) and on an Anion Exchange Membrane (AEM).

In the Figure shown at page 154, the chloride ions (Cl\(^-\)) are moving in the electric field through the AEM to the anode. There, they are collected at the inner side of the cation-selective BM; together with the protons produced in the BM they react to form hydrochloric acid, HCl.

In the same way an NaOH-lye (Lauge) is produced at the anion-selective side of the BP. Correspondingly, a dilute, depleted of ions, is formed in the central (yellow) part, the so-called raw solution chamber.

**Applications**

- Disalination of a sodium chloride (NaCl) solutions
- Converting water soluble salts to their corresponding acids and bases
- The Bipolar Membrane (BM) - Electrolysis is an alternative method to electrolysis for the generation of H\(^+\) and OH\(^-\) ions which can be used to generate acid and base from salts without the production of oxygen and hydrogen gases.
- Production of organic acids such as lactic acid, for traditional applications [additives for food and pharmaceutical industries] as well as for new applications such as for plastic industries [biodegradable materials].

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**The Proton Exchange Membrane Fuel Cell: PEFC**

A membrane-combustion cell contains two electrodes with an intermediate proton-conducting membrane acting as the electrolyte. The electrodes are brought into contact with external H\(_2\) and O\(_2\) gas. At the anode, H\(_2\) is oxidized: with the help of a catalyst (e.g. platinum), protons H\(^+\) and electrons e\(^-\) are formed; the protons migrate through the polymer–membrane, while the electrons pass through the external circuit (→ Watt current!). At the cathode, oxygen is reduced by the arriving electrons, thereby reacting with the protons to form H\(_2\)O: liquid water is formed. In addition to H\(_2\)O also molecular O\(_2\) is produced.
Corrosion : 1

Definition
Corrosion is a chemical or an electrochemical reaction of a material containing certain substances in his environment which results in a observable change of the substance.

Examples:
Oxygen corrosion: This is a corrosion process in which a metal in the presence of water (air humidity), is oxidized by reacting with oxygen. In this redox reaction, oxygen is the oxidizing agent (similar to the combustion/oxidation in a pure oxygen atmosphere). However, the process takes place at room temperature with the help of water or an electrolyte solution without flame appearances. For a mono-valent metal (Me) the total reaction is:

\[ 4 \text{Me} + \text{O}_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{Me}^+ + 4 \text{OH}^- \]

Hydrogen corrosion is a form of corrosion of metals, which occurs in the presence of water but in an oxygen deficient environment. The final product is elementary hydrogen:

The metal is oxidized and is dissolved in the form of ions in a solution. In the acid environment, the protons of the hydronium ions (H\(_3\)O\(^+\)) accept electrons and are reduced to hydrogen \(\text{H}_2\) and \(\text{H}_2\text{O}\) is formed. This process occurs often during oxidation of Fe:

\[ \text{Fe} \rightarrow \text{Fe}^{2+} + 2 \text{e}^- \quad \text{(oxidation of metal)} \]
\[ 2 \text{H}_3\text{O}^+ + 2 \text{e}^- \rightarrow \text{H}_2 + 2 \text{H}_2\text{O} \quad \text{(reduction of hydronium ions)} \]

Corrosion : 2

Galvanic corrosion and pitting corrosion

Galvanic corrosion: (at right in the Figure)
By contacting a non noble metal with a noble metal in the presence of water, galvanic corrosion occurs. This type of corrosion is particularly frequent for non noble metals, because in this case already small impurities at the interface between the metals are sufficient for their initiation. At the surface of the more noble metal, \(\text{H}_2\text{O}^+\) ions are reduced to hydrogen. Since carbonic acid, (\(\text{H}_2\text{CO}_3\)), is also contained in distilled water, such processes occur also in water.

Pitting corrosion: (at left in the Figure)
A second important type of corrosion is pitting corrosion, in which the less noble metal is dissolved: at the interface of the metal with water, the metal is ionized:

\[ \text{Me} (s) \rightarrow \text{Me}^+ (aq) \text{ and the electrons migrate to the metal interface.} \]

Figure adapted by P. Brüesch)
Freezing point temperature $T_{fr}$ and temperature of maximum density $T_m$ as a function of Salinity $S$

Solid red curve $T_{fr}(S)$: Adding salt to pure water at 0°C an almost linear decrease of the freezing point is observed. At 35 psu (mean salinity of sea water) the freezing point of the solution is -1.8°C. [1 psu is the practical salinity unit which measures the salinity similar to 1 part per thousand (ppt)].

Dashed green curve $T_m(S)$: The density maximum of pure water is at 4°C. Increasing the salinity, the density maximum is shifted linearly towards lower temperatures and at $T_{fr}(S) = 24.7$ psu it intersects the freezing point line. For salinities above 24.7 psu (S of most ocean waters is higher than this), the temperature of maximum density equals the freezing point – line of the solution.
3. Aqueous Solutions

3.1 Water as a Solvent

R.3.1.1 WATER AND AQUEOUS SOLUTIONS
Structure, Thermodynamics and Transport Properties
Edited by R. A. Horne
Wiley-Interscience
Copyright @ 1972 by John Wiley and Sons, Inc.

R.3.1.2 WASSERCHEMIE FÜR INGENIEURE
H. Sontheimer, P. Spindler, und U. Rohmann
Engler-Bunte-Institut der Universität Karlsruhe (1980)

R.3.1.3 General References: R.2.0.3, Chapter 6: Solutions, pp 274-312

R.3.1.4 General References: R.2.0.4, Chapter 10: Equilibrium Electrochemistry, pp 311-355

R.3.1.5 pp 129–130: General Texts (P. Brüesch)

R.3.1.6 p. 131: Process of dissolution of a salt, i.e. NaCl
CHEMIE
Hans Rudolf Christen
Vogel Diesterweg–Salle
Frankfurt am Main
Achte Auflage (1971)
Figure at p. 107

R.3.1.7 p. 132: Hydration of Na⁺⁺ and Cl⁻⁻ ions
from: Internet: Google–Bilder: „chloride-sodium.jpg“
familywaterusa.com
Diameter of Na decreased and colour modified by P. Brüesch

R.3.1.8 p. 133: 3D-Structure of a NaCl-solution
Reference R.2.0.15, pp 248, 249
3.2 Sea Water


R.3.2.2 p. 143: Temperature distribution in an Ocean; Dr. David Voelker: The temperature distribution in Oceans as a function of depth; http://130.133.88.4/projekte/geomeer/inhalt/seatemp01

R.3.2.3 p. 145: Density as a function of depth in Sea Water; Figure from: www.windows.ucar.edu/tour/link=/earth/Water/density.html

R.3.2.4 p. 146: Black Smokers; en.wikipedia.org/wiki/Black_smoker

R-3-2

3.3 Water in Electrochemistry

R.3.3.1 ELEKTROCHEMISTRY

R.3.3.2 General References: R.2.0.3: pp 365 – 375

R.3.3.3 General References: R.2.0.4: pp 834 – 846

R.3.3.4 p. 148: Electrolysis: General; wiki.one-school.net/index.php/Analysing_elect... Figure modified by P. Brüesch; Text from different References

R.3.3.5 pp 149, 150: Electrolysis of pure Water; Figure and Text combined from different sources by P. Brüesch; also: http://www.der-brunnen.de/wasser/allgwasser/allgwasser.htm

R.3.3.6 p. 151: Decomposition of water by Hoffmann; http://de.wikipedia.org/wiki/Hoffmannscher_Wasserzersetzungsapparat

R.3.3.7 p. 152: Current – Voltage Characteristics for Electrolysis; Reference R.3.1.8: p. 233


R.3.3.9 pp 154, 155: Bipolare Elektrodialyse; www.syswasser.de/deutsch/am(rb)gb_membran_elektrodialyse.pdf

R.3.3.10 pp 154, 155: Principle of bipolar Electrolysis; Principle of bipolar electrolysis (Zum Funktionsprinzip der bipolaren Elektrodialyse) Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) Institut für Technische Thermodynamik

R-3-3

3 – 19
R.3.3.11 p. 156: The Membrane Combustion Cell
http://www.chorum.de/

R.3.3.12 p. 156: FUEL CELLS AND THEIR APPLICATIONS
Karl Kortesch and Günter Simader
Wiley – VCH (März 1996)

R.3.3.13 a) pp 157, 158: Corrosion Processes (Korrosions – Prozesse)
KORROSION UND KORROSIONSSCHUTZ VON METallen
P.J. Gellings
Carl Hanser Verlag München (1981)

b) CORROSION AND CORROSION CONTROL
H.H. Uhlig
John Wiley and Sons Inc. (1971)

R.3.3.14 p. 3-A2-1: The effect of salinity on the temperature of maximum density
www.colorado.edu/geography/class-homepages/geog_/weak_6_7.pdf
The Figure has been adjusted and completed by P. Brüesch

For a Table of $T_{fr}$ and $T_{m}$ versus Salinity $S$ see:
www.teos-10.org/puks/gsw/pdf/temps/maximum_density.pdf
4. Water in Nature:
Selected Examples
4.1 Some Examples

Survey of some Examples

• The world of clouds
• Precipitations
• Frozen seas, vertical temperature distribution
• Photosynthesis
• Examples from Biology
• The ascent of water in tall trees
• Water plants
4.2 The world of clouds

Cloud formation

Warm and humid air is lighter than the surrounding air and therefore rises upward. During its rise the air cools down with the result that the (molecular) vapour condenses to small water droplets or frozen crystals suspended in the atmosphere: a cloud is formed.
Nice-weather clouds: Aggregation of water droplets with diameters ranging between 1 to 15 μm (1 μm = 0.000001 m). Droplets are formed often at condensation nuclei (Aerosols). (Note that for the purpose of illustration, the diameters of the droplets are shown much too large!)

Rain clouds: Diameters of droplets up to 2 mm → formation of rain drops!

Cumulus - Clouds

Cumulus-cloud with anvil at the top (anvil cloud): contains very small water droplets
Why do clouds not fall from the sky?

A water droplet in a cloud has a typical diameter of 10 μm and a small speed of fall of some cm/s (several 100 m/h).

But upwinds are counteracting the small speed of fall, causing the drops to float or even to move upwards.

Colours of clouds: white

This cloud is composed of very small and densely packed droplets such that the sunlight can not penetrate deeply before it is reflected. Since all colours are contained in the reflected light, its superposition combines to the observed characteristic white colour.
The sunlight is composed of several colours (red – green – yellow – blue,...), which combine to the white colour.

The colour of the cloud is the result of the scattering of the sunlight by the water droplets. Our eye observes the scattered (and reflected) light. The latter depends on different factors such as of the size of the droplets, of the viewing angle, the distance and the dust between the cloud and the observer.

If a large number of small droplets combine to large rain drops, then the distances between the drops become larger. As a consequence, light can penetrate much deeper into the cloud and is partly reflected and partly absorbed. Thus the reflection–absorption process gives rise to a whole range of cloud colors, which extends from grey to black.
Clouds at sunrise and sunset: dark-red - orange-pink

Such clouds can almost always be observed during sunrise or sunset. Their color is the result of scattering of sunlight by the atmosphere where the short-wavelength blue light is scattered most strongly. The clouds then reflect the remaining light which contains mainly the long-wavelength red light.

Electrical structure of thunderstorm clouds

- Upper part: positive charge range, which can extend up to the anvil.
- Negative charge range in the lower part of the cloud.
- Small positive charge layer close to the base of the cloud which is generated by precipitations.

The detailed mechanism of the charge formation and of the charge separation is not clarified until now.
Threatening Thunderstorm Cloud
4.3 Water drops and Precipitations

Shape of a raindrop in a wind channel

Only very small raindrops with diameters smaller than about 140 μm will be perfect spheres due to their high surface tension. Larger drops tend to be flattened, leading to oblate shapes.

If larger raindrops begin to fall they are also spherical in shape. But then they quickly become shaped more like hamburger buns – flattened base and rounded top. The distortion is caused by the air flow which pushes against the lower drop surface and thus flattens its base as it falls.

The hamburger-bun shape shown in the Figure is based on the observation of single drops in a steady flow, particular in heavy rains. In fact, as rain falls, the drops have many different sizes.

Speed of fall:
- d = 0.5 mm: 7 km/h
- d = 1 mm: 14 km/h
- d = 3 mm: 29 km/h
- d = 8 mm: 43 km/h

Simulation of shape of a large falling raindrop
Shapes of vertically falling Water drops of different sizes

Falling water drops of different sizes (d in mm)

The white arrows indicate the directions of the air streaming around the falling drop.

Bergeron – Findeisen: Formation and Morphology of Snowflakes

Left: Snowflakes are formed if water vapour molecules from supercooled water droplets condense directly to ice leading to the growth of an agglomeration of ice crystallites. Right: The hexagonal symmetry of a snowflake derives ultimately from the hexagonal symmetry of ice Ih, which in turn is related to the hexagonal symmetry of H₂O-clusteres (pp 41, 43, 50, 52). Several factors are responsible for the form of snowflakes such as temperature, relative humidity and air currents. The "Water saturation" curve corresponds to the difference between the saturation vapour pressure of supercooled water droplets and snow crystals (s. Appendix 4_A_3_1).
The fascination of snowflakes

Snowflakes always possess a hexagonal form; this is due to the hexagonal symmetry of the crystal structure of ice.

According to Bentley (1880), who collected and studied snowflakes during 40 years, all of them were different!!

All snowflakes have hexagonal symmetry, but the details of their building units are all different!
Zeus has struck a terrible blow!!

**electrical voltage:** some 100 million Volts!
**electrical currents:** several 100,000 Ampère!
**maximun air temperature:** up to 30,000 °C!
**local air pressure:** up to 100 atmospheres!
**explosion of air:** thunder!

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**Hail**

**Formation:** Hailstones are formed in the inner layers of the lightning where supercooled water transforms into ice with the help of crystallizing nuclei.

**The cycle of ice grains:** They are first lifted upwards by the upwind, then they fall back to lower air layers, take up more additional water, rise up again to higher levels whereby additional water is frozen at the surfaces.

This process is repeated several times up to the point where a hailstone is too heavy to be carried by the upwind.

**Fall velocity:** normally, the diameter $d$ of hailstones are about 0.6 to 3 cm. For $d = 3$ cm, the fall velocity is about 90 km/h.

Exceptions: diameters up to 10 cm with weights of more than 1 kg and fall velocities of more than 150 km/h have been observed!!
Hailstones after a Hailstorm

After a hailstorm

Picture of one of the largest hailstones: diameter about 10 cm, weight about 154 g.
The hailstorm is compared with the size of a 9 Volt accumulator.

Cross section through a hailstone

The rings have been produced by the different depositions of layers during the complex vertical growth of the hailstone.
Lymnology is the study of inland waters. It is often regarded as a division of ecology or environmental science. It covers the biological, chemical, physical, geological, and other attributes of all inland waters (running and standing waters, both fresh and saline, natural or man-made). This includes the study of lakes and ponds, rivers, springs, streams, and wetlands.

Lymnology is closely related to aquatic ecology and hydrobiology, which study aquatic organisms in particular regard to their hydrological environment.

Density anomaly of water and implications for lakes

The lighter ice is swimming on the water

Ice: good thermal insulation ➔ further freezing of the water below the ice is prevented.

➔ Biological system can survive in water!

The interface ice/water is at 0 °C

The most dense water at 4 °C is located at the ground of the lake.
The surface of ice is “wet”!

Ice: only the O- atoms are shown. O- atoms form an ordered lattice structure.

Air

Water-like surface film (~ 2 nm)

Structurally disordered O- atoms

Ice: only the O- atoms are shown

O- atoms form an ordered lattice structure

A glass filled with Ice - Water

Unstired ice – water in a glass of water: at the bottom of the glass the temperature is approximately 4 °C.
The depth–dependence of the density is essentially due to the depth–dependence of temperature. The latter is small in winter (between 0°C and 4°C) but large in summer (between about 25°C and 4°C) as is also shown explicitly at page 188.

Since the compressibility of water is very small, its influence on density is negligible, even in deep oceans.

D. M. Imboden and A. Wüest: “Environmental Physics” (Eawag)
The deep blue colour of the Crater Lake is due to its large depth (597 m), the clarity and high purity of water, as well as to the selective absorption of sunlight: red, orange, yellow and green light are absorbed more strongly than blue light. Blue light is scattered in water more strongly and a part of this scattered light returns back to the surface where it can be observed.

In pure and deep lakes and seas, the red, orange, yellow and green colours contained in the light of the sun are more strongly absorbed than the blue colour. The depth of penetration of blue light is therefore larger than that of the other colours. In addition, it is scattered more strongly by the water molecules and partly returns to the surface of the water where it can be observed.
Groundwater

Groundwater is our most important source of drinking water!

The groundwater is part of the water cycle (s. Chapter 1, p. 20). It is water located beneath the ground surface in soil pore spaces and in fractures of rock formations; its flow is mainly due to gravitational forces and frictional forces. The body of rocks in which groundwater is present and in which it is flowing is known as an aquifer.

The water table is the upper level of the underground surface in which soil or rocks are permanently saturated with water.

Nearly all of the groundwater comes from surface precipitation which soaks into the ground. Groundwater is naturally replenished by surface water from precipitation, streams, and rivers when this recharge reaches the water table.

An artesian well is a spring water in the hollow of a valley, in which the groundwater is subjected to a certain pressure. This pressure is sufficiently high that the water reaches (without the need for pumping) the surface of the earth or even higher. An artesian well is artificial, i.e. it is produced by boring a hole.
Water in Life before Birth

Fetus in amniotic fluid

The amniotic fluid is a clear, slightly yellowish liquid that surrounds the unborn baby (fetus) during pregnancy.
It is contained in the amniotic sac.

The amniotic fluid contains 98 – 99 % water !!

The embryo contains more than 85 % water !
Water is contained in all body fluids such as sweat, urine, tears and blood.

The main functions of water in the body are: as a transport and solvent medium, as a cooling and heating medium, and as a chemical reaction partner.

Compare also with the Figure of p. 195.

In this Figure the water content of the baby is somewhat smaller than that in the Figure of p. 194, which is probably more realistic. The two symbols (*) indicate, however, that the values shown here are also approximate figures.

Note that the content of fat is strongly increasing with increasing age!
Water content in human body - 1

“A handful of salts and proteins dissolved in water!”

Body mass 70 kg ➔ 50 kg water ➔ ca. 72 % water

<table>
<thead>
<tr>
<th>Organ or tissue</th>
<th>% Water content</th>
</tr>
</thead>
<tbody>
<tr>
<td>teeth (without hair!)</td>
<td>10</td>
</tr>
<tr>
<td>skeleton</td>
<td>22</td>
</tr>
<tr>
<td>blood</td>
<td>69</td>
</tr>
<tr>
<td>liver, spinal cord</td>
<td>70</td>
</tr>
<tr>
<td>skin</td>
<td>72</td>
</tr>
<tr>
<td>brain</td>
<td>75</td>
</tr>
<tr>
<td>lung</td>
<td>79</td>
</tr>
<tr>
<td>kidney</td>
<td>83</td>
</tr>
<tr>
<td>vitreous body of the eye</td>
<td>99</td>
</tr>
</tbody>
</table>

Compare with the Table on p. 197

Water content in human body - 2

<table>
<thead>
<tr>
<th>tissue</th>
<th>water content (%)</th>
<th>percentage of body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>blood</td>
<td>83</td>
<td>7.5</td>
</tr>
<tr>
<td>kidneys</td>
<td>83</td>
<td>0.5</td>
</tr>
<tr>
<td>heart</td>
<td>79</td>
<td>0.5</td>
</tr>
<tr>
<td>muscular system</td>
<td>76</td>
<td>41</td>
</tr>
<tr>
<td>brain</td>
<td>75</td>
<td>2</td>
</tr>
<tr>
<td>skin</td>
<td>72</td>
<td>18</td>
</tr>
<tr>
<td>liver</td>
<td>68</td>
<td>2</td>
</tr>
<tr>
<td>skeleton</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>fat tissue</td>
<td>10 – 30</td>
<td>12.5</td>
</tr>
</tbody>
</table>

197

4 – 20
Starting from the hydronium ion, $\text{H}_3\text{O}^+$ (marked light blue) at the left, a proton jumps to the next $\text{H}_2\text{O}^-$ molecule, and this hopping mechanism repeats continuously.

Although in each elementary jump the individual protons are displaced by only about 0.7 Ångström, the $\text{H}_3\text{O}^+$ ion propagates with high speed to the right and finally arrives at the position of the right side (marked light blue).

This process is important for nervous conduction!

The Code of Life is the DNA:
It is the carrier of genetic information

side rails of the spiral staircase

rungs of spiral staircas

rungs: consist of base pairs, which are linked together via hydrogen bonds:

\[
\begin{align*}
\text{N} & \quad \text{H} \quad \text{----} \quad \text{O} \\
\text{or} & \quad \text{N} \quad \text{H} \quad \text{----} \quad \text{N}
\end{align*}
\]

schematic structure of the DNA double helix

side rails: consist of a very large number of alternate units of sugar—(deoxyribose) and phosphates.

schematic structure of the DNA double helix

34 Å = 3.4 nm

3.4 Å

10 Å
DNA: Structure and Hydrogen Bonds - 1

Space-filling model of DNA, the nucleic acid that stores genetic information.

DNA unfolded: the side rails consist on phosphate groups, $\text{PO}_4^{2-}$, and of sugar (Desoxyribose). The two side rails are linked by hydrogen bonds, namely by $\text{N-H}----\text{O}$ ( ) and by $\text{N-H}----\text{N}$ ( ). (s. symbols in the Figure above). Each H-bond links two bases, i.e. ($\text{C}: \text{Cytosine} ; \text{G}: \text{Guanine}$) ($\text{T}: \text{Thymine} ; \text{A}: \text{Adenine}$) (s. p. 4-A-5-1).

DNA: Structure and Hydrogen – Bonds - 2

A side rail of DNA

O–H----O hydrogen bonding

The negatively charged phosphate groups are mutually screened by water molecules, thereby reducing strongly their Coulomb repulsion.

Water must be considered without doubt as an integral component of biological molecules such as the DNA. Example: water is a stabilizer of the DNA molecule, e.g. by reduction of the Coulomb repulsions between phosphate groups.
Water and Photosynthesis

From carbon dioxide (CO₂) and Water (H₂O) together with light and the action of the green pigment chlorophyll, the products sugar (glucose) and oxygen are formed (O₂).

\[ 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \]

Note: Chlorophyll is contained in the chloroplast (s.p. 218)
4.6 The Ascent of Water in tall and very tall Trees

Remarks:
In general, several mechanisms for the ascent of sap in plants and trees are responsible or have been proposed:

1) Capillary forces (p. 209)
2) Root pressure and Osmosis (pp 210 – 212)
3) Cohesion–Tension Theory and Transpiration (pp 214 - 216)

For the ascent of sap in tall and very tall trees, the third mechanism is dominant and is closely coupled with „capillarity“ in the Mesophyll - cells of the leaves (p. 217 - 219)

For experimental verification of tensile stresses as a function of tree – height in Coast – Redwood trees s. p. 216.

Ascent of sap in tall and very tall trees

How does water ascent tall trees against gravitational forces to heights between 100 and 120 m in Mammoth - or Redwood trees?

Remark:
During a hot summer day, a typical beech tree evaporates more than 600 liters of water per day!

Question:
→ What is the main mechanism for water transport in tall trees?
• Capillarity?
• Root Pressure / Osmosis?
• Root Pressure / Guttation?
• Transpiration – Cohesion?
• A combination?

The „Giant Eucalyptus tree“ is one of the tallest leaf trees (70 – 100 m)!

A giant Coast Redwood tree with a height of 115 m!
Anatomy of a tree trunk

Sap transport in Xylem and Phloem conduits

1) Roots absorb water and dissolved minerals from soil
2) Water and mineral salts are translocated upward from roots to shoots in Xylem
3) Transpiration of water from the leaves due to sunshine creates a tension force that pulls water upward in Xylem conduits
4) Gas exchange \((\text{CO}_2 \text{ and } \text{O}_2)\) occurs through the stomata of the leaves
5) Sugar is produced in the leaves by photosynthesis
6) Sugar is transported to other parts of the plant in the Phloem

There are three levels of transport in plants:

- **a)** The individual cell levels (membrane transport)
  - Uptake and export of materials in root cells
- **b)** Short distance - cell to cell through mesophyll
  - Sugar loading from mesophyll to phloem
- **c)** Long distance transport - tissue to tissue or organ to organ
  - Xylem and Phloem
The xylem transports water and mineral salts from the roots to the leaves, and the phloem transports sugars and other products of photosynthesis from the leaves to the roots. These photosynthetic products are in solution, the water having come from the xylem. At the root end of the system sugars are removed by the cells for use in metabolic processes, and water flows out by osmosis into the intercellular spaces. Some of the water which flows out of the roots is taken up by the xylem and is transported up to the leaves again where it may be used in photosynthesis, lost by evaporation through the stomata or drawn into the phloem again whence it may return to the roots. So, although there are two distinct transport systems, xylem and phloem, it is possible for water to be transported between leaves and roots in a closed loop, travelling up in xylem and down in the phloem. Plants therefore, may be said to have a circular system (Münch – model: s. also p. 4-A-6-1 and References R.4.6.17, R.4.6.18).
Capillary forces are able to rise water to a certain height $h$

$h = 2 \sigma \cos(\theta) / (\rho r g)$

Example:
for $r = 10 \, \mu m$
$\Rightarrow h \sim 1.5 \, m$ for water with completely wettable capillaries ($\theta = 0$)

Important Note:
The spongy mesophyll tissues in the leaves between the water-air interfaces have radii of about $r = 5$ to $10 \, nm$ and are highly wettable; they act as very efficient capillaries with effective (or nominal) heights $h$ of up to $3 \, km$ (!) for $r = 5 \, nm$ and are very important for water ascent of sap in tall trees (s. pp 218 - 219).

Root pressure

$H \sim \rho_{osm}$:
$\rho_{osm}$ ca. 1 - 3 bar
$\Rightarrow H \sim 10 \, m - 30 \, m$

solution 2:
concentration $c_2 > c_1$

C$_2$ > C$_1$ → more water is flowing from outside to inside than the other way around.
$\Rightarrow$ solution is deluted
$\Rightarrow$ total pressure: $p \sim (c_2 - c_1)$
Osmosis and Turgor in plant cells and roots

Osmotic pressure is the main cause of support in many plants. The osmotic entry of water raises the turgor pressure exerted against the cell wall, until it equals the osmotic pressure, creating a steady state.

Suppose a plant cell is placed in an external medium of sugar or salt in water.

- If the medium is hypotonic—a dilute solution, with a higher water concentration—than the cell (right-hand picture below) will gain water through osmosis.
- If the medium is hypertonic—a concentrated solution, with a lower water concentration—than the cell (left-hand picture) will lose water by osmosis.
- If the medium is isotonic—a solution with exactly the same water concentration as the cell (central picture), there will be no net movement of water across the cell membrane.

Root pressure and Guttation

The root pressure is an osmotic pressure within the cells of a root system that causes sap to rise through stem to the leaves. It occurs in the xylem vessels of some vascular plants when the soil moisture is high either at night or when transpiration is low during the day. When transpiration is high, xylem sap is usually under tension, rather than under pressure, due to transpiration pull (pp. 214 - 215).

Root pressure provides a force, which pushes water up the stem, but it is not enough to account for the movement of water to leaves at the top of the tallest trees. The maximum root pressure measured in some plants can raise water only to about 20 meters, but the tallest trees are over 100 meters!

At night, transpiration usually does not occur because plants have their stomata closed. When there is a high soil moisture level, water will enter plant roots, because the water potential of the roots is lower than in the soil solution. The water will accumulate in the plant, creating a slight root pressure. The root pressure forces some water to exude through special leaf tip or edge structures, hydathodes (special stomata), forming drops (Guttation). Root pressure provides the impetus for this flow, rather than transpiration pull.
Tracheids of a Douglas fir (side view) showing bordered pits in the walls. Water is transported from one tracheid to other tracheids through bordered pits. (The tracheid’s bordered pits allow for the rapid movement of water from one tracheid to other tracheids).

Scanning electron micrograph of a cross section of tracheids of an untreated Douglas fir (top view) showing nearly destroyed latewood below and apparently intact earlywood above (175 x).

Evaporation at the yew branch:

- Due to the transpiration suction, the Hg column can rise above 760 mm and hence a water column can rise above 10.24 m, → tensile stress > 1 atm.

1 atm corresponds to 760 Torr = 760 mm Hg; this corresponds to the pressure of a water column of 10.37 m; 1 bar corresponds to a water column of 10.24 m.
The Cohesion–Tension Theory (CTT) for the ascent of sap in tall trees

In the following we quote some statements of the ascent of sap in tall and very tall trees which are based on the Cohesion–Tension Theory (CTT) (References R.4.6.1 – R.4.6.5, R.4.6.25, R.4.6.26). Although CTT is not able to explain all the phenomena completely, it is considered today by most plant physiologists as the most satisfactory theory.

During most of the vegetation period, water is pulled up into the trees and the pressure in the Xylem conduits is lower than that of the atmosphere. Under the right circumstances, when the xylem is cut, one can even here the hissing sound of air being drawn into the injured vessels”.

The „motor“ of sap ascent must be in the crown of the tree. This motor is powered, of course, by sunlight which provides the energy for the evaporation of water, i.e., the energy to break the hydrogen bonds in liquid water. About 99% of the vapor is evaporated into the air and the rest is engaged in photosynthesis.

Through the cell membranes of the tiny stomata, or pores, on the surface of the leaves, the water is transpired a molecule at a time: the molecules that escape into the air are replaced by molecules pulled up from below by surface tension forces. The water xylem-columns are continuous, all the way from the rootlets to the nanometer interstices between the mesophyll cells in the leaves (s., pp 218, 219). They do not, therefore, depend on the pressure of the atmosphere for support but are held up by cohesion forces within the water itself and adhesion between the water and the cell walls.

Summarizing, we can state that in a narrow and airtight tube, water can reach heights much higher than 10 m, in trees higher than 100 m. To this case the pressure reaches very large and negative values (a negative pressure of -10 atm for a 100 m high tree), i.e., it is subjected to very large tensile stresses (see also p. 122). If the tensile stress becomes too high, the water column in the xylem conduits of the tree ruptures, giving rise to air bubbles and embolism! Part of the air bubbles are healed out by specific repair mechanisms (see p. 222 and References R.4.6.3 and R.4.6.26).

Tree – height versus (negative) Xylem pressure at the top of trees

Height profiles of Xylem versus (negative) pressure (tension) in very tall trees at midday (filled symbols) and at predawn (open symbols) during the dry season for three coast Redwood trees [1 MPa = 10 bar = 9.87 atm]. The experiments shown in this Figure are consistent with the Cohesion–Tension–Theory (CTT) (pp 214, 215).
Leaf surfaces and leaf veins

Adaxial and abaxial leaf surfaces:
left: adaxial leaf surface: the side facing against the shoot axis (= direction of growth; upper side of the leaf).
right: abaxial surface: the side facing away from the shoot axis (underside of the leaf; this side is drying out less rapidly).

- It contains the veins (the xylem and phloem conduits for sap transport) and provides mechanical stability of the leaf.
- This surface also contains the stomata for water vapour transport into the atmosphere.

Leaf veins at underside of the leaf:
The "veins" in leaves are primary vascular bundles. They transport water and photo–synthates via primary xylem and primary phloem (s. pp 208 and 218).

The primary vein is located in the center of the leaf and is termed the midrip. From this vein branch the secondary veins, and from these veins the tertiary veins.

Tensile stresses and ascent of sap due to capillary forces between mesophyll - cells and subsequent evaporation through the stomata

In tall trees, the relevant capillary dimensions are not those of the relatively large Xylem conduits (pp 213, 214). Rather, the appropriate dimensions are determined by the water – air interstices between the highly wettable mesophyll – walls. The dimensions of these interstices correspond to radii ranging between 5 to 10 nm:

[Chlorophyll is contained in the Chloroplasts [s. p. 202]]

- Water from Xylem in the leaves enters into the mesophyll cells.
- It then penetrates the cell walls into interstitial spaces where it forms very thin films at the walls as well as filled capillaries with "radii" between 5 and 10 nm.
- The thin films and the minisci of the capillaries evaporate and are continuously refilled from the Xylem conduits.
- The water vapor leaves the interstices through the stomata.
- Thus, the water transport in tall trees is due to CTT (p. 215), the driving force of which is mainly due to capillarity in the very tiny interstices between the mesophyll cells followed by the sun–driven evaporation through the stomata.
Vascular tissue in the leaf

The vascular tissue in a leaf contains the xylem and the phloem which are often protected by an epidermis, known as a bundle sheath or bundle cell (p. 218). The vascular tissues are located between the palisade mesophyll cells and the spongy mesophyll cells. The xylem is oriented toward the upper leaf surface (upper epidermis), whereas the phloem is oriented toward the lower epidermis (p. 218).

The bundle sheath controls the mass exchange between the vascular tissue (xylem and phloem) and the mesophyll. The vascular tissues form a dead end within the mesophyll. Thereby, the vascular tissue is more and more reduced until the sieve tubes are fading away; in the xylem, only spiral tracheids are left over which eventually also form dead ends. This allows an exchange between xylem and phloem, i.e. water is flowing from xylem to phloem. A corresponding exchange is also possible within the roots. In this way a closed circle between xylem and phloem is established (p. 208); this is known as the Münch-model.

As a rule, the entire leaf is filled out so densely with vascular tissues such that no leaf cell is more distant away from a vascular tissue than seven cells. The resulting small regions between the vascular tissue are called „open areas“ or intercoastial fields.

The function of vascular tissues consists in the transport of water and minerals within the leaf via the xylem, and the transport of products of photosynthesis via the phloem out of the leaf.

Transpiration – Cohesion: Water is under stress!

Water is boiling if the external pressure \( P_{\text{ext}} \) is equal to or smaller than the vapor pressure of water, \( P_w \).

Examples:
- \( P_w = P_{\text{ext}} = 1 \text{ bar} \Rightarrow T_{\text{boiling}} = 100 ^\circ C \)
- \( P_w = 0.0317 \text{ bar} \); if \( P_{\text{ext}} \leq P_w \), water is boiling at or below \( T_{\text{boiling}} = 25 ^\circ C \)

Vacuum pump:

At very small pressures, water is usually boiling, and this holds especially for water at negative pressures, i.e. under tension (s. p. 122).

In trees, however, water is not boiling although it is under tension! How can this be explained?

- Water is enclosed and in the superheated state!
- No room for vapor!
- Water is in a metastable state!

Inside the conduits of trees, there are several mechanisms which suppress the formation of bubbles i.e. the formation of embolism! In this way the superheated state can be stabilized to a large extent!
Vulnerability of Xylem to cavitation and embolism; Repair mechanisms

• Plants open and close their stomata during daytime in response to changing conditions, such as light intensity, humidity, and CO₂ concentration.

• A cavitation event causes a rapid relaxation of a liquid tension that produces an acoustic emission in the audio-frequency and ultrasonic range.

• The walls of xylem conduits are extremely hydrophobic, decreasing the likelihood of cavitation at the wall–water interface.

• 2 neighboring tracheids are connected: in case of air infiltration into one of the tracheids, the second tracheid is closed by a membrane; in this way, the second tracheid can continue to work.

• Cavitation is important biologically because embolized conduits reduce the hydraulic conductivity of the Xylem.

There is considerable evidence that water-stress induced embolism occurs by air seeding at pores in the intervessel pit membranes.

• Air within the bubbles can be dissolved by diffusion into the water contained in the Xylem capillaries.

• There is evidence that the growth of small air bubbles is partially hindered by an energy barrier.
4.7 Water plants

Plant zones at a shallow lakeshore

With increasing depth of water in the lake, the intensity of light for photosynthesis decreases rapidly. This gives rise to a zoning of the plant population at the shore, such that the most light-hungry plants are growing at the shallowest waters, whereas deeper below the surface, more modest species are found. Therefore, at a natural flat sea or at a pondside, the above illustrated plant zoning is usually found.

General remarks and properties

In our lakes most of the higher plants belong to the pondweed and have nothing to do with „seawood“ or algae.

In contrast to terrestrial plants, water plants do not possess a rigid supporting tissue. If they are removed from water they are flabby. In water, however, they are standing upright and are following the water movement flexibly without braking. Their stems are very tenacious and elastic. In contrast to land plants, water plants do not need an evaporation protection; their leaves are therefore very soft and tenuous. This allows for a direct uptake of nutrients from water through the leaves.

The roots function in the first place as ground anchors to the bottom of the pond.

According to the Figure at p. 223, the following species of water plants exist:

- a) Reed bed plants
- b) Floating leaf plants
- c) Pondweed plants
- d) Plants which are completely submerged under the surface of the water
a) Reed beds

Reed beds constitute a subgroup of march plants. They are located at river banks and penetrate the water up to a depth of about 1.5 m. With the help of their strong rhizomes (*) they are able to form dense reed beds. An important example is the reed (Schilfrohr).

b) Floating leaf plants

The floating leaf plants such as the „Water lily“ and the „Lotus flower“ (s. p. 226, 227), are of particular interest because their roots anchor at the bottom of the pond while there leaves are swimming at the surface of water. The leaves have hollow air cells which are important for two reasons: firstly, the leaves are swimming at the surface of the water, and secondly, the air is conducted through the hollow petioles (Stängel) down into the roots such that they do not suffocate in the oxygen-deficient mud. In contrast to terrestrial plants, the stomata necessary for respiration are located at the upper surface of the leaves; this is in contrast to terrestrial plants (p. 218). In addition, the leaves have wide-mashed air passages in the tissue; the breathing air collected by the stomata is then transported through the petiole (leaf stalk = Blattstiel) to the rhizome (Rhizome: Root-like underground horizontal stem of plants that produce shoots (Triebe) above and roots below).

Nymphaea alba, a species of water lily

Blue water lily

Air channels in the petiole (leaf stalk = Blattstiel)

The leaves of a normal water lily is wetted completely by water (hydrophilic) and the stomata are located at the upper side of the leaves.
Lotus flower

Lotus leaves in rain: On the top of the Lotus leaves, raindrops are formed, i.e. the upper leave surfaces are hydrophobic (water-repellent). On the other hand, the leaves of the water lily are completely wetted, i.e. they are hydrophilic or water-attracting.

Pondweed

The pondweed zone has a depth of 2 – 5 m. The leaves of this plants are growing under water, only the blossoms extend over the surface of the water. Within the dense populations of pondweeds, swarms of juvenile fishes, all possible species of invertebrates and lurking pikes can be observed during summer time.

On the leaves of pondweeds one finds many snails, insects, grubs, hydra, and water-mites. Some fish species use to deposit their spawn on the surface of these pondweeds.

Blooming alpine pondweed: Some inflorescences (Blütenstände) have already penetrated the water surface.
Completely submerged water plants

These plants are blooming under water. Normally, no part of the plant ever reaches the water surface.

The leaves of the naiad (Nixen-kraut) are dark green, hard and jagged. In late summer the leaf axil contain nutty seeds with diameters of 2–3 mm.

Muskgrass Chara (Armleuchteralgen):
The appearance of this plant resembles strongly to a flowering plant, although it is an algae. The luster-like branching and the rough, brittle nature of the plant which is due to the incorporation of silicic acid (Kieselsäure) is typical for the muskgrass chara.

These plants are blooming under water. Normally, no part of the plant ever reaches the water surface.

Plankton

Plankton is the name for organisms which live in water and the key feature of which is the fact that their swimming direction depends on the flow of water. Plankton exist in all possible forms and sizes. Very small organisms (4–40 μm) are assigned to the nanoplanckton. The smallest plankton are bacteriums. Phytoplankton are usually smaller than the diameter of a human hair. Zooplankton exist in tiny forms but also in the form of very tall jellyfishes (Quallen) with sizes up to 9 m! Plankton do not swim actively but are rather drifting passively in the direction of the water current. The following species of plankton exist:

• Bacterioplankton
• Phytoplankton (plant plankton), such as diatom (Kieselalgen) and green algae
• Zooplankton (animal plankton)

Phytoplankton

Single-celled diatom (Kieselalgen) constitute the bulk of the phytoplankton. The cells are surrounded by a two-part shell of silicic acid. Today, about 6’000 different species are known. A characteristic feature of diatom cells is that they are encased within a unique cell-wall made of silica (hydrated silicon oxide, SiO₂•n H₂O), called a (glassy) frustule. Theses frustules show a wide diversity in form, but usually consist of two asymmetrically sides with a split between them, hence the name „diatom” (see Figure at the right). The phytoplankton is also known as the primary production of the sea, because it represents the basic food resource for all other living beings in the sea. Without the phytoplankton, no life would exist in the sea! In waters having a green shimmer, a relatively large concentration of phytoplankton exists. A large Figure of Phytoplanktons is shown in the Appendix at p. 4_A_7_1.
Clouds: Fall streaks of ice particles or Virga

Translated literally from Latin, Virga means as much as "twig" or "stick". In meteorology it signifies precipitations (ice crystals or rain) which originate from the base of the clouds but which evaporate before reaching the ground. Fall streaks or Virga are often observed if a very humid air layer at high altitudes is present over a dry layer below.

[It should be mentioned that for fair weather clouds as shown at p. 164, small snow crystals can exist in the upper region of the clouds].

Appendix: Chapter 4
Saturation vapour pressures of supercooled water droplets and snow crystallites in clouds (Bergeron process)

The saturation vapour pressure of ice particles is lower than the saturation vapour pressure of water droplets. Water vapor interacting with a water droplet may be saturated, but the same amount of water vapor would be supersaturated when interacting with an ice particle. The water vapor will attempt to return to equilibrium, so the extra water vapor will condense into ice on the surface of the particle. These ice particles end up as the nuclei of larger ice crystals. This process only happens between 0 °C and about -40 °C. Below about -50 °C, liquid water will spontaneously nucleate and freeze. The corresponding curves for bulk ice and bulk supercooled water are shown in the Appendix 2-A-8-1.

The Leidenfrost effect, also known as Leidenfrost phenomenon, is the effect of a water drop dancing on a hot base plate. This effect has been described for the first time by Gottlob Leidenfrost (1715 – 1794) in 1756.

If the base plate is essentially hotter than the boiling point of water, only the lower layer of the drop evaporates, while the upper part of the drop is still colder. In this way, a thin layer of water vapor is formed (0.1 bis 0.2 mm), which lifts the drop and protects him from evaporating. Gases, in this case the water vapor, is a poor thermal conductor. On the top of this cushion of steam, the water drop is gliding back and forth. The Figure at the right hand side illustrates that the lifetime of a water drop between 100 and 200 °C is very small and then strongly increases. At the so-called Leidenfrost point, somewhat higher than 200 °C, the lifetime of the drop reaches its maximum, in the present case at about 72 seconds.
The A–T (Adenine–Thymine) and G–C (Guanine–Cytosine) pairs of the DNA fit exactly to form very effective hydrogen bonds with each other. It is these hydrogen bonds (N–H----O and N–H----N) which hold the two chains together (s. p. 200).

Hydraulic coupling between Xylem and Phloem

s. also p. 208
Aquaporins: Water channels in roots and leaves

In the Xylem – conduits the long-distance transport of water from the roots up into the leaves takes place (s. pp 206, 207). On the other hand, a short-distance transport exists both, in the roots as well as in the leaves between neighbouring cells. For the transport of water between the cells, so-called Aquaporins are responsible; Aquaporins are water pores between adjacent cells. The Aquaporins are neither pumps nor exchanger and for this transport no energy is required. The transport of water is rather established by osmotic gradients. The channel is working bidirectional, i.e. water can propagate in both directions through the channel. Aquaporins are of great importance in tissues, in which a large physiological current exists, i.e. by the establishment of the turgor pressure (p. 211) or in the kidneys.

Schematic cross section in leaves with representations of the tissue-specific expression patterns of aquaporins and paths of transport are shown. (see also p. 216).

Aquaporins = Water + Pores

The Aquaporins PIP1s (Plasma membrane Intrinsic Proteins) are regulating the water conduction through the cells.

The Aquaporins TIP1s (Tonoplast Intrinsic Proteins) regulate the volume increase of the cell by absorption of water.

Deciduous leaves

Photosynthesis takes place within the green chloroplasts – small corpuscles in the interior of the mesophyll cells (s. also p. 218). The chloroplasts contain the chlorophyll. Chlorophyll, CO₂ and water are engaged in photosynthesis (s. p. 202).

During summer, chlorophyll absorbs sunlight selectively (in the blue and red spectral range), whereas green light is not absorbed but rather scattered; this is the reason for the green colour of the leaves.

If in autumn the days are getting shorter and colder, chlorophyll is deactivated and loses its colour. At this time the yellow and orange-colored carotenoids which have always been present in the leaf become active. The yellow carotine or the red anthocyanin are now producing the radiant beautiful colors of autumn.
Evergreen plants

In botany, an evergreen plant is a plant that has leaves in all seasons. For these trees, the individual leaf exists at least 12 months. Evergreens will grow in almost all parts of the globe that will support vegetation. They have largely solved the problem of excessive water loss through their leaves caused by extremes of temperature. Thus, evergreens such as conifers are comfortably at home as far north as the tundra, while all tropical forests have rich quota of huge evergreens with waxy leaves. In temperature climates too, evergreens such as holly and laurel abound.

Plants lose water through their leaves, and evergreen leaves commonly have one or more modifications to cut down the loss of water. Conifer leaves are thin and needle-shaped, exposing only a relatively small surface area to the atmosphere. Temperature and tropical evergreens have leaves with a thick waxy cuticle (covering) on their surfaces which help to keep water inside the plant. An example is the Cherry laurel shown below.

![Cherry laurel and Leaves of a cherry laurel](image)

Another mechanism of sap flow: the Maple tree

During summer, an average-sized maple tree loses more than 200 L of water per hour through the leaves; this water loss is due to osmosis and/or to cohesion–tension, i.e. sap is under negative pressure as discussed in the Cohesion-Tension Theory (CTT) at pp 214 - 219.

In winter and spring, however, the pressure of the sap of sugar maple is greater than the atmospheric pressure, causing the sap to flow out, much the same way as blood flows out of a cut. If one visualizes a portion of the tree trunk as being under positive pressure, a tap-hole drilled into the tree is like a leak so that sap moves toward the point of lowest pressure from all directions, i.e. towards the atmospheric pressure present at the outside of the tree.

A similar behaviour is observed for the birch tree.

![Maple tree in fall, Tapping a maple tree in winter or spring, Collecting sugar maple in winter or early spring](image)
Developing fruit of an apple tree

In tall fruit trees, the Cohesion – Tension – Theory (CTT) (s. p. 215) is still valid, but the fruits are additional sinks for phloem saps.

After sugars are produced in photosynthesis, these sugars must be transported to other parts of the plant for use in the plant’s metabolism. The sucrose is moved by active transport into the phloem of the phloem leaf veins. A developing fruit is one example of a sink. Sucrose may be actively transported out of phloem into the fruit cells. This raises the sugar concentration in the fruit. In response to this concentration difference, water will follow the sugar into the fruit by osmosis.

Phytoplankton: Art works of nature!

Diatoms are unicellular; the lengths of the cells are 30 – 500 micrometers.

Full Text see p. 230: „Plankton and Phytoplankton“

[Selection from Ernst Haeckel’s „Kunstformen der Natur“, (1904) or „Artforms of Nature“.]
4. Water in Nature

4.1 Some selected examples

Some examples concerning the central role of water in nature has already been mentioned in Section 1.2. In the following, the topics of some aspects are discussed and illustrated.

4.2 The world of clouds

R.4.2.1 A short Course in Cloud Physics
R.R. Rogers and M.K. You
Elsevier Science 1988
Oxford UK

R.4.2.2 Cloud Physics
A Popular Introduction to Applied Meteorology
Louis J. Battan
Dover Publications.com; Amazo.de

R.4.2.3 Water from Heaven
Robert Kandel
Columbia University Press, New York
Chapter 9: p. 135
R.4.2.4 DIE ERFINDUNG DER Wolken: „The invention of Clouds“
Richard Hambyn
Suhrkamp Taschenbuch 3527; Erste Auflage 2003

R.4.2.5 WOLKENGUCKEN
Gavin Pretor-Pinney
Heyne - Verlag, 2006

R.4.2.6 p. 163: Cloud Formation
From Internet: Cloud formation; Bilder. Csupomona.edu

R.4.2.7 p. 164: Droplets and Crystalites in Clouds
Figure prepared by P. Brüesch

R.4.2.8 p. 165: The World of Clouds
Cumulonimbus Clouds: bretaniongroupp.com

R.4.2.9 p. 166: Why do Clouds not fall from the Sky?
http://www.islandnet.com/~see/weather/elements/cloudfloat.html

R.4.2.10 p. 167: Colours of Clouds: white

R.4.2.11 p. 168: Colours of Clouds: blue-white
http://weathersavvy.com/cumulonimbus5_OPT.jpg

Regenwolken: foto.community.de

www.yunphoto.net/es/photobase/hr/hr545.html

www.sferics.physik.uni-muenchen.de/Messgrundl...

R.4.2.15 4-A-2-1: Clouds: Fall streaks or Virga:
http://meteo.sf.tv/sfmeteo/wwn.php?id=201108111

R.4.3.1 Precipitations

R.4.3.2 Clouds Rain, and angry Skies: Ref. R.4.2.3: Chapter 9; pp 135-154

R.4.3.3 About Precipitations and Rain Fall: Ref. R.1.3.12: „Les précipitations“: pp 32-38

R.4.3.4 p. 174: Fallender Wassertropfen im Windkanal
Source: Falling raindrop in the wind channel; jpg; Film und Standard: R. Jaenicke, IPA Universität Mainz, 2002

R.4.3.5 p. 175: Shapes of falling rain drops of different sizes
(Form von fallenden Wassertropfen verschiedener Grösse)

R.4.3.6 p. 176 – 182: Literature to Snowflakes and Hail :

R.4.3.7 p. 176: Formation and Morphology of snowcrystals
left: found under: Der Bergeron-Findeisen-Prozess-ethz.ch iacweb.ethz.ch/staff/eszter/...Bergeron-Findeisen.pdf
right: http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.html

R.4.3.8 p. 181: After a Hailstorm:
p. 181: A very large Hailstone (Ein sehr grosses Hagelkorn)
http://home.arcor.de/student/wetter/aktuell/bild2.html

R.4.3.9 p. 182: Cross section through a Hailstone showing grothw rings
Querschnitt durch ein Hagelkorn mit Wachstumsringen
www.fotocommunity.de/pc/pc/display/17206268

R.4.3.10 p. 4-A-3-1: Bergeron – Findeisen Prozess:
Saturation vapor pressure over water and ice
http://apollo.tsc.vsc.edu/classes/met130/notes/chapter7/eswgtesi.html
4.4 Limnology

- PHYSICS AND CHEMISTRY OF LAKES
  A. Leemann, D.M. Imboden, J.R. Gat

- HYDRODYNAMICS OF LAKES
  K. Hutter
  Springer (1983)

- LEHRBUCH DER LIMNOLOGIE
  W. Schönborn
  E. Schweizerbart'sche Verlagsbuchhandlung ( Nägeli u. Obermiller ) Stuttgart 2003

- EINFUEHRUNG IN DIE LIMNOLOGIE, 9. Auflage
  J. Schwoerbel und H. Brendelberger
  Spektrum Akademischer Verlag, Heidelberg 2005

- LYMNOLOGY, 3rd Edition
  R.G. Wetzel
  Academic Press, 2001; p. 188
  About "Black Smokers": Ueber „Schwarze Raucher"

- THE ECOLOGY OF DEEP–SEA HYDROTHERMAL VENTS
  Cindy L. Van Dover

- MICROBIOLOGY OF DEEP–SEA HYDROTHERMAL VENTS
  David M. Karl

Density anomalies of water and implications for freezing lakes and skiting
Density maximum: http://dc2.uni-bielefeld.de/dc2/wasser/w-stoff.htm

Reference R.3.1.1: pp 180, 181
Figure composed by P. Brüesch

Photograph courtesy of O. Mishi Published by H.E. Stanley in:
MRS Bulletin/Mai 1999, p. 2

In the Figure, the indications of the months in the temperature profiles have been added by P. Brüesch
4.5 Water and Biology

R.4.5.1 LIFE BEVORE BIRTH: The Challenge of Fetal Development
Peter W. Nethanielsz

R.4.5.2 AMNIOTIC FLUID DYNAMICS
Alberto Bacchi Modena and Stefania Fieni
Acta Bio Medica Ateneo Parmense 2004, 75; Suppl. 1: 11 – 13
(Conference Report)

R.4.5.3 p. 193: Life before Birth : www.aenvironment.com/Pictures/Fetus2.jpg

R.4.5.4 Figure at p. 194, 195: Dehydration of men with increasing age
from http://www.elmar-schuerr.de/Wasser_und_Salz.htm (adjusted by P. Brüesch)

R.4.5.5 pp 196 - 197: Water contents in human beeings: 1 and 2; from:
PHYSIOLOGIE DES WASSERS - UND ELEKTROYTHAUSHALTS
Dr. Sylvia Kaap
Fachhochschule Wiener Neustadt
Seminar Physiologie WS 2006 / 07

R.4.5.6 p. 198: About the Groththus – diffusion of proton mouvement in water

R.4.5.7 pp 199 – 201: DNA: Structure, Chemistry and H– Bonds
“The role of water in the structure and function of biological macromolecules”
contains 20 literature citations ; the conclusion of the article is the following:
“Both hydrophobic and hydrophilic effects are dominant driving forces for biochemical
processes: protein folding, nucleic acid stability and molecular recognition/binding events.
Water, without any doubt, must be considered an integral part of biological
macromolecules. For the Figures showing explicitly the N – H ---- O and N – H ---- N bonds in A-T and G-C
illustrated in the Appendix 4-A-5-1, see Reference:
http://www.chemguide.co.uk/organicprops/aminoacids/dna1.html

R.4.5.8 p. 202: Concerning the Photosynthesis
“Where does the water in the brutto reaction of photosynthesis com from?”
Rainer Eising und Stefan Höllzenbein
PDF/Adope Acrobat - HTML-Version
with 14 Literature citations.
4.6 Water ascent in tall trees

R.4.6.1 PLANT PHYSIOLOGY
Hans Mohr and Peter Schopfer
Berlin : Springer 1995

R.4.6.2 XYLEM STRUCTURE AND THE ASCENT OF SAP
M.T. Tyree and M.H. Zimmermann

R.4.6.3 The Cohesion-Tension theory of sap ascent: current controversies (Review Article)
M.T. Tyree

R.4.6.4 The Dynamics of an Evaporating Meniscus
R.H. Rand, Ithaca, New York

R.4.6.5 The limits of tree height
G.W. Koch, S.C. Sillett, G.M. Jennings, and S.D. Davis
The tallest known tree on Earth is a Sequoia sempervirens in wet temperature forests of northern California having a height of 112.7 meters. It is estimated that the maximum tree height is 122 – 130 meters (see p. 184 in this work)

R.4.6.6 Water ascent in plants: Do ongoing controversies have a sound basis?
Chunfang Wie, Ernst Steudle and M.T. Tyree
Trends in Plant sciences Vol. 4, No. 9, pp 372 – 375 ; September 1998

R.4.6.7 Water ascent in tall trees:
Does evolution of land plants rely on a highly unstable state?
Ulrich Zimmermann, Heike Schneider, Lars H. Wegner, and Axel Haase

R.4.6.8 M. J. Canny : A New Theory for the Ascent of Sap - Cohesion Supported by Tissue Pressure

R.4.6.9 Ascent of sap in plants by means of electrical double layers
M. Amin
Journal of Biological Physics
Volume 10, Number 2, / June 1982 , pp 103 - 109

R.4.6.10 W. Nultsch
Allgemeine Botanik
Georg Thieme Verlag , Stuttgart (1964) , pp 163 – 164

R.4.6.11 METASTABLE LIQUIDS : Concepts and Principles
Pablo G. Debenedetti

R.4.6.12 LEHRBUCH DER BOTANIK
Neubearbeitet von: R. Harder; F. Fritsas, W. Schuhmacher und D. Von Derfifer Gustav Fischer Verlag, Stuttgart (1962), pp 188 - 205 , s. speziell p. 204

R.4.6.13 p. 204 : left: A giant Eucalyptus tree
Eucalyptus Wikipedia, the free encyclopedia
en.wikipedia.org/wiki/Eucalyptus
right: A "Coast Redwood" tree : s. Internet – Bilder : Coast Redwood tree

http://bio1151.nicerweb.com/locked/media/ch35/35_20TreeTrunkAnatomy.jpg

R.4.6.15 p. 206 : Sap transport in Xylem and Phloem conduits
[PDF] Chapter 36. Transport in Plants
www.holmodel.k12.nj.usl/.../plant%20transport.pdf

R.4.6.16 p. 207 : Upward sap transport in plants
http://plantcellbiology.masters.grkraj.org/html/Plant_Cellular_Physiology5-Translocation_OF_Wat...
Figure slightly changed and explaining text added by P. Brüesch

R-4-8

R-4-9

4 – 48
R.4.6.17 p. 208: Xylem and Phloem arranged in vascular plants
Figure left: www.fairchildgarden.org/%7e/Anatomy%20and%20Physiology%20of%20Plants.pdf
Figure right: E. Münch: Die Saftbewegungen in der Pflanze; Gustav Fischer, Jena (1930): and: Journal of Experimental Botany, Vol. 57, No. 4, pp 729 – 737, 2006


R.4.6.19 p. 209: Capillary rise
Figure by P. Brüesch
s. also the following References:
R.2.0.3: pp 340 – 341 (Barrow); R.2.0.4: pp 965 – 967 (Atkins); R.2.0.5: pp 148 – 149 (Westphal)

R.4.6.20 p. 210: Root pressure and Osmosis
Figure by P. Brüesch
s. also the following References:
R.2.0.3: pp 303 – 305; R.2.0.4: pp 227 – 229; R.2.0.5: pp 261 – 263

R.4.6.21 p. 211: Osmosis and Turgor in Trees
http://en.wikipedia.org/wiki/Osmosis

R.4.6.22 p. 212: Root pressure and Guttation:
Wikipedia, the free encyclopedia
Root pressure: http://en.wikipedia.org/wiki/Root_pressure
p. 212: Guttation general and at Equisetum
Guttation – Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Guttation

R.4.6.23 p. 213: Tracheids of a Douglas fir
Literature: from Google Images

R.4.6.24 p. 214: Vacuum pump and evaporation at the yew branch
Figure left: Vacuum pump (P. Brüesch)
Figure right: Evaporation from a yew branch
Reference: R.4.6.10: p. 163

R.4.6.25 p. 215: The Cohesion – Tension Theory (CTT) for the ascent of sap in tall trees
additional References: R.4.6.2 – R.4.6.12

R.4.6.26 p. 215: The Cohesion – Tension Theory has first been proposed by H.H. Dixon and J. Joly and is still the most important and accepted Theory of water transport in tall trees. see: Transport of Water and Minerals in Plants
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/X/Xylem.html
Henry Horatio Dixon: http://www.tcd.ie/Botany/tercentenary/300-years/chairs/henry-horatio-dixon

R.4.6.27 Xylem
From Wikipedia, the free encyclopedia
An interesting description of the ascent of sap on the basis of the Cohesion – Tension Theory

R.4.6.28 p. 216: Redwood tree height profiles of Xylem pressure: Experiments
Plant Physiology Online: How water climbs up the Top of a 112 m tall tree: Essay 4.3, p. 5 (May 2006): http://4e.plantphys.net/article.php?ch=-&id=100

R.4.6.29 p. 217: upper Figure: adaxial and abaxial leaf surfaces
Round-leaved dock: left: upper side; right: lower side of the leaf from Internet under „Leaf veins: Bilder (CLRV leaf veins – sympt)
p. 217: lower Figure: Leaf veins (abaxial leaf surface) from Internet under „Leaf veins: Bilder: www.plb.ucdavis.edu

R-4-10

R-4-11

4 – 49
R.4.6.31 p. 219: Vascular tissue in the leaf
http://de.wikipedia.org/wiki/Blatt
R.4.6.32 p. 220: Superheated states in trees; Figure from P. Brüesch
R.4.6.33 p. 221: P-T diagram of water in superheated state; s. p. 241 in Reference R.2.0.5
R.4.6.34 p. 222: Vulnerability of Xylem to Cavitation and Embolism: Repair mechanisms
M.T. Tyree and J.S. Sperry
R.4.6.35 M.J. Lampinen and T. Noponen: Thermodynamic analysis of the interaction of the xylem and phloem sugar solution and its significance for the cohesion theory.
R.4.6.36 Equation of state of water under negative pressure
Kristina Davitt, E. Rolley, F. Coupin, A. Arvangas, and S. Balibar
The Journal of Chemical Physics 133, 174507 (2010)
R.4.6.37 Optical measurements probe the pressure and density under tension
Johanna Miller
Physics Today, January 2011, pp 14–16

R.4.6.39 In 2003, Peter Agre obtained the Nobel – Price in Chemistry for Aquaporine which are proteins, allowing the rapid transfer of water molecules through cell membranes.
http://wps.pearsoncustom.com/pcp_80577_bc
R.4.6.40 Aquaporins
http://de.wikipedia.org/wiki/Aquaporine
R.4.6.41 Ernst Steuble: „Aufnahme und Transport des Wassers in Pflanzen”
R.4.6.42 The role of aquaporins in cellular and whole plant water balance
I. Johansson, M. Karlsson, U. Johannsson, Ch. Larsson, and P. Kjellbom
Biochimica et Biophysica Acta 1465 (2000) , 324–342
R.4.6.43 „Aquaporine: Wasserspezifische Kanalproteine in Zellmembranen”
www.tp2.uni-erlangen.de/3.ehrveranstaltungen/seminar/ /1Gebert.pdf
Here, Aquaporines are considered in living creatures.
p. 8: „Aquaporine are neither pumps nor carriers, but always open pores, which allow the rapid passage through these pores...”
p. 27: The driving force is the osmotic pressure”
R.4.6.44 Figure at p. 4-A-6:1: Hydraulic coupling between xylem and phloem; see in: Journal of Experimental Botany, Vol. 57, pp 729–737, 2006
Thorsten Will and Aart J.E. Van Bel
4.6.45 Figure on p. 4.A.6.2: Aquaporins
Ch. Maurel, Lionel Verdoucq, D-Trung Luu, and Véronique Santoni
For this Reference I am indebted to Dr. H.R. Zeller
s. also p. 218: Mesophyllzellen and Stomata

4.6.46 Figure on p. 4.A.6.6:
Moving water, minerals, and sugar. Plant Transport: p. 34: an apple trea
www.wou.edu/ /bledsoak/103materials/presentations/plant_transport.ppt

4.6.47 to Figure on p. 4.A.6.6:
Shifts in xylem vessel diameter and embolisms in grafted apple trees of differing rootstock growth potential in response to drought
Bauerle, T.L., Centinari M. And Bauerle W.L. , SpringerLink

4.6.48 to Figure on p. 4.A.6.6:
Relationships between Water Stress and Ultrasonic Emission in Apple (Malus domestica Borkh)
H.G. Jones and J. Pena
http://jxb.oxfordjournals.org/content/37/8/1245.abstract

4.6.49 Related to Figure on p. 4.A.6.6
Is xylem cavitation resistance a relevant criterion for screening drought resistance among Prunus species?
H. Cochard, S. Tete Barigah, Marc Kleinhentz, and Amram Eshel

4.6.50 Do Woody Plants Operate Near the Point of Catastrophic Xylem Dysfunction Caused by Dynamic Water Stress?
M.T. Tyrre, and John S. Sperry; Plant Physiology (1988) 88, 0574-0580
[The Paper considers Thuja, Acer, Cassipurea, and Rhizophora]

4.7 Water plants

4.7.1 An introduction is found in:
Aquatic plants–Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Aquatic_plant

4.7.2 Another excellent introduction has been worked out by:
Dr. Patrick Steinmann, Stein am Rhein
Gewässerbiologie: Wasserpflanzen
pp 223, 224 : Plants with increasing water depths : p. 2 of this Reference
http://www.psteinmann.net/bio_wasserpfl.html

4.7.3 p. 225: Red beds
http://de.wikipedia.org/wiki/Röhrichtpflanze

4.7.4 Water lily – generain:
de.wikipedia.org/wiki/Seerosen

4.7.5 p. 226: Blue Water lily
from Google – Suche
Pictures to „Blue Water lilies”

4.7.6 p. 226: Air channels in the petiole and Leaves of a water lily:
Wasserpflanze - Wikipedia
http://de.wikipedia.org/wiki/Wasserpflanze

4.7.7 p. 227: Lotus flower:
Lotus flower, Lotus fruit and Lotus leaves in rain – comparision with leafves of water lily
http://de.wikipedia.org/wiki/Lotusblumen

4.7.8 p. 226: Pondweed
Reference R.4.7.2 : pp 7 and 12
R.4.7.18 Figure 4_A_7_1 : Diatoms (Kieselalgen) : http://de.wikipedia.org/wiki/Kieselalgen

Nitszschia is a species diatoms
http://de.wikipedia.org/wiki/Nitzschia

R.4.7.16 p. 230 : Figure from
Phytoplankton : Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Phytoplankton , p. 3

R.4.7.17 In 2003, Peter Agre obtained the Nobel – Price in Chemistry for Aquaporine which are proteins, allowing the rapid transfer of water molecules through cell membranes.
http://wps.pearsoncustom.com/pcp_80577_bc-campell_biology_8/...
5. Water and Global Climate
5.1 Water, Air, and Earth

All the Water on the Earth

All the water on the Earth amounts to a volume of about $1.4 \times 10^9$ km$^3$, which corresponds to a mass of about $1.4 \times 10^{18}$ Tons.

This includes all the water in the oceans, seas, ice caps, lakes and rivers as well as the ground water and the water in the atmosphere.

This total amount of water is illustrated by the blue sphere with a radius of about 700 km.

From the total amount of water, only about 3% is freshwater (salt-free water) which corresponds to about 42 millions km$^3$ and to a radius of a sphere of about 216 km.

From this freshwater less than 1% is readily available for human consumption because a large part of this freshwater must first be purified or is stored in the form of icebergs, etc.
Sphere with a radius of about 1000 km
At technical normal conditions (20 °C and 1 atm)
This corresponds to a mass of about $5140 \times 10^{12}$ Tons

The air layer is very thin: troposphere + stratosphere together only about 50 km

Air layer = protection layer: stores the heat radiated by the Earth in the infrared region → pullover effect!

Without the air layer, the global temperature of the Earth would be as low as about -15 to -18 °C!

No liquid water would exist on our planet; only ice!

All the Air of the Earth

Without the air layer, the global temperature of the Earth would be as low as about -15 to -18 °C!

No liquid water would exist on our planet; only ice!

Air layer: thickness about 50 km

thickness of troposphere: about 11 km
thickness of stratosphere: about 50 km

The protection layer stores the heat radiation from the Earth in the infrared region of the spectrum → pullover!

Without protection layer: global temperature on the Earth would be about -15 to -18 °C!

No liquid water would be present on the Earth!

Erde

R = 6357 km

Protection layer is very thin! contains more than 99% of the mass of the terrestrial atmosphere
Structure of terrestrial atmosphere

Layering of terrestrial atmosphere viewed from space

- Troposphere
- Stratosphere
- Mesosphere
- Thermosphere
- Ionosphere (Aurora)
Composition of the dry atmosphere
(in volume % and / or in parts per million (ppm))

- **Carbon dioxide**: \( \text{CO}_2 \)
  - \( 0.036 \% \) (360 ppm)

- **Argon**: \( \text{Ar} \)
  - \( 0.934 \% \) (9340 ppm)

- **Oxygen**: \( \text{O}_2 \)
  - \( 20.946 \% \) (209460 ppm)

- **Nitrogen**: \( \text{N}_2 \)
  - \( 78.084 \% \) (780840 ppm)

- **Residual gases**: i.e., methane: \( \text{CH}_4 \), nitrous oxide: \( \text{N}_2\text{O} \), noble gases, \( \text{H}_2 \)

Solar radiation at the Earth (without atmosphere)

The solar energy falling onto a hemisphere of the Earth is equivalent to the energy which falls onto a spherical disk with the radius \( R \) of the Earth. If \( S = 1368 \text{ W/m}^2 \) is the specific power, also called solar constant, then the power falling onto the surface of the disk is equal to \( S \times \pi R^2 \text{ Watt (W)} \).

(The same result is obtained if the integral of all normal components of the radiation falling onto the hemisphere is evaluated).

Now, the Earth is not a disk but rather spherical. Therefore, the surface onto which the solar radiation is impinging during 24 h or more onto the rotating earth is not \( \pi R^2 \) but rather \( 4 \pi R^2 \), hence 4 times larger.

Therefore, the solar power density, averaged over the surface of the whole earth, is given by

\[
1368 \text{ W/m}^2 \times \pi R^2 / 4 \pi R^2 = (1368 / 4) \text{ W/m}^2 = 342 \text{ W/m}^2 = S / 4 .
\]
Greenhouse gases are gases in an atmosphere that absorb and emit radiation within the thermal infrared range. Both, absorption and radiation of infrared gases are caused by specific molecular vibrations which change the dipole moment of the molecules.

The major atmospheric constituents, nitrogen (N₂), oxygen (O₂) and Argon (Ar) (s., p. 231) are not greenhouse gases. This is because molecules containing two atoms of the same element such as N₂ and O₂ and monoatomic molecules such as Ar have no net change in their dipole moment when they vibrate and hence are almost totally unaffected by infrared light.

The main greenhouse gases in the Earth’s atmosphere are water vapour, carbon dioxide (CO₂: about 350 ppm), methane (CH₄: 1.7 ppm), nitrous oxide (N₂O: 0.3 ppm) and ozone O₃ (in the ppb range). CO₂, CH₄, N₂O, are anthropogenous greenhouse gases (i.e. they are produced to a large extent by men’s activities).

Water vapor is still the most important greenhouse gas, because its concentration in the atmosphere is on average about 25 times that of CO₂. Water vapour is the only greenhouse gas whose concentration is highly variable in space and time in the atmosphere. Note, however, that water vapour is not an anthropogenous greenhouse gas (see also p. 256). The highest concentration of water vapour are found near the equator over the oceans (enhanced by the warming up of Sea Water) and in tropical rain forests. On the other hand, cold polar areas and subtropical continental deserts are locations where the concentration of water vapour can approach zero percent.

The influence of water vapour to climate change and its positive feedback onto global warming is discussed at pp 248 - 251.
### Temperatures and some greenhouse gases

<table>
<thead>
<tr>
<th>Remperatures:</th>
<th></th>
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<tbody>
<tr>
<td>Temperature without</td>
<td>- 18 °C</td>
</tr>
<tr>
<td>greenhouse effect</td>
<td></td>
</tr>
<tr>
<td>Temperature with</td>
<td>+ 15 °C</td>
</tr>
<tr>
<td>greenhouse effect</td>
<td></td>
</tr>
<tr>
<td>Difference:</td>
<td>33 °C</td>
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</table>

<table>
<thead>
<tr>
<th>Greenhouse gases:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water:</td>
<td>H₂O</td>
</tr>
<tr>
<td>Carbon dioxide:</td>
<td>CO₂</td>
</tr>
<tr>
<td>Methane:</td>
<td>CH₄</td>
</tr>
<tr>
<td>Nitrous Oxide:</td>
<td>N₂O</td>
</tr>
<tr>
<td>CFCs: i.e. Chlorofluorocarbons</td>
<td>CCl₃F</td>
</tr>
<tr>
<td>Ozone:</td>
<td>O₃</td>
</tr>
</tbody>
</table>
Solar spectrum and spectrum of heat radiation of a body (Earth) at 15 °C

The sun is heating the Earth → heat increases the vibrations of the atoms thereby increasing the emission of Infrared Radiation (IR) → heat radiation increases!

Blue curve: global heat radiation corresponding to a temperature of 15 °C

Greenhouse gases are climate-active trace gases, i.e. gases which absorb sunlight in the infrared spectral region and greatly affect the temperature of the Earth; without them, Earth’s surface would be on average 33 °C colder than at present.
Global warming is unambiguous today. This conclusion follows from observations of the global increase of the average temperature of air and oceans, the melting of ice and snow over large areas, as well as from the global increase of Sea levels.

The most important part of the increase of the mean temperature observed since the middle of the 20th century is due (with a high degree of probability) to the observed increase of the concentration of anthropogenic greenhouse gases, in particular CO$_2$, which accounts for about 60%.

Mean average global temperature between the year 1000 and 2100. The Figure is based on a reconstruction of the climate (1000 - 1860), on observations between 1860 - 2000, and on different extrapolations for 2000 – 2100. (Source: IPCC)
Carbon dioxide is the most important anthropogenic greenhouse gas. The global atmospheric concentration of CO\textsubscript{2} has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005.

The atmospheric concentration of CO\textsubscript{2} in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300 ppm). This follows by analysing ice cores from 1750 to 2005 which show an increase of 100 ppm in this time. The annual CO\textsubscript{2} concentration growth rate was larger during the last 10 years (1995 – 2005 average: of 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960 – 2005 average: 1.4 ppm per year) although there is year-to-year variability in growth rates.

The primary source of the increased atmospheric concentration of CO\textsubscript{2} since the pre-industrial period results primarily from the increase of fossil fuel use. An additional but smaller increase of CO\textsubscript{2} is due to the “land-use change”; an example of the latter is the commutation of woodland into agriculture land.

Note the very marked increase in CO\textsubscript{2} concentrations starting at the beginning of industrialization after 1800.
The global atmospheric concentration of methane (\( \text{CH}_4 \)) has increased from a pre-industrial value of about 715 ppb to 1732 ppb in the early 1990’s, and was 1774 ppb in 2005. The atmospheric concentration of \( \text{CH}_4 \) in 2005 exceeds by far the natural range of the last 650,000 years (320 to 790 ppb) as determined from ice cores. It is very likely that the observed increase in \( \text{CH}_4 \) concentration is due to anthropogenic activities, predominantly agriculture and fossil fuel use.

The global atmospheric nitrous oxide (\( \text{N}_2\text{O} \)) concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The growth rate has been approximately constant since 1980. More than a third of all \( \text{N}_2\text{O} \) emissions are anthropogenic and are primarily due to agriculture.
Correlation of atmospheric CO₂ – concentration and temperature variation with time

The so-called "Vostok Ice – Curve" shows a very strong correlation between the CO₂ – concentration and temperature development during the last 160'000 years. The data have been obtained from chemical measurements of fossil air bubbles in antarctic ice. Here, the most recent CO₂ – and temperature increases starting around 1860 and shown at pp 246 – 249 and 253 are not included.

Global climate change: Correlation of temperature with CO₂ - concentration

Development of global temperature of the Earth as a function of the CO₂ – concentration between 1860 and 2000
Today: 90% of the global energy requirement is obtained from fossil fuels (mineral oils, natural gases, brown- and hard coal, deforestation, etc.):

**Anthropogenous combustion of fossil fuels**

- CO₂-emission: 30 Giga-Tons (GT) per year!
- About 50% (15 GT) is absorbed by the earth:
  - Absorption of CO₂ in the Seas
  - Photosynthesis in woods
- About 50% (15 GT) diffuses into the atmosphere
- Greenhouse effect
- Global warming!

1 GT = 1’000’000’000 tons

---

**Interaction between global warming and water**

- Water vapor
- Oceans, Lakes
- Clouds
- Snow
- Ice

Global Warming

---

5 – 12
Water and Climate: Basic Facts

- Water vapour is the most important climate-active gas
- However: water vapor is not anthropogenous (i.e. not man-made) and is unevenly distributed
- Strong positive feedback: self inforced warming
- Clouds, snow and ice reflect the sun light and there net effect produces a cooling (albedo-effect)
- By global warming: snow recedes to higher altitudes; ice is melting ➔ warming with positive feedback
- During the last century, the Sea level rise due to global warming is about 200 mm.
- Without water vapor, the global warming would only be about 50% of the total warming!

Influence of water vapour on climate change

CO₂ in atmosphere

↑
increase of temperature of oceans, lakes, dry land and air:

↓
stronger evaporation of water ➔ higher concentration of water vapor in the air ➔ the warmer the air, the higher is the saturation concentration of water vapor:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°C</td>
<td>9.4 g/m³</td>
</tr>
<tr>
<td>20°C</td>
<td>17.2 g/m³</td>
</tr>
</tbody>
</table>

↑
the air is further warmed up and radiates back to the Earth ➔ water vapour of the air absorbs more infrared-radiation, which is back radiated from the warm Earth.
The positive feedback of water vapour onto global warming

Water vapour: most important climate active gas but it is not anthropogenous!

Doubling the present CO$_2$– concentration:

\[ \Delta T = 2 \text{ to } 4.5 \, ^\circ\text{C} ! \]

Without water vapour: temperature increase only about 50% of $\Delta T$!
5.2 Some implications of Climate Change

Temperature increase → increase of evaporation → higher concentration of water vapour → more clouds → more rain!

Flood in Switzerland (2007)

Flood in Délémont
Floods in Switzerland (2007)

Flood in Laufental

Flood in a hamlet in the Canton Jura

Flood in Turgi (Canton Aargau, Switzerland)

August 7, 2007: the BAG TURGI ELECTRONICS AG (below) and the Armory in Brugg (above) appear as islands!

The whole “Limmatspitz” is completely flooded!
Australia 2007: The “Drought of the Century”

Increased temperature of ground and air $\Rightarrow$ stronger evaporation $\Rightarrow$ drying out!

Ice + Snow Climate

- Sunlight is reflected by ice and snow $\Rightarrow$ albedo effect
- The albedo is defined as the intensity ratio of the reflected and incident radiation.

$\text{CO}_2$: Ice melts $\Rightarrow$ warming up by decrease of albedo

$\text{CO}_2$: covering of snow decreases and is present only for short times $\Rightarrow$ warming up by decreasing the albedo

warming up: positive feedback!
**Climate** ↔ **Clouds**

- About 60% of the surface of the earth is covered permanently with clouds.
- Clouds are formed only in the presence of aerosols (condensation nuclei) on the surface of which water vapour can condense.
- Clouds appear very often in the form of supercooled water droplets or of ice crystals.

Clouds are important regulators for the climate:

- By reflection of the sunlight → cooling effect
- By absorption of IR – radiation from the earth

**Net effect:** cooling → Albedo - effect

---

**Planetary Albedo effect**

At the white regions of the surface (clouds, snow, glaciers and ice-covered areas of the antarctic), the sunlight is reflected → cooling! (Albedo – effect)

**Planetary albedo:**

From the power of the sunlight irradiated to the earth, about 1/3 is reflected and 2/3 is absorbed.
Direct observation of the more recent climate change

Global mean temperature (°C)

Global average sea level (mm)

Northern hemisphere snow cover (km²)

Global change of the Sea level during the last 250 millions of years

maximum Sea level (460 millions years ago)

Deepest sea level

Cretaceous age: time of global warming; Sea level about 170 m higher than today!

- global maximum sea level: 200 - 250 m higher than today
- mean concentration of CO₂: 700 - 2000 ppm (today: 380 ppm)
- average global temperature: about 21 °C (today: 15 °C)

• reasons: stronger magma flow at the sea grounds → evaporation of CO₂; melting of ice; repression of water by magma....
During the time 1870 – 2005, measurements of the mean Sea–level in geologically stable regions show an increase of about 25 cm.

The water temperature in the Mediterranean was never as high as in recent years.

The warm water of the Mediterranean has attracted globefishes - the native species are gradually superseded.
Computer – based climate prognosis with the help of the Super Computers ESS: Earth Simulator System

Dr. Mitsuo Yokokava: Chef - constructure of ESS

The World’s Fastest Supercomputer System for Resolving Global Environmental Problems Completed

The Earth Simulator

Speed: 40 TFlops = 40 x 10^{12} floating point operations per second;
Memory: 10 TB = 10 x 10^{12} Bites

ESS – based climate – prognosis for different scenarios: from “Special Report Emission Scenarios” (SRES)

ESS: Earth Simulator System

IPCC: Intergovernmental Panel on Climate Change (2007)

Results of some SRES - Models (1990 - 2100)

As shown in the graph, the various models have a fairly wide distribution of results over time. For each curve, on the far right, there is a bar showing the final temperature range for the corresponding model version.

As expected, the further into the future the model is extended, the wider is the variance between them.

Roughly half of the variations depends on the future climate forcing scenario rather than on the uncertainties in the model.

IPCC Graph of the models of the temperature increase as a function of time

ESS – based climate prognosis for different scenarios: from “Special Report Emission Scenarios” (SRES)
Increase of Sea-Level extrapolated to 2100

The Graph shows estimates of the development of the Sea-Level in the past (grey), the observations during the last decades by measurements of the tide gauge and satellites (red), and prognosis for the future according to the IPCC A18 scenario (blue).

Global glacier receding - 1

Average Change of Glacier Thickness (cm/yr)

Cumulative Mean Thickness Change (Meters)
Remarks to Figure at p. 274

The Figure shows the mean rates of the change of thicknesses of the ices on the Earth.

This information is also known as the Glaciological Mass Balance (GMB). The GMB is evaluated by forming the difference of two measurements: a) measurements of the Annual Increase of Snow (AIS) on the one hand and b) measurement of the Annual Loss of Snow (ALS) due to melting- and sublimation processes on the other hand, i.e. $GMB = AIS - ALS$.

The upper graph of Figure 274 shows the annual average thickness changes of the glaciers (in cm/year). The lower curve gives the accumulated change of the thickness decrease. During this time a thickness increase is observed only during 3 years (between 1965 and 1970). For the thickness decrease see also p. 277.

The Figure shows that during the whole observation period the average thickness of the glacier ices (measured in m) decreases essentially continuously during the time between 1957 and 2004 and that the total decrease is about 14 m!

Global glacier receding: the glaciers are melting more rapidly!
The global receding of glaciers has been occurred within the last years. This is the conclusion reached by "World Glacier Monitoring Service" (WGMS), which has published the newest results at January 29, 2009. At the average, the glaciers have been receded in 2007 as much as 75 cm. The most dramatic situation has been observed in the Alps: Some glaciers have lost up to 3 m of ice! ……

The data of WGMS have been collected from more than 80 glaciers all over the world. At the end of each summer, scientists are monitoring the changes of the thickness of the ice at different places of the glacier. ……

Collected over several years, the measurements of the thicknesses demonstrate the present climate change (s. Graphs, pp 274, 277). From the start of the measurements in 1980, thickness increases have been observed only in the years 1984, 1987 and 1989. Furthermore: "The loss is accelerating, the values became increasingly negative", sais Michael Zemp, WGMS member and glaciologist at the Geographical Institut of the University of Zürich.

The melting glaciers contribute each year 1 mm to the increase of the height of the Sea. "This is roughly one third of the total increase, sais Zemp". An additional increase of one third is believed to be due to the melting ice of Grönland and in the Antarctic. The remaining increase is due to the heat extention of the Sea water, sais Zemp.

The 100 glaciers studied today constitute only a small portion", sais Zemp. ….. Worldwide there exist 160'000 to 200'000 glaciers. ….. Despite this fact, the receding of the glaciers is accelerating", according to Zemp. The exact extent is, however, still unclear. „In Switzerland, the receding of glaciers in 2008 was about the same as in 2007“.
Appendix : Chapter 5

Development of Greenhouse gases: 1978 - 2010

Growth trend of the most important anthropogenes Greenhouse gases between 1978 and 2010. CO₂ and N₂O (laughing gas) are constantly increasing, while after 1999 NH₄ remained constant for some years and started to increase again only recently. Due to their chemical inertness, CFC-12 (Dichlorofluoromethane) and CFC-11 (Trichlorofluoromethane) have a long dwell time in the atmosphere. For this reason they are rising up into the stratosphere where they decompose by UV radiation. The reaction products are chlorine- and fluorine radicals which react with ozone leading to a depletion of the ozone layer. Thanks to the Montreal Protocol for the protection of the ozone layer, CFC-12 and CFC-11 remain stable or even decrease slightly after 1996 (right Figure below).
The CO₂ data (red curve) shows the monthly observed CO₂ concentration in dry air, observed in the Mauna Loa Observatory in Hawaii. The figure shows the longest measuring observation for the CO₂ concentration: from 1958 to 2010.

The data show the mole fraction of CO₂ in dry air in units of ppm. The black curve illustrates the average concentration.

---

**Decrease of O₂ in the atmosphere as a function of time**

The figure shows the decrease of O₂ normalized to N₂, δ(O₂/N₂) in Mouna Loa Vulcano in Hawaii as a function of time between the years 1990 and 2006. The quantity δ(O₂/N₂) is defined as follows:

\[
δ(O₂/N₂) = \left\{ \left( \frac{[O₂]/[N₂]_{\text{sample}}}{[O₂]/[N₂]_{\text{Reference}}} - 1 \right) \times 10^6 \right\} \text{ in units of "per meg". (*)} \\
\text{([*) 1 per meg = 0.001 \%]} \\
\]

A regularly yearly cycle is observed. The average long-time trend represented by the blue dashed line L as well as the blue grid have been added by P. Brüesch.
Remarks about the $\delta(O_2/N_2)$ - dada from 5-A-1-3

a) The $O_2/N_2$ – ratio can be changed both by a variation of the $O_2$ - and the $N_2$ concentrations. The air contains about 20.9% $O_2$ and 78.1% $N_2$. Since air contains several times more $N_2$ than $O_2$, and since the natural sources and sinks of $N_2$ are much smaller than those of $O_2$, the $O_2/N_2$ – ratio reflects essentially the changes of the $O_2$ – concentration.

b) The quantity $\delta$ is zero if the sample has the same $O_2/N_2$ – ratio as the reference, and $\delta$ is negative, if the sample has a smaller ratio than the reference. The presently observed values of $\delta$ are negative because the $O_2$ – concentration is decreasing since about the year 1985.

c) The changes in $(O_2/N_2)_{sample}$ of $\delta(O_2/N_2)$ (p. 5-A-1-3) are very small: For typical air of the year 2000, $\delta = -0.000270 = -0.0270 \% = -0.270^{\circ}/oo = -270$ per meg = $270 \times 10^6$ (s. Fig. p. 5-A-1-3). [1 per meg = $0.001^{\circ}/oo = 0.0001 \%$].

d) The average time dependence $\delta(t)$ of the dashed line L in in the Figure of p. 5-A-1-3 can be approximated by (P. Brüesch)

$$\delta(t) = 3.274 \times 10^4 - 16.5 \times t$$

<table>
<thead>
<tr>
<th>t (year)</th>
<th>$\delta(t)$ (per meg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>$\approx$ 0</td>
</tr>
<tr>
<td>1990</td>
<td>$\approx$ -85</td>
</tr>
<tr>
<td>1995</td>
<td>$\approx$ -190</td>
</tr>
<tr>
<td>2000</td>
<td>$\approx$ -270</td>
</tr>
<tr>
<td>2005</td>
<td>$\approx$ -370</td>
</tr>
<tr>
<td>2010</td>
<td>$\approx$ -450</td>
</tr>
</tbody>
</table>
5. Water and global climate

5.1 Water, Air and Earth

R.5.1.1 For helpful information and interesting discussions about important topics discussed in this Chapter, in particular about the role of water for climate change, I should like to thank Professor Thomas Stocker of the University of Bern. Prof. Dr. Th. Stocker Climate and Environmental Physics; Physics Institute, University of Bern Siedlerstrasse 5, 3012 Bern, Switzerland

R.5.1.2 WELTATLAS DES KLIMAWANDELS
Karten und Fakten zur globalen Erwärmung
Kirsten Dow und Thomas E. Downing; Europäische Verlagsanstalt Dr. Götze Land & Karte; Hamburg (2007)

R.5.1.3 Important additional information can also be found in:
Google unter: „Water and Global Climate Change“

R.5.1.4 p. 233: All the Water of the Earth
p. 234: All the Air of the Earth
http://www.adammniemann.co.uk/vos/index.html*

R.5.1.5 p. 235: Air Layer of the Earth
Compilation by P. Brüesch from different Literature sources

R.5.1.6 p. 236: Structure of terrestrial atmosphere:
From: Paul Scherer Institut (PSI), 5232 Villigen, Schweiz „Aerosolforschung auf dem Jungfraujoch“
s. Glossar: Sphere representing the atmosphere:
http://aerosolforschung.web.psi.ch/Glossar/Glossar Page htm
A slice through the earth’s atmosphere viewed from space:

Figure text by P. Brüesch

Positive increase and heat concentration:
http://openlearn.ac.uk/mod/resource/view.php?id=172073

Figures adapted and commented by P. Brüesch

Greenhouse gases:
Text composed by P. Brüesch from different Literature data

The Greenhouse Effect 1: Incident and reflected solar radiation

The Greenhouse Effect 2: A giant natural climate machine
http://www.klimawandel.global.de/bilder/co2-vs-temperature.jpg

Radiation absorption characteristics of water vapour and carbon dioxide

Figure adapted by P. Brüesch

Global Temperature Increase (1860 – 2005)
http://wikipedia.org/wiki/Globar.warming

Global Temperatures between the Years 1000 and 2100
http://www.te-software.co.nz/blog/augie_auer.htm

Carbon Dioxide Variations (between -400’000 to present)
http://www.te-software.co.nz/blog/augie_auer.htm

Correlation of CO2 with temperature and with time back to - 160’000 years
http://www.te-software.co.nz/blog/augie_auer.htm

Global Climate Change: CO2-concentration and temperature increase
http://www.klimawandel-global.de/klimawandel/ursachen/co2-emission/neue-klimawandel
http://www.klimawandel-global.de/bilder/co2-vs-temperature.jpg

Water and climate: Basic facts
http://www.klimawandel-global.de/klimawandel/ursachen/co2-emission/neue-klimawandel
http://www.te-software.co.nz/blog/augie_auer.htm

Positive feedback of climate change (Positive Rückkopplung, …)
http://www.schulphysik.de/akkli2t04.html
http://www.espire.net/Grmamy/water/detroposde.html

Klimawandel” p. 20
Joachim Curtius; Institut für Physik der Atmosphäre
www.staft.uni-mainz.de/curtius/Klimawandel/
Login: Klimawandel, Password: CO2
Universität Mainz, WS 05 7 06
Some implications of the climate change

5.2 Some implications of the climate change

5.2.1 Flood in Délémont, (Hochwasser in Délémont), Switzerland (2007)
http://www.baz.ch/images/imagegallery/Delémont.jpg

5.2.2 Flood in Laufental, Switzerland (2007)
Laufental: www.polizeibericht.ch/ger_details_3154/kanton_Basel_Land_Hochwasserlage....


5.2.4 Drought of the Century in Australia
MZ Mittwoch, 26. September 2007 (p. 2)

5.2.5 : The Albedo Effect by Ice (left) and Snow (right)
left hand Foto: „Iceberg“ from: tagesanzeiger (TA) of Switzerland; WISSEN- 27.1. 2005

5.2.6 Clouds as regulators for the climate
Foto of Cumulus Cloud: p. 164

5.2.7 Planetary Albedo Effect
in Reference R.5.1.9: p. 4

5.2.8 More recent climate changes
Smoothed curves represent decadal average values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series ©. from: IPCC 2007

5.2.9 Global change of sea level during the last 250 millions of years
http://www.bbm.me.uk/portsdown/images/CretEnv/Seal.vl02.gif

5.2.10 Average increase of Sea Level since 1870 - 2009
http://en.wikipedia.org/wiki/File:Recent_Sea_Level_Rise.png

5.2.11 Tropic fishes in the Mediterranean

5.2.12 Earth Simulator Computer
NEC Global – Press Release
http://www.thocp.net/hardware/nc


R.5.2.15 p. 274: Global glacier receding: Graph – 1 http://wikipedia.org/wiki/Global_warming

R.5.2.16 p. 275: Text to Figure 267 composed by P. Brüesch


R.5.2.18 p. 277: Global Glacier receding: Graph - 2 originally from: www.durangobill.com/Swindle_Swindle_html
Bill Butler: Debunking the Deniers of Global Warming
Graph found under: „Graphs of receding glaciers“
(The quality of the Graph has been improved by P. Brüesch)
(s. also: MZ (Mittelland - Zeitung): Freitag, 30 Januar, 2009, p. 22)

Quotations by Michael Zemp, WGMS member and „Glaziologist at the Geographical Institute of the University of Zürich"

R.5.2.20 Sea Level Rise, After the Ice Melted and Today
Vivian Gornitz – January 2007
NASA GISS; Science Briefs: Sea Level Rise, After the ice Melted and Today http://www.giss.nasa.gov/research/briefs/gornitz_09/

R.5.2.21 Worlds glaciers continue to melt at historical rates (25. Jan. 2010)
www.guardian.co.uk/.../world-glacier-monitoring-service

R-5-6
6. Water and the „Blue Gold“
6.1 The struggle for the „Blue Gold“

All the Water on the Earth

The total mass of water on the Earth fills a sphere with a radius of about 700 km.

This amounts to a weight of about $1.4 \times 10^{18}$ tons.
Note the completely cracked and dry floor!

Women in Ethiopia are carrying water

1.2 billion of people do not have access to drinking water and are permanently risking their life!
A Samburu - warrior in the Nyuru – mountains of North Korea is quenching his thirst

Drinking water after the return of rain
Thirsty Zebras at a water–hole in Namibia

World Population and Water scarcity

World population 2005: 6.5 billion men
World population 2025: 7.9 billion men

A: Sufficient availability: available and renewable source of fresh water per capita and year is larger than 1700 m³
B: Water scarcity: available fresh water ranges between 1000 m³ and 1700 m³ per capita and year
C: Water shortage: available fresh water is less than 1000 m³ per capita and year

In 2005 about 745 millions of people lived in countries in which there was water scarcity or water shortage. It is expected that by the year 2025 this number will be about 4 times larger. According to present estimations, about 2.8 to 3.3 billions of people will then suffer from chronical or repeated shortage of drinking water and most of them will live in Africa.
Virtual Water - General

Virtual water, also known as embedded water, or hidden water, is the amount of water that is contained in a specific food or in other specific products for its production.

We are dealing therefore with that kind of water which is contained fictitiously or seemingly within this product.

Professor John Anthony Allen (King’s College, London) was the creator of the virtual water concept, which measures how water is embedded in the production and trade of food and consumer products (he was the winner of the Stockholm Water Prize 2008).

The total real water consumption of a country is the sum of inland use, added by the import of virtual water (import of products), and by subtracting the export of virtual water (export of products) of a country.

Virtual Water for different Crops - 1

<table>
<thead>
<tr>
<th>Plant / Fruit</th>
<th>Litres of water per kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>255</td>
</tr>
<tr>
<td>Maiz</td>
<td>350</td>
</tr>
<tr>
<td>Oats</td>
<td>1597</td>
</tr>
<tr>
<td>Wheat</td>
<td>1334</td>
</tr>
<tr>
<td>Rice (paddy)</td>
<td>2300</td>
</tr>
<tr>
<td>Carrots</td>
<td>131</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>184</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>242</td>
</tr>
<tr>
<td>Cranberries</td>
<td>152</td>
</tr>
<tr>
<td>Dry onions</td>
<td>346</td>
</tr>
<tr>
<td>Apple</td>
<td>697</td>
</tr>
<tr>
<td>Apricots</td>
<td>1391</td>
</tr>
<tr>
<td>Cherries (sweet)</td>
<td>1543</td>
</tr>
</tbody>
</table>
The Water Footprint is related to the virtual water. For an individual, it is simply the water used and is expressed in litres per day or in m³ per year. But at the national level, this becomes complex: it is equal to the use of domestic water resources, minus the virtual water export flow, plus the virtual water import flow.
The water footprint concept was introduced in 2002. It is an indicator of water use that includes both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business. Water is measured in water volume consumed per unit of time.

Examples for Water Footprints:

USA: 2480 m³ per capita and year or of 6900 liters per capita and day.
China: 700 m³ per capita and year or of 1950 liters per capita and day.
Global average: 1240 m³ per capity and year or of 3450 liters per capita and day.

Water Footprint of a nation:

When assessing the water footprint of a nation, it is essential to quantify the flows of virtual water leaving and entering the country. If one takes the use of domestic water resources as a starting point for the assessment of a nation’s water footprint, one should subtract the virtual water flows that leave the country and add the virtual water flows that enter the country.

Three shocking facts:

• One third of the world population has no access to clean drinking water!
• In the third world, contaminated drinking water is the major cause for illnesses.
• Every day, about 6000 children are dying by illnesses which are due to contaminated water!
Israeli settlers are occupying the water of Jordan

The 21st century

Water war

Arming against thirst!

Bone of contention: Water of Jordan. Israeli settler (p. 294 requires the lion’s share of the life-supporting liquid. But also the Jordanians (this picture shows an armoured training) and the Palestinians require their contribution!}

Both, the Jordanians and the Palestinians are eager to get their necessary water contributions.
Egyptian’s president Sadat warned more than 30 years ago: “Who is playing with the water of the Nile, is declaring us the war!” Back in 1979 he said: “The only matter that will take Egypt to war is water.” Thirty years later, there are still few effective mechanisms to resolve the growing political and economic disputes over the Nile’s water.

Opposition against the dam projects “Blue Nile” of the States neighbouring the upper part of the Nile

Egyptian’s supply with surface water depends more than 90% of the water of the Nile.

More and violent wars because of water scarcity can be foreseen in our planet!!

“Of all the social and natural crises we humans face, the water crisis is the one that lies at the heart of our survival and that of our planet Earth”

Unesco’s director-general, Koichiro Matsuura in: Mechanical Engineering, September 2003, p. 47

The precious Water of the Nil
6.2 Technologies for Water Treatment and Control of Drinking Water

Methods for controlling drinking water

Physical methods: Colour, conductivity, smell, taste, clouding, optical investigations

Chemical methods: pH – monitoring, analysis of different impurities, ....

Microbiological methods: Detection of different germs
Compulsory:
Global research, development and efficient detection by methods of water treatment

- Distillation
- Microporous filter
- Ion-exchange
- Ultra-filter
- Reverse osmosis (p. 303)
- Photo oxidation
- Absorption by activated carbon
- SODIS: Solar Disinfection


Water treatment methods - 2

- Distillation: heating up to boiling point ➔ condensate
- Ion-Exchange: replacement of cations and anions of impurities by $\text{H}_3\text{O}^+$ and $\text{OH}^-$ ions using ion-exchange resins.
- Electrodeionization: Elimination of foreign ions by means of electric fields and by using a combination of ion-exchange resins and ion-selective membranes. The method has been developed from electrolysis (s. pp 153-155).
- Reverse Osmosis: By application of an external pressure, osmosis (diffusion of water molecules across semi-permeable membranes into the solution) can be reversed ➔ purification of the solution, i.e. removing salts from Sea Water.
- Microporous Filtration and ultra-filtration across membranes
- Photo-Oxidation: UV-radiation destroys bacteria
Distillation plant for households

Heating element brings water to boiling $\Rightarrow$ evaporation; vapour condenses in condensing coil $\Rightarrow$ distilled water

Commercial plants are based on “flash-evaporation”, i.e. by sudden evaporation of water:

- salt water is heated up; the vapour is free of salt
- then it is pumped into a vessel with low pressure
- with decreasing pressure the boiling point of water decreases $\Rightarrow$ saving energy!; the method works with superheated water!
- sudden evaporation! “flash evaporation”
  - In the condensing coil, the vapour condenses to distilled water

Multi-Stage-Flash (MSF): Distillation-plant for desalination of Sea Water in Jebel Ali near Dubai

Capacity: 300 millions m$^3$ water per year (about 820'000 m$^3$ water per day!)
**Osmosis**

The small water molecules are able to diffuse across the “semi-permeable” membrane into the solution: in equilibrium, an osmotic pressure, $p_{osm}$, of several bars is building up (p. 304).

**Reverse Osmosis**

The “semi-permeable” membrane (thin polyamid-film) allows to cross only the small water molecules, but not the salts, dirt, bacteria, heavy metals and other contaminations.

By application of a pressure $p > p_{osm}$ in the solution compartment, the water molecules from the aqueous solution are pushed into the water ➔ from the solution, pure water is obtained!

---

**Desalination plant in Perth (Australia)**

Technology: Reverse Osmosis

Capacity: 140’000 m³/day; expandable to 250’000 m³/day

In its final capacity the plant is able to produces 17% of the required drinking water of Perth.
Zeolites for water softening

**Left:** the pore spaces of zeolith A are usually occupied by highly mobile Na\(^{+}\)-ions (yellow), which neutralize the negative charge of the framework. They can easily be replaced or exchanged by other ions → ion exchanger.

**Right:** hard water contains much calcite (CaCO\(_3\) ↔ Ca\(^{2+}\) + CO\(_{3}^{2-}\)); the Na\(^{+}\)-ions are replaced by Ca\(^{2+}\) ions (red), preventing the deposition of calcite.

\[2\text{Na}^{+} + \text{CO}_{3}^{2-} \leftrightarrow \text{Na}_2\text{CO}_3 \rightarrow \text{good water solubility.}\]

---

**History of SODIS: Solar Disinfection**

- The idea for disinfection of water by using sun radiation has been found already some 30 years ago by Aftim Acda, Professor for microbiology, in Beirut. During the war, he filled plastic bottles filled with water who served as an emergency stock for drinking water and he stored these bottles on his balcony. During this time of exposure, he discovered that the sun was able to kill the microorganisms present in water.

- 1984: Publication in a scientific journal, but his conclusions have not been accepted!

- 1991: The method has been tested and confirmed by Eawag Sandec (Federal Institute of Aquatic Science and Technology) in Dübendorf, Switzerland.

- During this time the method has been thoroughly tested during more than 10 years, both, in the laboratory as well as in the field.
SODIS: Solar Disinfection

Start: contaminated and eventually clouded water

By suitable methods, clear water is produced:

• sedimentation
• filtration

Imperatively: Improving water treatment methods!

Important example of a simple and cheap method: SODIS

Principle of SODIS:

Clear plastic bottles are filled with contaminated but clear water. The bottles are exposed during 6 to 24 hours to the sun light. By exposure to the UV light as well as by warming up, the bacteria causing diarrhoea are killed up to 99.99%!
Exposition of bottles filled with contaminated water to the sun

Characteristics of the method:

• cheap

• Water temperature can increase over 50 °C

• Coli-bacteria are killed by 99.9 to 99.99 %

• can not be applied under all climate conditions

• virus and heavy metals can not be eliminated.

Sodis from Eawag

Instructions of the SODIS – method at a school in Lombok (Indonesia) by Federal Institute of Aquatic Science and Technology (Eawag), Switzerland.
Appendix - Chapter 6

- Catastrophic Drought in the Horn of Africa
- Global Water Utilization in Percent
- Contamination of Sea-Water by Oil disasters

Catastrophic drought in the Horn of Africa

Samalia’s drought: Some parts of the Horn of Africa have been hit by the worst drought in 60 years, with tremendous humanitarian consequences.

Kenya: Drought leaves dead and dying animals in northern Kenya.
Agriculture is very thirsty: 70% of freshwater is used for agriculture! Irrigation of crops is the main user of freshwater resources in most developing countries and in Australia. ACIAR (Australien Centre for International Agriculture Research) is supporting research on more efficient irrigation in developing countries, to release some of this pressure.

The "World Wide Fund for Nature (WWF) is one of the World’s largest international Environmental Organizations. It took place at August 21, 2011 in Stockholm together with an international Team of "World Water Week": "Big Cities, Big Water, Big Challenges". In the following we quote some results and facts:

Mega-Cities all over the world are menaced in the years to come by a further aggravating of the water crisis. They are especially threatened by a further shortage of drinking water, declining water quality as well as by a breakdown of canalizations.

- In many Metropolises the situation is untenable and menacing already today. In Mexico-city, for example, the overexploitation of ground water reserves by boring of artesian wells, (s. p. 191) causes a loss of 5 to 40 cm per year. For this reason, water reserves at distances of 150 km away from the city must be used.

- The rivers of Buenos Aires are called "public sulages" by the WWF. Worldwide, the most heavily contaminated one is the Riachuelo; it contains huge concentrations of Lead, Zink and Chromium.

- In Karachi, the southern port city of Pakistan, studies have shown that each year about 30,000 people are dying as a consequence of contaminated drinking water.

- Although the chinese Metropolis Shangh hai has sufficient freshwater, it is concerned because of water scarcity.

- If the severe water problems in the above Mega-cities would be transferred to Germany, it is estimated that about every third citizen of Berlin would not have access to drinking water (Martin Geiger, WWF – expert for potable water). In the case of extreme weather conditions it would be necessary to boil the drinking water for several weeks. In addition, the rivers Spree, Havel and the lakes around Berlin would be contaminated, blocked with refuse or would be pumped out.
Contamination of Sea Water by oil – spills:
Chronicle of the most serious oil disasters

• March 1967: The supertanker Torrey Cayon struck a rock → loss of about 120'000 tons of crude oil leading to an oil spill between the Cornish mainland and the Scilly Isles.

• March 1978: Amoco Cadiz was a very large crude carrier who struck a rock close to the Bretagne → 223'000 tons oil spill over a coastal area of 350 km.

• June 1979: Explosion of the Oil rig Ixtoc I → Oil caught fire and about 1 million tons of oil contaminated the Gulf of Mexico → drilling rig Sedco collapsed into the sea.

• March 1989: Tanker Exxon Valdez grounded near Alaska → oil spill of 45'000 tons.

• 1991: Gulf war oil spill → about 1 million of oil contaminated the Persian Gulf thereby contaminating about 560 km of the coast. Reason: bombardments of tankers.

• October 1998: Cargo „Pallas“ → most serious oil spill at the German coast → 244 tons of crude oil spilled into the Wattenmeer → about 16’000 birds were killed.

• December 1999: Tanker „Erika“ sank off the coast of France near the Bretagne → Loss of 17’000 tons of fuel oil contaminating about 500 km of the coast. → about 300’000 sea birds were killed

• November 2002: The tanker „Prestige“ sank and caused an oil spill of about 70’000 tons of fuel oil → contamination of hundreds of kilometers of the north-west coast of Spain.

• April 2010: Explosion of the Deepwater Horizon Oil rig of „British Petroleum“ (BP) in the Gulf of Mexico → Explosion killed 11 men working on the platform and injured 17 others. After two days: → sinking of the platform. According to US Information, about 254 millions liters of oil are still swimming in the sea → exceeding by far all former oil spills!

a) Oil disaster of Deepwater Horizon, BP Mexico in April 2010.

b) Oil spill of BP Deepwater Horizon. An oiled dead bird at the coast at East Grand Terre Island of the Louisiana sea coast.

c) Tony Hayward presided over the worst oil US – history in Mexico. He is one of the most responsible person for this disaster in 2010. He had to resigne as BP chief officer.

d) Oil cleanup operations having adverse side effects on workers.
Possible actions after an oil spill disaster

After an oil spill disaster, several more or less effective treatments are possible, but considering the enormous ecological consequences, only a small protection is achieved. In spite of the astonishing regenerative capacity of nature, oil is an extreme environmental poison. A liberation of such huge quantities of oil as in the Gulf of Mexico is associated unavoidably with damages beyond repair. In the following we quote some possible measures and problems associated with such a huge oil spill:

1) **Containment with booms**: Booms are floating barriers used to contain the spilled oil and keep the slick from spreading. The method is not useful for very large spills.

2) **Skimming**: On the surface of water, oil can be skimmed with special ships using vacuums or oil absorbant ropes.

3) **Chemical dispersants**: The use of dispersants accelerates the natural dispersion of the oil and at the same time it prevents the adherence to suspended solid materials. Rough seas prevent the use of dispersants, because of the naturally accelerated dispersion. The mixture known as Corexit 9500 is aimed to disperse the oil at large depths below the surface, thereby avoiding the oil to rise to the surface so that it can not be washed ashore.

But environmentalists such as Terry Hazen from the Lawrence Berkeley National Laboratory are warning from the toxic effects of the Corexit components, especially since many solvents may be more harmful than the oil itself! In Great Britain Corexit has been forbidden already ten years ago. However, BP is still insisting at Corexit: since the beginning of the oil spill disaster in Mexico, more than 6.8 million liters of chemicals have been used!

4) **Burning**: is highly disputed, because by burning the oil, the problem is not solved but only transferred to other areas: The reason is that controlled burning of oil slick produces a large number of toxic gases. Furthermore, burning of oil in contact with sea water produces other toxic compounds. In addition, more than 10% of the oil is not burned but rather evaporates in the form of micro-droplets. These micro-droplets can eventually be transported as oily precipitations over distances of thousands of kilometers. Since burning produces particularly toxic compounds, this method is even less recommendable than chemical dispersion.

5) **Biodegradation**: It is well known that some bacteria are living on crude oil. In spite of the advantageous circumstances for the bioremediation of crude oil by means of oil-consuming bacteria and by other micro-organisms, the quantity of oil lost in the accident is simply way too large for the bacteria cultures in the natural cycle of the Gulf of Mexico. Furthermore, the oxygen content in water is replenished much too slowly by the heavy swell and by storms.

The tragedy of Mister Werner Kroh: his disdained invention

The German inventor Werner Kroh developed a non-toxic substance composed of a mixture of various rock meals (originally known as Gees61), which is able to neutralize crude oils. After a most gruelling large time during which he lost all his money as well as his health, he was finally able to sell his product to the Company „Oil Treatment International AG“ (OTI) in Switzerland for marketing. Today, the product is known as SOT-11 (Solid Oil Treatment) and LOT-11 (Liquid Oil Treatment). It is the best-selling product for indoor cleaning of oil.

Together with oil, the product reacts to amino acids, sinks to the ground and can even be consumed by fishes!

Until today the Oil Companies have ignored the product in a humiliating manner! For this reason it has never been used for decontamination of oil spills in seas!

6-A-2-3

6-A-2-4
Ecological impact of the oil disaster in the Gulf of Mexico

- The oil rig is located in the center of an area of wild-life reservation.
- Threatened by oil is in particular the delta of the Mississippi river and the wild-life reservation Pass à l'outre. Experts assume that the disaster will be worse than the one caused by the tanker accident of the Exxon Valdez.
- Trying to burn the oil slick under controlled conditions resulted in a considerable air pollution. In addition, by applying this strategy, the pollutants from the burned oil (polycyclic aromatic hydrocarbons) create toxic residues in the sea and enter the food chain.
- The US „National Oceanic and Atmospheric Administration“ (NOAA) declared that birds and mammals could escape more easily a fire than an oil slick. The effects to other marine creatures and to fishes are, however, less clear.
- Concerning the amount of oil still present in the sea after closing the leak at the bottom of the sea, there exist widely different opinions. NOAA believed that until the end of August 2010, about 74% of the oil has been burned, sucked off or biodegraded. On the other hand, scientists from the University of Georgia arrived at the opposite conclusion: Due to the chemical Corexit, about 80% of the split oil has simply been pushed below the surface of the sea. There, it still threatens the plankton and hence the entire food chain.
- The oxygen content of water has already been decreased by 30% and the concentration of methane is extremely high. Such a sizable decrease of oxygen causes a considerable damage of the plankton. In the long term, this strongly disturbs the base of life of marine creatures.

There exist more plastics than plankton in some seas!!

Trashing of Oceans:

A giant pacific plastic garbage is drifting through the North Pacific: The size of the plastic carpet is comparable to Africa!! In each square meter, up to 18'000 plastic chunk pieces are drifting through the world’s oceans, and this quantity is increasing each year by about 6.5 million tons! „Sea birds are confusing with increasing rate plastics with food and are dying an agonizing death!“
6. The battle about the „Blue Gold“

6.1 All the water on the Earth

R.6.1.1 The Big Thirst: The Secret Life and Turbulent Future of Water
Charles Fishman
Free Press: 2011

R.6.1.2 Vandana Shiva
Water Wars: Pollution, Profits and Privatization
Softcover, Pluto Press, ISBN 0745318371

R.6.1.3 WATER SCARCITY & CLIMATE CHANGE
Authored by the Pacific Institute
Jason Morrison, Mari Morikava, Michael Murphy, and Peter Schulte
Ceres, Pacific Institute, February 2009, A Ceres Report

R.6.1.4 H₂O: A BIOGRAPHY OF WATER:
Philip Ball, Weidenfeld & Nicolson (London, 1999; pp 313-346

R.6.1.5 p. 281: All the Water on the Earth (see p. 226 and Reference R.5.1.4:
Adam Niemann, http://www.adamniemann.co.uk/ vos/index.html

R.6.1.6 p. 282: Indian woman are carrying Water
„Neue Zürcher Zeitung“ : NZZ
R.6.1.7 p. 283 : Woman in Ethiopia are carrying Water
In Internet under „Woman in Ethiopia carry Water“ „Developing Countries , Issues in dam,building,rivers,effects…“

R.6.1.8 p. 284 : A Samburu – waterer in the Nyuru – mountains of North Korea quenching his thirst
Reference R.1.3.18 , p. 21

R.6.1.9 p. 285 : Drinking after the return of rain
Le Grand Livre de L’EAU

R.6.1.10 p. 286 : „Thirsty Zebras at a water – hole in Namibia“
Ethona National Parc , Namibia
in : Reference R.1.3.14 , p. 60

R.6.1.11 p. 287 : World population and Water scarcity
(Weltbevölkerung und Wasserknappheit)
www.dow-online.de/pdf/wasserknappheit.pdf

R.6.1.12 p. 288 : Virtual Water : General Remarks
http://de.wikipedia.org/wiki/Virtuelles_Wasser

R.6.1.13 pp 289 – 290 : Virtual Water
John Anthony Allan : was awarded the Stockholm Water Prize in 2008 for his revolutionary „Virtual Water Concept“, http://en.wikipedia.org/wiki/John_Anthony_Allan
http://en.wikipedia.org/wiki/John_Anthony_Allan
for Data at pp 289 and 290 see :

a) Virtual Water : by Darshan Sachda
see in Internet under : „Table of virtual water content“
b) http://edro.wordpress.com/water/virtual-water-content/

d) www.fao.org/nr/water/does/VirtualWater_article_DZDP.pdf

R.6.1.14 p. 291 , 292 : „Water Footprint“ :
p. 291 : Water Footprint – Wikipedia, the free encyclopedia
p. 292 : Water footprints of nations : Water use by people as a function of their consumption pattern .

R.6.1.15 p. 293 : Three shocking facts : Collected from different Literature Data by P. Brüesch

R.6.1.16 p. 294 : Israelis settlers are occupying the Water of Jordan
Bild der Wissenschaft 1/2000 , p. 36

R.6.1.17 p. 295 : Armer training of the Jordanians ; Bild der Wissenschaft 1/2000 , p. 37

R.6.1.18 p. 296 : In Africa , the waters of the Nile are shared by ten countries in the east and north of the continent .

upper picture : Dying child : found in : „Worst drought in the Horn of Africa“ lower picture : found in : „Drought in Kenya leaves dead animals“

ACIAR : Australien Centre for International Agricultural Research
http://www.focus.de/magazin/verlagssonnerveröffentlichungen.grue...

R.6.1.21 Water crisis in Mega – cities (Wasserkrise in Mega – Städten)
WWF – Studie : Megastädte in der Wasserkrise
http://www.gmx.net/themen/wissen/klima/92810mg-megastaedte-in-der-wasserkrise

WWF – Studie sieht Megastädte von verschärfter Wasserkrise bedroht
http://www.bluewin.ch/de/index.php/26,452131/WWF-Studie_sieht_Mega%C2%A4dte_vonversch%
Wasserkrise_bedro...

R.6-3

6 – 23
6.2 Methods for Water Treatment

R.6.2.1 WATER TREATMENT
From Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Water_treatment

R.6.2.2 WATER PURIFICATION
From Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Water_purification

R.6.2.3 PROCESS TECHNOLOGIES FOR WATER TREATMENT
Edited by Samuel Stucki; Asea Brown Boveri, Ltd., Baden, Switzerland

R.6.2.4 Reference R.3.2.8: Desalination of Seawater by Electrolysis

R.6.2.5 WATER MANAGEMENT, PURIFICATION & CONSERVATION IN ACID CLIMATES
Technomic Publishing Company, Inc.
851 New Holland Avenue, Box 3535
Lancaster, Pennsylvania 17604, USA
Copyright 2000 By Technomic Publishing Company, Inc.

R.6.2.6 CHEMISTRY OF WATER TREATMENT
Samuel Denton Faust and Osman M. Aly
CRC Press, 1998
2nd Edition

R.6.2.7 WATER RESOURCES OF ARID AREAS
D. Stephenson, E.M. Shemang, and T.R. Chaoka
Taylor & Francis, 2004

R.6.2.8 WATER TREATMENT MEMBRANE PROCESSES
American Water Works Association, 1996
Printed and bound by R.R. Donnelley and Sons Company
(22 contributors)

R.6.2.9 WATER AND SUSTAINABLE DEVELOPMENT: OPPORTUNITY FOR THE CHEMICAL SCIENCES
Workshop Report to the Chemical Sciences Roundtable
Publication year: 2004
Chemical Sciences Roundtable,
National Research Council
http://www.aquaprix.com/What_is_Distillation.html; p. 2

R.6.2.10 pp 297 – 300: Methods for Water Treatment and Purification
see: R.6.2.1, R.6.2.2, and R.6.2.4

R.6.2.11 p. 301: Distillation plant for households:
http://www.aquaprix.com/What_is_Distillation.html; p. 2

R.6.2.12 p. 302: Multi-stage flash distillation:
http://en.wikipedia.org/wiki/Multi-stage_flash
Desalination Plants in Jebel Ali near Dubai
http://www.lahneyer.de/en/en/projects/details/browse/0/project/212/model/1show/show
www.meyer.de

R.6.2.13 p. 303: Principle of Osmosis and Reverse Osmosis
Figures of Osmosis and Reverse Osmosis:
http://www.aquatechnology.net/aropix1.jpg
Reverse Osmosis:
http://en.wikipedia.org/wiki/Reverse_osmosis

R.6.2.14 p. 304: Perth Seawater Desalination Plant based on Reverse Osmosis:
Figures:
http://www.water-technology.net/projects/perth/

R.6.2.15 p. 305: Zeolites:
http://de.wikipedia.org/wiki/Zeolith_A:
The structure of Zeolith can accept Ca2+-ions and get rid of Na+-ions.
s. Dr. Arnold Chemie - Beratung, Claudia Arnold, ca@arnold-chemie.de

R-6-5
R.6.2.16 pp 306 - 310 : Literature about SODIS : Solar Disinfection
Martin Wegelin and Camille De Stoop, Eawag, Switzerland
"Potable water for all: promotion of solar water disinfection"

Household Water Treatment Systems:
Establishing a SODIS Reference Centre at Eawag
Sandec News 8 / 2007
The SODIS Africa Net (SAN)
http://www.sodisafricanet.org/

Solar water disinfection – Wikipedia, the free encyclopedia

R.6.2.17 p. 6-A-2-1 : The most serious oil disasters in history
http://www.welt.de/die-welt/wirtschaft/article8755697/De-schlimmsten-Oelkatastrophen...

R.6.2.18 p. 6-A-2-2 : Images from Google
a) in: "Images" from "Oil disaster in the Gulf of Mexico"
b) in: "Images" from "Deepwater Horizon – an oiled dead bird in coastal Louisiana"
c) in: "Images" from "Oelkatastrophe in the Gulf of Mexico"
d) in: "Images" from "Oelkatastrophe in the Gulf of Mexico"

R.6.2.19 pp. 6-A-2-3 - 6-A-2-5: Strategies to and consequences of oil disasters
a) Oil Spill Cleanup Procedures:
   http://www.ehow.com/way_5340818_oil_spill_cleanup-procedures.html
b) How do you clean up an oil spill?
   http://www.ceoe.udel.edu/oilspill/cleanup.html
d) Oil dispersants and environmental "cfapsshoot"
   http://www.msnbc.msn.com/id/37282611/ns/disaster_in_the_gulf/t/oil-dispersants-environmental-c...
e) Oil spill-Wikipedia, the free encyclopedia
   en.wikipedia.org/wiki/Oil_spill

f) Werner Kroh: CH-3077 Enggistein: Literatur über Bekämpfung der Oelpest
   - "Neue Energie – Technologien" (NET), Mai Juni 2010; Jahrgang Nr. 15, Heft Nr. 5/6
   http://www.highspirits.co.cc?p=308
   - http://www.importers.com/Exporter/ID.153218/OTI_Oil_Treatment_International_AG.html
   - "Der späte Triumph des Werner Kroh": Migros-Magazin 16, 18. April 2011
   - OTI AG – Product & Services
     Toxic Oil Spill Rains Could Destroy North America. Corexit Rain?
     http://www.besplatnestvari.biz/video/Toxic-Oil-Spill-Rains-Warn...

R.6.2.20 p. 6-A-2-6: Plastics in the Oceans
There exists much more plastics than plankton in the Oceans (KEYSTONE)
Author: Nils Guse: Forschungs- und Technologiezentrum in Büsön

R-6-6
7. Water, Light and Colours
The Figure shows the solar radiation spectrum for direct light at both the top of the Earth's atmosphere and at the sea level. The sun produces light with a distribution similar to what would be expected from a 5525 K (5250 °C) blackbody, which is approximately the sun's surface temperature. The absorption bands (H$_2$O) in the near-infrared region (NIR) are due to combination frequencies of the normal modes of vibration of the water molecules.
Spectral decomposition of Sunlight showing the visible range in an expanded scale

The wavelength range from $\lambda = 390$ nm to $\lambda = 750$ nm is the visible light and corresponds to the spectrum of the Sunlight. From $v = \frac{c}{\lambda}$ (where $v$ = frequency, $\lambda$ = wavelength, and $c$ = velocity of light), this corresponds to a frequency range from $v = 7.69 \times 10^{14}$ s$^{-1}$ to $v = 4.0 \times 10^{14}$ s$^{-1}$.

At the left-hand side the whole range of the electromagnetic spectrum from Gamma rays to Radio Waves is shown.

Water and visible light

Refraction of a light beam entering from air to water:
refractive index of air: $n_a = 1$,
velocity of light in air = $c_a = c_0$,
in water: $n_w = 1.33$,
$c = \frac{c_a}{n_w} < c_a \rightarrow$ refraction

The velocity of constant phase in water is smaller by a factor of $1 / n_w = 0.75$ than in air
$\rightarrow$ refraction

Law of refraction:
$\frac{\sin(\alpha)}{\sin(\beta)} = \frac{c_a}{c_w} = \frac{n_w}{n_a} = n_w$
**Explanation of refraction according to the principle of Huygen:** each point of contact along the interface between the two media with refractive indices \( n_1 \) und \( n_2 \) can be viewed as the starting point of a spherical wave, the velocity of which depends on \( n_1 \) and \( n_2 \). For the air-water interface, \( n_1 = 1 \) and \( n_2 = 1.333 \). The tangents to the principle circles of the sphere determine the refractive index.

---

**A rod immersed into water**

Real rod: dark-gray

Refraction gives rise to a sharp bend at \( P \) viewed from above, the (light-grey) rod appears to be bent.

A light beam radiates from the end of the rod at \( Q \) towards the surface of water at \( R \) (solid yellow line). At the transition into the air it bends in such a way that it enters the eye \( A \).

But the eye does not know anything from the refraction of light and assumes, that it is radiated from the point \( S \) of the light-gray rod (dashed yellow line).

In a refracting medium which is in contact with air an image lifting occurs (difference of height between \( S \) und \( Q \)) by the fraction \( r = (n - 1) / n \) of the real depth (difference of height between \( R \) und \( Q \)); for water with \( n = n_w = 1.333 \) the fraction \( r \) is equal to \( 1/4 \). This also accounts for the fact, that water, observed from above appears to be less deep than in reality. At the same time this is also the reason that a sloping rod immersed into a liquid appears to be bent.
Reflection and construction of mirror images

From the point $S$, light is radiated in all directions such as $SA_1$, $SA_2$, $SA_3$. The radiations are reflected by the mirror $O$.

$p_1$, $p_2$, $p_3$ are the verticals of $O$ through $A_1$, $A_2$, and $A_3$. $A_1B_1$, $A_2B_2$ and $A_3B_3$ are the reflected beams.

The reflected beams appear to be irradiated from the point $S_1$. Therefore, $S_1$ is the mirror point or the virtual image or mirror image of the light source $S$. To our eye it appears as though the light is emanated by the mirror point $S_1$.

The flash $A-B$, which is reflected by a mirror (a water mirror, for example), is therefore viewed by our eye in such a way, as though it is emanated by the mirror image $A_1-B_1$ (i.e. by the virtual image of the flash $A-B$).

Remark: a mirror image or a virtual image $S_1$, or a flash $A_1-B_1$ is also produced in shallow water or by a very thin mirror.

Interference of two plane waves

The two individual water waves interfere to produce a superimposed wave. If the maxima or minima coincide, they combine to produce a wave with larger amplitudes. If the maximum of the first wave combines with the minimum of the second wave, the two waves cancel each other.
If plane water waves are transmitted through a narrow slit with a slit width comparable to the wavelength of the water wave, circular waves are produced.

If two slits are present, two waves propagate and combine by interference. The superposition gives rise to constructive and destructive interference patterns.

The photograph shows the interference of two water waves at the surface of a stretch of water. Each wave propagates with a certain velocity in the radial direction. Depending on the location of interference, the two waves can reinforce or quench each other (s. Ref. R.7.1.9).
Mirror picture at the surface of a pond

Mirror image of a bridge

Friedensreich Hundertwasser
Little Egret reflected by shallow Water:
„Self-awareness“ or „Self-recognition“?

Depth of penetration of light into Sea Water

<table>
<thead>
<tr>
<th>Depth in m</th>
<th>Light penetration in open ocean</th>
<th>Light penetration in coastal waters</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td></td>
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</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Depth of penetration in clear water of the open ocean
Depth of penetration in contaminated coastal waters
mixed colours
To p. 325: left–hand Figure: „Light penetration in open Ocean“

The intensity of light decreases by about a factor 10 over a depth of 75 m. From this it follows that only a negligible part of light reaches the Sea floor in deep waters. The Figure at the left hand side of p. 325 shows the decrease and the spectral distribution of light over a depth between 0 and 200 m.

With increasing depth, the intensity of light is not only reduced dramatically but also its colour is changed. The absorption of the long-wavelength red light (with large wavelengths $\lambda$) by the water molecules is much stronger than for the short-wavelength blue light (with short wavelengths $\lambda$). It is only the violet light which is again strongly absorbed. The deeply penetrating blue light, however, is scattered most strongly by the water molecules (scattering is proportional to $1/\lambda^4$), which is responsible for the blue colour of water.

To p. 325: right–hand Figure: „Light penetration in coastal water“

The depth of penetration into coastal waters is strongly reduced. This is mainly due to the phytoplankton (p. 230) and by other components, which absorb and scatter light in different ways. The phytoplankton contains chlorophyll (p. 202) for which the absorption maxima are located near 430 nm (violet) and near 670 nm (red). The maximum transmission of light is therefore in the green part of the spectrum which explains the green colour of coastal water.
A rainbow is a phenomena of atmospheric optics. It appears as a circular light stripe containing many spectral colors with a characteristic sequence of colors.

A rainbow is generated by the interaction of approximately spherical water droplets with sun light. Depending on the wavelength of light, the incoming and outgoing light is refracted slightly differently. At the inner surface it is reflected according to its specific direction.
The sun rays 1 - 12 (upper half of Figure) arrive from the left and strike the spherically shaped rain drop. After striking its surface, they are refracted and at the back side they are reflected. The back reflected waves are refracted once more at the exit.

There exists a "minimal deviation angle" $\phi_{A,\text{min}}$, shown by the ray 7 above; all other rays have a larger deviation angle (extreme case: ray 1 with $\phi_A = 180^\circ$). Many rays (6, 8 - 11) appear in the vicinity of ray 7 with deviation angles $\phi_A$ very close to the minimal deviation angle $\phi_{A,\text{min}}$; in this region the concentration of light is relatively high. The minimal deviation angle $\phi_{A,\text{min}}$ is 138.7° (s. p. 331).

Formation and deviation angle of rainbows

(1) : $\Delta OAB : \alpha + 2 \theta_2 = \pi$ ;
(2) : $\Delta AOP : \theta_1 + \alpha + \beta = \pi$ ;
(3) : point $P : \phi_A + 2 \beta = \pi$ ;

(4) : Law of refraction : $\sin \theta_1 / \sin \theta_2 = n_{\text{water}} / n_{\text{air}} = N = 1.333$ at $\lambda = 600$ nm

Combining equations (1) - (4) and elimination of $\alpha$, $\beta$ and $\theta_2$ gives the following expression for the deviation angle $\phi_A$:

$$\phi_A = \pi + 2 \theta_1 - 4 \arcsin (\sin \theta_1 / N)$$
The viewing angle $q_B$ for the minimum deviation angle is given by

$$q_B = 180^\circ - f_{A,\text{min}} = 41.9^\circ \approx 42^\circ$$

(see Figures at p. 330, 333, 334)

$\theta_B$ is also known as the aperture angle of the rainbow.

The minimum of the deviation angle, $\phi_{A,\text{min}}$, follows from $d\phi_A / d\theta_i = 0$:

$$\sin(\theta_{i,\text{min}}) = [(4 - N^2) / 3]^{1/2}$$

$\theta_{i,\text{min}} = 59.4^\circ$ and $\phi_{A,\text{min}} = 138.7^\circ$ for $N = 1.333$.

Formation of coloured rings of rainbows: due to the dispersion of colours (larger refractive index for shorter wavelengths) the violet rays are more strongly deviated than the red rays; the violet rays therefore appear at a smaller viewing angle, i.e. at the inner part of the rainbow.
The rainbow appears as a bow, because it consists of rays, all of which are deflected backwards by approximately the same viewing angle $\theta_B \approx 42^\circ$ (relative to the sun rays).

The locus of all rays, which are forming the same angle with respect to a fixed axis (that of the sun rays), is a cone; the observer is viewing a section of this cone area, which depends on the distance to the droplets deviating the light.

A rainbow is the result of refraction and reflection of sunlight within raindrops. The different colours are refracted differently: the violet colour of the sunlight is refracted most strongly whereas the red colour is refracted most weakly. The deviations are $180^\circ - \theta_B$, where the viewing angle $\theta_B$ depends slightly on colour with a mean value of about $\theta_B = 42^\circ$. 
By a double reflection of the light within the droplets, a second rainbow is generated, also called the secondary bow which is weaker than the primary bow. The above picture shows that the order of the color arrangement in the secondary bow is reversed.

A complete and detailed theory of the rainbow is complex and must be based on wave theory.
The intensive primary bow is generated by a single reflection in the water droplets.

By a double reflection of light in the droplets, a second and considerably weaker rainbow is generated. This rainbow is called the secondary bow, in which the sequence of colours is reversed.

Intensive primary and secondary rainbows

Note the reversal of the colour sequence in the two rainbows.
A Rainbow between Sky and Water
7.3 Water Fountains, Droplets and Rivers

Water Fountain in Geneva during day

Height of Fountain: 140 m
Part of the light climbs upward by total reflection within the water Fountain; the diffuse light is due to scattering at the water droplets.
If a water droplet falls on a water surface, a circular wave is generated. After hitting the water surface, the droplet can be reflected and can split into several smaller droplets.

“Our knowledge is a droplet, what we do not know, is an Ocean”

Isaac Newton (1642 - 1727)
Part of the Rhine Falls in Schaffhausen (Switzerland)

The Iguacu Water Fall (Argentina / Brazil) - 1
The Iguacu Water Falls (Argentina / Brazil) - 2
Appendix: Chapter 7

Mirror of a bridge over the Loire - France
Principle of Caustic Effects

This Figure shows how the two kinds of caustics work: The waves act like curving mirrors (Caustic Reflections) and lenses (Caustic Refractions or Projections) at the same time.

The rays impinging the bottom of the pool give rise to a network of ridges of bright lines that is constantly in motion. This network is also called a diacaustic pattern (s. p. 7-A-1-4).

"Holocaust" is a word of Greek origin and means "sacrifice by fire". Holocaust: holos: "whole"; kaustos: "burnt"

During World War II, it refers to the genocide of European Jews and others by the Nazis.

7-A-1-3
Let’s imagine a sunny day at the swimming pool. A glance to the bottom of the pool shows a layer of a constantly moving pattern consisting of lines of bright light (see Figure above). These structures are so-called optical caustics (Diacaustics), i.e. lines of maximum intensities. They are produced by the fact that the small waves on the water surface are refracting the sunlight, thereby producing a bright pattern at the bottom of the pool: The rippling water surface concentrates the light only in specific regions at the bottom of the pool, rather than illuminating it uniformly. The Figure shows a snap-shot in time of a fascinating diacaustic pattern at the bottom of the pool.
7. Water, Light and Colours

7.1 Refraction, Reflection, and Interference

R.7.1.1 PHYSIK
Wilhelm H. Westphal (Springer Verlag (1956); 18. und 19. Auflage)
Brechung, Spiegelung (Reflexion) und Interferenz des Lichtes: (Refraction, Reflection and Interference of Light)
Refraction: pp 495 - 498
Reflection: 192 - 193, 489 - 490
Interference: 195 - 199, 535

R.7.1.2 p. 313: Solar radiation spectrum

R.7.1.3 p. 314: Spectral decomposition of Sun light
Ergebnisse Bildersuche nach spectrum of sunlight
www.thermoderngreen.com/tag/light-spectrum/

R.7.1.4 pp 315 - 317: Refraction of Light:
Josef F. Alward, PhD, Department of Physics, University of the Pacific
http://sol.sci.uop.edu/~jfalward/refraction/refraction.html

R.7.1.5 p. 317: Rod immersed into Water
(Eingetauchter Stab im Wasser)
http://www.filmscanner.info/Strahlenoptik.html
Patrick Wagner, Fa. ScanDig

R.7.1.6 p. 318: Construction of mirror images
Konstruktion von Spiegelbildern
http://library.thinkquest.org/22915/reflection.html
7.1 Interference of two plane waves

7.1.8 Water propagation through slits (Ausbreitung und Interferenz von Wasserwellen)
"http://www.alexander-unzicker.de/LK/050413.pdf"

7.1.9 Interference of two water waves
http://www.artbula.ch/artbula.Fotografie Images : postkarten

7.1.10 Eigenschaften des Wassers Wikipedia
de.wikipedia.org/.../Eigenschaften_des_Wassers

7.1.11 Mirror image of a bridge; Gespiegelte Brücke: Friedensreich Hundertwasser:
http://www.waldhausel.eu

7.1.12 Little Egret reflected by shallow Water
http://www.waldhausel.eu

7.1.13 Depth of penetration of light in to Sea Water
http://michaeldowney.net/colour-in-the-deep-s

7.2 Rainbow

7.2.1 Rainbow – Phenomena
http://sol.sci.uop.edu/~jfalward/physics17/chapter12/rainbowmeadow.jpg

7.2.2 Optical Caustics and Rainbows
http://www.physik.fu-berlin.de/~brewer/ph3_regenb.html

7.2.3 Theory of Rainbows
(Zur Theorie von Regenbögen, Glorien und Halos)
Eugen Willerding
Argelander Institut für Astronomie (AlFA)
der Bonner-Universität
Auf dem Hügel 71 (Raum 1.10)
D - 53121 Bonn / Germany

7.2.4 Formation of primary Rainbow

7.2.5 Formation of secondary Rainbow

7.2.6 Primary and secondary rainbows

7.2.7 A Rainbow between Sky and Water
Home Page of Eugen Willerding
http://www.astro.uni-bonn.de/~wllerd/
7.3 Fountains, Drops and Rivers

R.7.3.1 p. 341 : Water Fountains in Geneva during day
(Wasserfontäne in Genf bei Tag)
http://www.ville-ge.ch/fr/decouvrir/en-bref/jet.htm

R.7.3.2 pp 342, 343 : Water Fountains in Geneva during night - 1 and 2
(Wasserfontäne in Genf bei Nacht)
File: Jet d'eau de Genève de nuit.jpg
http://commons.wikimedia.org/wiki/File:Jet_d_eau_de_Gen%C3%A9ve_de_nuit.jpg

R.7.3.3 pp 344 - 347 : Raindrops are falling on to water
(Regentropfen fallen auf Wasser)
http://www.chiark.greenend.org.uk/~andrewm/misc-photo/raindrops.jpg

R.7.3.4 p. 348 : Part of the Rhine Falls in Schaffhausen, Switzerland
http://www.pictures-switzerland.com/rheinfall/rheinfall-h38y.jpg

R.7.3.5 pp 349, 350 : The Iguazu Water Falls in Argentina (Brazil)
(Der Iguazu Wasserfall in Argentinien (Brasilien))
http://www.lauerweb.de/Lauerweb/images/foz-di-iguazu-2.jpg

Over a width of nearly three times of that of the Niagara – Falls, the water precipitated here into the depths and from far away it sounds as an earthquake.
The droplets in the atmosphere produce a rainbow.
In the language of the Guarani – Indians, Iguazu means „Large Waters“.
(Auf einer Breite von fast dreimal so gross wie die Niagarafälle stürzen die Wassermassen hier in die Tiefe, und von weitem schon tönt es wie ein Erdbeben. Die Tröpfchenatmosphäre schimmert in allen Regenbogenfarben. Iguazu bedeutet in der Sprache der Guarani-Indianer „grosse Wasser“.)

R-7-4
8. Water in Art and Culture
8.1 Water in Painting and in Photography

„The Fountain of Youth“

Lucas Cranach, 1472 to 1553
Lucas Cranach: The “Fountain of Youth” - Detail

Arrival of the old Woman

Leonardo da Vinci (1452 - 1519)

A jet of water flows into a standing body of water and causes a turbulence
Katsushika Hokusai (1760 - 1849)

Gustave Courbet (1819 – 1877)
Cloud study

John Constable: English romantic painter (1776 - 1837)

Claude Monet (1840 – 1926)
The Japanese Bridge in Monet's Water–lily pond in Giverny

„The Water–Lily Pond“ in Claude Monet's Garden in Giverny
Claude Monet: Water-lilies

Tivoli is famous for its magnificent gardens and the fountains of the Villa d'Este near Rome.
Dew drops on a leaf

Dewdrops on Spider web

8 – 7
Raindrops

A water drop falling on a water surface
8.2 Water Sound Images

Ernst Chladni
German physicist
(1756 – 1827)

Ernst Chladni excited his sound images of sand using a violin bow
Dr. Hans Jenny
Swiss physician
(1904 - 1972)

Experimental setup for the excitation of sound images - 1

Hans Jenny: Electrical generation of Chladnis sound images - 2
Jenny called this new area of research cymatics, which comes from the Greek "kyma": waves. The higher the frequency of excitation, the more complex is the pattern. In the dark areas within the material on the plates, the vibrations are most intense.

Hans Jenny: Sound images within water drops for different excitation frequencies and different volumes of the drops.
Hans Jenny:
Cymatic water patterns: vibrating water drops

Water sound images

Alexander Lauterwasser
German philosopher and artist

Cymatic water patterns
In addition to the frequency, the shapes and structures of the water sound images also depend on the amplitude, the water quantity and the temperature.
Analogies:

- bellflower
- Water sound images as a function of frequency
- Hibiscus flower
- cornflower
- snail shell
- grapefruit
- cauliflower - floret or romanesco – brocoli

Housi Knecht:
The „strings“ of the harp are jets of water
8.3 Water in Literature

Johann Wolfgang von Goethe (1749 - 1832)
The poem
„Gesang der Geister über den Wassern“
or
„Song of the Spirits over the Waters“

was written by Johann Wolfgang von Goethe on 9–11 October 1779 at Lauterbrunnen in Bern, Switzerland. It was sent to Charlotte von Stein on 14 October and published in Goethe's chief works in 1789.

The Water Fall, called „Staubbach“, inspired the poem. The image of falling water and rising spray is extended to cover the course of the river down to the lake and provides a parable of the life of men.

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Song of the Spirits over the Waters

The soul of men is like the waters:
It comes from heaven, it returns to heaven,
and down again to earth must go,
ever ending.

When from the high, sheer wall of rock
The pure stream pushes, it sprays its lovely vapor
in billowing clouds toward the smooth rock,
it goes enshrouded,
Softly hissing down to the deep.

Opposing its fall. Annoyed, it foams
step by step into the abyss.

Wind is the wave's handsom suitor:
Wind stirs up from the depths foaming billows.

Soul of men, how like to the water!
Fate of men, how like to the wind!

Johann Wolfgang von Goethe
Antoine de Saint Exupéry
(1900 - 1944)

A Poet of aviation
and a Father of
Air Transport

“What makes the desert beautiful is
that somewhere it hides a well“
WATER!
WATER, you have neither taste, nor colour, nor scent. You cannot be defined. You are savoured, but you remain unknown. You are not a necessity of life: you are life. You fill us with a joy that is not of the senses. You restore to us all powers we had surrendered. Through your grace, all the desiccated springs of our hearts flow forth once more.

Of all the riches in the world you are the greatest, and the most delicate, you who lie so pure in the womb of the Earth. A man can die by a magnesium spring. He can die a yard from the salt lake. He can die in spite of a quart of dew with chemicals suspended in it. You can accept no mixing, bear no adulteration; you are a sensitive divinity...

But you spread within us an infinitely simple happiness.

Antoine de Saint Exupéry, from: “Wind, Sand and Stars” or “Terre des Hommes”

(English Translation)
The Goddess

In the beginning, before the world was created, God was wandering around through the nothingness trying to find something. He had almost given up hope and was dead tired when suddenly he came to a big shed. He knocked. A Goddess opened the door and asked him to come in.

She said she was just busy working on Creation but he should take a seat for a while and watch what she was doing. At the moment she was planting various water plants in an aquarium.

God was astonished at what he saw. He would never have come up with the idea of creating a substance like water. It is precisely this, the Goddess said smilingly, that was, so to speak, the basis of life.

After a while God asked if perhaps he could help a bit and the Goddess said she would be very grateful if he could take the water and the things she had created so far to one of the planets that she had set up a little further in the back. She would like to start with the least significant one as a test.

So God began to deliver the Goddess' creations one after the other from her shed to the Earth, and it is not a surprise that later, people on this planet knew only about the God who had brought it all and who they assumed was the actual creator of all.

Of the Goddess who had thought it all up, however, they knew nothing, and therefore it's high time she gets mentioned.

Franz Hohler
translated from „Die blaue Amsel“
8.4 Water and Music

H₂O – The Mystery, Art, and Science of Water

MUSIC AND WATER

A Summary from
Professor Jonathan Green

Water – Music Festival
The Water Music of Händel

The Water Music is a collection of orchestra movements, often considered three suites, composed by Georg Friedrich Handel (1685–1759). It premiered on 17 July 1717 after King Georg I. had requested a concert on the River Thames. The concert was performed by 50 musicians playing on a barge near the royal barge from which the King listened with close friends.

Franz Liszt: Les Jeux d’Eau à la Ville d’Est

„Les jeux d’eau à la Ville d’Este“ (The Fountain of the Villa d’Este) in Tivoli near Roma is one of the 19th century most brilliant demonstrations of pictural music, and one of the most virtuosic pieces Liszt ever wrote.

„Les jeux d’Eau“ is a piano piece reminiscent of the fluidity of water and its transparency.
Maurice Ravel: Jeux d’Eau

Jeu d’Eau is a piece for solo piano. The title is often translated as „Fountains“, „Water Games“, or „Playing Water“.

According to Ravel, he was inspired by Franz Liszt’s piece „Jeux d’Eau à la Villa d’Este“ (p. 392). It appeared in 1901.

Bedrich Smetana: The Moldau

Vltava, also known by its German name „The Moldau“, was composed by Smetana between 20 November and 8 December 1874. It is about 12 minutes long, and is in the key of E minor.

In this piece, Smetana uses tone painting to evoke the sounds of one of Bohemia’s (Böhmen’s) great rivers.

The piece contains Smetana’s most famous tune written below:

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8 – 23
Further examples for „Music and Water“

Frédéric Chopin:
Prélude, op. 28, no. 15, „The Raindrop“

Claude Debussy:
„La cathédrale englouté“;
„La Mer“;
„Reflets de l’eau“

Camille Saint-Saëns:
„Aquarium“ from Carnival of the Animals

Ralph Vaughan Williams:
„Sea Symphony“

Antonio Vivaldi:
2 Concerti, RV 253 and 433, „La Tempesta di mare“

Ludwig van Beethoven:
Symphony No. 6: 2th mouvement: „Scene at the brook“; 4th mouvement: „The Thunderstorm“

Franz Schubert:
„The Trout Quintet“ in A major, Opus post. – D 667 (1819)
The piece is known as the „Trout“ because the fourth movement is a set of variations on Schubert’s earlier Lied „Die Forelle“ (The Trout).
The Sourcerer's Apprentice - J.W. Goethe (1797/1827)

Good! The sorcerer, my old master
O, you ugly child of Hades!
Left me here alone today!
The entire house will drown!
Now his spirits, for a change
Everywhere I look, I see
my one wishes shall obey!
Be you damned, old broom,
Having memorized
why won't you obey?
What to say and do,
Be a stick once more,
With my powers of will I can
please, I beg you stay!
Do some witching, too!

Go, I say, go on your way,
Is the end not in sight?
do not tarry, water carry,
I will grab you, hold you tight,
do not tarry, water carry,
with my axe I'll split the brittle
and prepare a bath for me!
old wood smartly down the middle.

Come on now, old broom, get dressed,
Here he comes again with water!
these old rags will do just fine!
Now I'll throw myself upon you,
do not tarry, water carry,
you're a slave in any case,
and do not stop.
and today you will be mine!
I will test, o spirit, on you.
May you have two legs,
and a perfect hit!
and a head on top,
See how he is split!
take the bucket, quick
and the sharpness of my axe
hurry, do not stop,
with my axe I'll split the brittle
let it flow abundantly,
and I can breath free!
and prepare a bath for me!

Look, how to the bank he's running!
Woe is me! Both pieces come to live anew,
And now he has reached the river,
and I can breath free!
he returns, as quick as lightning,
now, to do my bidding I have servants two!
once more water to deliver.
Help me, o great powers!
Look! The tub already
Please, I am begging you!
Ah, here comes the master!
And now he is filling
Is allmost filled up!
From the spirits that I called
Every bowl and cup!
Sir, deliver me!

Stop! Stand still! Heed my will!
And they're running! Wet and wetter
I've enough of the stuff!
Get the stairs, the rooms, the hall!
I've forgotten—woe is me!
What a deluge! What a flood!
What the magic word may be.
Lord and master, hear my call!
He keeps bringing water
Ah, here comes the master!
Quickly as can be,
I have need of Thee!
and a hundred rivers
From the spirits that I called
he poors down on me!
Sir, deliver me!

Oh, the word to change him back
„Back now, broom, into the closet!
Into what he was before!
Be thou as thou wert before!
Oh, he runs, and keeps on going!
Until I, the real master
Wish you'd be a broom once more!
call thee forth to serve once more!“
He keeps bringing water
call thee forth to serve once more!“
Quickly as can be,
and a hundred rivers
and a head on top,
and a hundred rivers
he poors down on me!

No, no longer can I let him,
he poors down on me!
I must get him with some trick!
I am beginning to feel sick.
What a look! - and what a face!

This ballad may be representative for the occurrence of various catastrophes among others for global floods as a result of anthropogenous climate change (see Chapter 5, pp 259–263).
The Sorcerer’s Apprentice

Johann Wolfgang von Goethe

The old broom

The Sorcerer’s Apprentice (Picture from Ferdinand Barth (1882))

The old Master
8. Water in Art and Culture

8.1 Water in Painting and in Photography

R.8.1.1 p. 353: Lucas Cranach the Elder: „The Fountain of Youth“
http://de.wikipedia.org/wiki/Bild:Lucas_Cranach_d._%C3%84.007.jpg
The „Fountain of Youth“ as well as the „Fountain of eternal youth“ and the „Fountain of eternal Life“ often represent mythological pictures of a lake containing water which provides eternal youth and eternal life for everybody who is drinking it.

R.8.1.2 p. 354: The „Fountain of Youth“: Detail: „Arrival of old women“
http://www.gallery.net/popup_image.php?lid=6005/isid/0/XTCsid/6a61b185d227

R.8.1.3 p. 355: Leonardo Da Vinci: A jet of water is flowing into standing waters and creates a swirling
http://witcombe.sbc.edu/water/images/leonardowaterstudy.jpg

(From the Series of the 36 pictures of the Fudschijama)
www.kunstkopie.ch or Kanawaga/18285.html

R.8.1.5 p. 357: Gustave Courbet: The Wave (Die Welle)
www.kunstkopie.ch/a/courbet-gustave/die-welle.html

R.8.1.6 p. 358: „Cloud study“ from John Constable

R.8.1.8 p. 360: „The Japanese bridge in Monet’s Garden in Giverny“
Björn Quellenberg@Kunsthaus Zürich; Foto 2004
www.cosmopolis.ch/kunst/66/claude-monet-augenkrankheiten.htm

R.8.1.9 p. 361: „The Water Lily Pond“ in Claude Monets Garden in Giverny
www.cosmopolis.ch/kunst/66/claude-monet_augen...

R.8.1.10 p. 362: Claude Monet Water Lilies
www.allforthegreatergood.com/


R.8.1.12 p. 364: Dew drops on grass

R.8.1.13 p. 365: Dewdrops on Spider webs
http://upload.wikimedia.org

R.8.1.14 p. 366: Raindrops Raindrops Photograph by Kenna Westerman Raindrop Fine Art…

R.8.1.15 p. 367: Thomas Block: A water drop is falling on water in Google under: “The art of water”→images
s. also under: view:stern.de.de/spotlight/popup?page=24 – (VIEW SPOTLIGHT)
Image title: Water (Wasser)
Comment in German: … Auf seinen Fotos zeigt Thomas Block faszinierende Makraufnahmen von Tropfen, die den Beobachter erstaunen lassen. Wie macht ein Fotograf solche Bilder? Wurden sie digital nachbearbeitet? Wurden Spiegelungen hinzugefügt? „Nein“, sagt Thomas Block, „die digitale Bildbearbeitung beschränkt sich auf Schnitt, Schärfe und auch mal auf das Entfernen unschöner Flecken. Es wird nichts an der Form oder den Spiegelungen verändert oder hinzugefügt. …..

R.8.2.0 CYMATICS (Kymatik): „Wellenlehre und Schwingungen“
www.cymaticsourse.com/ - 26k
„Cymatics, the study of wave phenomena, is a science pioneered by Swiss medical doctor and natural scientist, Hans Jenny (1904 - 1972). For 14 years he conducted experiments animating inert powders, pastes, and liquids into life-like, flowing forms which mirrored patterns found throughout nature, art and architecture. What’s more, all of these patterns were created using simple sine wave vibrations (pure tones) within the audible range. So what you see is a physical representation of vibration, or how sound manifests into from through the medium of various materials“.

R.8.2.1 p. 369 at left hand side: Ernst Chladni:
http://en.wikipedia.org/wiki/Ernst_Chladni
p. 369 at the right hand side: CHLADNI PLATE INTERFERENCE SURFACES
Paul Barke, April 2001

R.8.2.2 pp 370 - 374: Sound images of Hans Jenny (Klangfiguren von Hans Jenny)
p. 370: Hans Jenny with experimental setup
(Figure arranged by P. Brüesch)

R.8.2.3 p. 371: Electrical excitations of Chladni - sound images
http://nemesis.ucsc.edu/waves/visible/visible2.html
(Figure arranged by P. Brüesch)

2. Water Sound Images

R-8-3
8 – 28
R.8.2.4  p. 372: Kymatik: Sound images of Hans Jenny
(Wasserklang - Figuren von Hans Jenny)

R.8.2.5  p. 373: Cymatics: The Structure and Dynamics of Waves and Vibrations by Hans Jenny
(Klangbilder im Wassertropfen …)
http://www.world-nysteries.com/sci_cymatics.htm

R.8.2.6  p. 374: Vibrating water droplets
(Schwingende Wassertropfen (Hans Jenny)
http://www.schwingung-undgesundheit.de/Experimente.html

R.8.2.7  p. 375: Water Sound Images - 1
The creative Music of the Universe
(Alexander Lauterwasser
AT Verlag (2004)

R.8.2.8  p. 376: Water sound images - 2
Secrets and beauties of interacting water - and sound colorus
(Geheimnisse und Schönheit im Zusammenspiel von Wasser - und Klangfarbe)
Lauterwasser Alexander
AT Verlag (2005)

R.8.2.9  p. 377: Water sound images - 3
(Wasser - Klang - Bilder-3)
http://www.flutetrends.ch/Lauterwasser.html

R.8.2.10 p. 378: Analogies of Sound Images - 4
Klangbilder mit Analogien
Alexander Lauterwasser
http://www.schwingung-undgesundheit.de/Experimente.html

R.8.2.11 p. 379: WATER – HARP
(WASSERHARFE)
Water – Light sculpture containig water strings
Housi Knecht:
Wasser - Licht - Skulptur : Material - Stahl feuerverzinkt und Bronze patiniert . Eingebauter
(Wassertank mit Pumpe für vom Wasseranschluss unabhängigen Betrieb .
Indirekte 12 Volt - Halogen - Beleuchtung .)

8.3 Water in Literature

R.8.3.1  p. 381: Johann Wolfgang Goethe (1749 – 1832)

R.8.3.2  p. 382: Waterfall near Staubbach
(inspired Goethe for his famous poem)
www.grindelwald-events.ch

R.8.3.3  p. 383: Song of the Spirits over the Water
(Gesang der Geister über den Wassern)
Johann Wolfgang von Goethe
http://www.onlinekunst.de/goethe/gesang_der_geister.html

R_8_5
8.3 Antoine de Saint-Exupéry

\[ \text{http://images.google.ch/imgres?imgurl=http://imansolas.freeservers.com/ASExupery} \]

8.3.1 p. 384: "The Little Prince,"
Antoine de Saint-Exupéry
\[ \text{http://images.amazon.com/images/P/015601398301 LZZZZZZZ.jpg} \]

8.3.2 p. 385: "Wind, Sand, and Stars"
Antoine de Saint-Exupéry

8.3.3 p. 386: "Terres des Hommes"
Antoine de Saint-Exupéry

8.3.4 p. 387: "Hymn to Water – 1"

8.3.5 p. 388: "Hymn to Water – 2"

8.4 Water and Music

8.4.1 H2O – The Mystery, Art, and Science of Water
Chris Witcombe and Sang Hwang; Sweet Briar College
MUSIC AND WATER (23.09.2007)
Professor Jonathan Green
\[ \text{http://witcombe.sbc.edu/water/music.html} \]
The three-page overview provides a good summary of „Water as a Musical Tool“, and „Water as Inspiration in Music“

8.4.2 p. 390: Water Music Festival
\[ \text{http://watermusicfestival.com/} \]

8.4.3 Water Music of Handel
History of Water Music
\[ \text{http://en.wikipedia.org/wiki/Water_Music_(Handel)} \]

8.4.4 p. 391: Water Music of Handel
Image of „Water Music“
\[ \text{www.thisislondon.com.uk/events/article-2341175} \]

\[ \text{http://everynote.com/piano.show/1321(note)} \]
\[ \text{http://everynote.com/goods.pic/Lis_Ann3-4.gif} \]

8.4.6 p. 393: Maurice Ravel: „Jeu d’Eau“
The title is often translated as „Fountains“, „Water Games“, or „Playing Water“
\[ \text{http://en.wikipedia.org/wiki/Jeu_d%27eau_(Ravel)} \]

8.4.7 p. 394: Bedrich Smetana: “The Moldau”
\[ \text{en.wikipedia.org/wiki/Ma_vlast} \]

8.4.8 p. 395: More examples for „Music and Water“
Reference R.8.4.1

Reference R.8.4.1
9. Water in World Religions, in Psychology and in Philosophy
9.1 Water in World Religions: General

Water in World Religions: Examples

In all world religions, water is of central importance:

- In all world religions, water is ambivalent, i.e. it is a symbol for both birth and death.
- Water is associated with purification and spiritual force.
- Living water is often associated with running water
  - John the Baptist baptizes Jesus in the Jordan
- Holy water is a sign of blessing and is associated with life and purification
- The Flood is the punishment of God for the sins of men
- Hinduism: Purification by a bath in the holy water of the Ganges
Water in the five world religions:
Judaism, Christianism, Islam;
Buddhism and Hinduism

In all five world religions, water is of central importance.

The main reasons are:

• Without water there is no life

• Water possesses a purifying force

• In every religion, water is a sign for both, birth and death.

Significance of Water in World Religions

Because of its natural qualities, water is of high significance in all world religions: it is often associated as being the residence of gods, ghosts and other powers; it is often even admired as a holy force.

In many religious and mythological narrations about the genesis of world, water symbolizes the state of creation or even the basic source for all beings.

The world's origin is the Sea, which creates the other cosmological elements. As a source of all life, water is considered to constitute a life-generating principle of order.

On the other hand, water is considered to be a power of destructive chaos, which destroys the world catastrophically as the flood, and threatens life. Seas and oceans are viewed as menacing homesteads of the evil.
9.2 Water in Judaism

Ritual purification with vivid water, i.e. with flowing water

Michelangelo: The Creation of the Sun and the Moon
The first book of Moses, called

GENESIS

1 In the beginning God created the heavens and the earth.

2 Now the earth was formless and empty, darkness was over the surface of the deep, and the Spirit of God was hovering over the waters.

GENESIS

6 And God said, Let there be a firmament in the midst of the waters, and let it divide the waters from the waters.

7 And God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament: and it was so.

9 And God said, Let the waters under the heaven be gathered together unto one place, and let the dry land appear: and it was so.

10 And God called the dry land Earth; and the gathering together of the waters called he Seas: And God saw that it was good.
Moses in the basket at the shore of the Nile

Michelangelo’s Moses
During the escape of the Israeli from the Egyptians

Moses divides the Red Sea

The Flood

“The Flood” from Buonarrotti Michelangelo (1475 - 1564)
In the background is Noah's ark, the only ship that would survive the Flood
“The Flood”: Section from the painting of Michelangelo

The Flood
Leonardo da Vinci
Noah’s Flood and Reality

Did a great flood once surge into the Black Sea, forming the basis of a Biblical tale?

Mark Siddall (University of Bern, Switzerland) investigates a computer model that has added weight to the idea.


„Oceanographers must have a natural interest in extreme events“
If we can't resolve the occurrence of such a huge flood, then what can we resolve?

Mark Siddhal

See also: W. Ryan and W. Pitman:
„Noah's Flood: The New Scientific Discoveries about the Event that Changed History“

(Simon and Schuster, New York 2000)

For purification, the Mikvah, a font filled with water, is important. The water must be composed at least partly of rain water and spring water. The latter originates from heaven and represents the relation to the primary flood. In the Mikvah, people take an immersion bath in order to regain the original spiritual purity.
During the immersion bath a spiritual force is exchanged.
9.3 Water in Christianity

In Jewish and Christian religion water is a symbol of the origin of creation. Water is a hierophany (i.e., a physical manifestation of the holy or sacred). It can represent a creative force of life or a destructive force of death.

- The fountains in the desert are similar to the sources in the mountains: a reason of pleasure of the nomads.
- The narration of the "Flood" (1. Mose 6 ff.) will remain a symbol of destruction as well as of salvation.

Pontius Pilatu's manual ablutions during the trial against Jesus (Math. 27, 24) is of Jewish origin. With his ceremonial protest of hand washing, Pilatus rejects any responsibility for the consequences.
Jesus Christ considered Water as the Symbol for eternal life.

Jesus proceeds to say:
“Unless one is born of water and the Spirit, you cannot enter the kingdom of God.”

John 3:1-13

At the Jacob’s well, Jesus answered to the Samaritan woman:
“Whosoever drinking of this water (from Jacob’s well) shall thirst again; but whosoever drinketh of the water that I shall give him shall never thirst; but the water that I shall give him shall be in him a well of water springing up into everlasting life.”

(John 4, 13, 14)

John the Baptist

When he was 30 years old, he went into the desert, to Jerusalem, and to the Jordan and declared the arrival of the Messiah.

Many people admired him, and many let have been baptized from him; Jesus also was baptized from him.

John the Baptist says:
“Behold the Lamb of God (Jesus), which takes away the sin of the world.”
John the Baptist baptizes Jesus in the water of the Jordan. Two angels are carrying the robe of the Messiah.

The Baptism of Jesus
Fresco de Giotto di Bondono
(1267 - 1337)

Jesus walking on the Sea and the rescuer in storm at high Sea

The physical laws are abolished and replaced by the divine laws!

Jesus, the rescuer in storm at high Sea!
After the baptism of a baby: his head is still held over the holy water font while his hands are directed against the future life.

The Grotto of Massabielle is a place of pilgrimage in Lourdes (France). For Bernadette Soubirous it was the place of apparition of the Blessed Virgin. With her help Bernadette discovered a water source. Today, the water of this source is believed to possess a strong healing force.
And he (one of the seven angels) shewed me a pure river of water of life, clear and as crystal, proceeding out of the throne of God and of Lamb.

In his midst of the street of it, and on either side of the river, was there the tree of life, which bare twelve manner of fruits, and yielded her fruit every month: and the leaves of the tree were for the healing of the nations.
„Be praised, my Lord,
through Sister Water;
She is very useful,
and precious, and pure.“

From: „The Canticle of the Sun“,  
Francis of Assisi
9.4 Water in Islam

Significance of Water

Do not the Unbelievers see that the heavens and the earth were joined together (as one unit of creation), before we clove them asunder? We made from water every living thing. Will they not then believe?

“The Holy Qur’an”
Surah 21: Al–Ambija 30 (The Profets)

In Islam, water is most important for purification. Muslim should be ritually pure, before they are approaching God in prayer.
In Islam, washing one’s hands frees oneself from the sins which have been committed by hands.

The ritual washing must be performed in running and pure water.

Running water signifies vivid water. The pure river carries the sins and dirt away.
9.5 Water in Buddhism

Water is a symbol for Life

In Buddhism, water symbolizes life, the purest form of food, and water is the particular element which in nature carries everything together.

Water symbolizes purity, clarity and calmness, and reminds us to cleanse our minds and attain the state of purity.

Water is used to clean away dirt. When everyone sees you (the water), they are happy and joyful. This is because they are reminded that they can wash away the filth of their minds. They should wash away selfish and unkind thoughts and be clean and pure like you.

“It is as with Ice and Water:
Without Water there is no Ice...”

(Hakuin’s song of meditation)

Water is also most important for funerals (see Reference R.9.5.2)
To a weak or indispositioned sick person, water is poored over his head.

The water then causes an energetical purification which improves the illness rapidly.

A Shingon Buddhist practitioner mediates under frigid waterfalls at the Oiwasan Nissekiji Temple in Toyama, Japan. In Shingon, a school of Japanese esoteric Buddhism, waterfall mediation, or "takigyo", is used to focus the mind and increase self-awareness.
Water sustains and makes possible new life.

Since water is given to us and is of such prime importance, it must also be returned.

For this reason it is sacrificed to the Gods in beautifully shaped bowls as a sign of admiration, of deep respect and of gratitude.
9.6 Water in Hinduism

Water as an original force

Water is considered to be an original force; it is the only element which is not assigned to a divinity.

The water of the Ganges is holy because its origin is the Himalaya, the highest known source of all, and falls to the valley.
The purification in the Ganges is a meditation which helps to understand the greatness of god.

A bath in the Ganges can be considered as a search to himself.

Hindu are purifying themselves in the holy river Ganges in order to gain freedom from their sins.
Water is offered God as a gift before washing themselves.

By this symbol of sacrifice, the gift of God is returned to the creator.

Water symbolizes the circle of life: everything has its origin from water and is created from water. After death, the ash is returned into the holy river.
9.7 Water in Psychology and in Philosophy

Water is an archetype i.e. a source image of the soul or of the unconscious layers of personality, which are inhabited by mysterious beings (see Carl Gustav Jung, p. 441).

- Water is the basic symbol of all unconscious energy in dreams:
  - positive: for standing and flowing waters:
    - ponts, lakes, Seas, strands, streams and rivers
  - negative: riptides, torrents, flood

- On the one hand, water is the most well-known life symbol, and on the other hand, water is also a symbol for death.

  Hence, the symbol water is ambivalent.
Carl Gustav Jung (1875 – 1961)

Water is an Archetype:

Water is a symbol of life, cleansing, and rebirth. It is a strong life force, and is often depicted as a living, reasoning force.

Thales of Miletus, 600 BC.

“The principle of all things is water.”

“Everything is made of water, and everything returns to water.”

Thales of Miletus thought that water is the principle basic substance of all existing things and that everything is imbued by the spirit of the Gods, and therefore, to everything is given a soul to.

“Spirit and matter are same”.

Water and Greek philosophy
The washing of the feet of Jesus by Maria Magdalena

Johann Christof Haas (1753 – 1829)
Baptism Sainte – Chapelle
Last quarter of the 12th century
Scene of baptism. Stained glass, Paris

The Baptism
References: Chapter 9

9. Water in World Religions, in Psychology and in Philosophy

9.1 Water in World Religions

R.9.1.1 Atlas of the World’s Religions
Second Edition
Frederick Denny
Nov., 2007

R.9.1.2 Hammond Atlas of World Religions
by Hammond (Author, Editor) and Stuart Murray (Author)

R.9.1.3 Atlas of World Religions
By Prentice Hall
Published Hall, 2006

R.9.1.4 Water in World Religion: An Introduction
Terje Oestigaard
Unifob Global

R.9.1.5 Water in World Religions
Jela Hasler and Ruben Hollinger
Kantonsschule, CH-Wettingen
(Switzerland)

R.9.1.6 World Water Day: Facts and Figures about Water Religions and Beliefs
http://www.worldwaterday.org/page/422

R.9.1.7 Facts and Figures - Water and Religions
http://fami.oszbuecherverw.de/wasser_in_religionen/index.html

R.9.1.8 LE GRAND LIVRE DE L’EAU
9.2 Water in Judaism


R.9.2.3a The Bible – GENESIS: The Creation and the Flood (DVD)

The Genesis story begins with the creation of Man and Woman, the sin committed by Adam and Eve, and the temptation by the snake, which led to their banishment from Paradise. The story continues with the first crime committed by mankind, Cain’s murder of his brother, the condemnation of God, mankind corruption and evil, and God’s regret from having created the Earth. The choice of Noah, a just and upright man, to build the Ark, the flood and its clearing the way for a new mankind, the pact of the eternal Covenant between God and all living beings, are told through the clear and simple words of an old named shepherd.

R.9.2.4 p. 405: Moses in the Basket: A Princess finds a Basket

The Bible story of baby Moses by Linda Sue Pochedzay Edwards
www.childrenschapel.org/biblestonries/babymoses.html

R.9.2.4a According to the Bible: EXODUS: Chapter 2:

And there went a man of the house (a slave) of Levi, and took wife a daughter of Levi. And the women conceived, and bare a son: and when she saw him that he was a goodly child, she hid him three months. And when she could no longer hide him, she took for him an ark of bulrushes, and daubed it with slime and with pitch (to form a basket) and put the child therein and she laid it in the flags by the river’s (the Nile’s) spring. And his sister stood afar off, to wit what would be done to him. And the daughter of Pharaoh came down to wash herself at the river; and her maidens walked along by the river’s side: and when she saw the ark among the flags, she sent her maid to fetch it. And when she had opened it, she saw the child: and, behold, the baby wept. And she had compassion on him, and said, This is one of the Hebrews’ children. Then said his sister to Pharaoh’s daughter, Shall I go and call to thee a nurse of the Hebrew women, that she may nurse the child for thee? And Pharaoh’s daughter said unto her, Take the child away, and nurse it for me, and I will give thee thy wages. And the women took the child, and nursed it. And the child grew, and she brought him unto Pharaoh’s daughter, and he became her son, And she called his name Moses: and she said, because I drew him out of the water.

R.9.2.5 p. 406: Michelangelo’s Moses i n Church San Pietro in Rom

R.9.2.6 p. 407: Crossing the Red Sea of the Israelis is the Biblical account of the crossing the Red Sea by Moses and the Israelites in their flight from the pursing Egyptian army and is part of the Exodus narrative on the journey out of Egypt, found in the Book of Exodus, Chapter 13:17 to 15:21.

According to the Book of Exodus, God parts the Red Sea for the safe passage of the Israelites, after which the pursuing Egyptians army is drowned when the waters return. At the end of these events, the Israelites sing the song of the Sea to celebrate their deliverance.


The actual details of the Flood are given in Chapters 7 and 8 of Genesis: „The Flood continued forty days upon the earth; and the waters increased, and bore up the ark (of Noah), and it rose high above the earth,...And the waters prevailed so mightily upon the Earth that all the high mountains under the whole heaven were covered; the waters prevailed above the mountains, covering them fifteen cubits (about 22 feet) deep.”

„And all flesh died that moved upon the Earth, birds, cattle, beasts, all swimming creature that swarm upon the Earth, and every man: everything on the dry land in whose nostrils was the breath of life died. ... Only Noah was left, and those that were with him in the ark. And waters prevailed upon the Earth a hundred and fifty days."​

R.9.2.8 p. 409: „The Flood": Detail of the left hand side of p. 408

R.9.2.9 p. 410: „The Flood“ of Leonardo Da Vinci (1452 – 1519)

In 1513 Leonardo Da Vinci was seriously thick - and threatened by mortal agony - created „The Flood" and over visions of the end of the world.

R.9.2.10 p. 411: The flood and reality; see also: Mark Siddhal: Nature 430, 12 August 2004, p. 718 - 719


R.9.2.12 p. 413: Spiritual immersion bath in the river see in Reference R.9.1.5, p. 33

9 – 29
9.3 Water in Christianity

| R.9.3.1 | p. 415 / 416: Christian Symbols and their Meanings – eBook  
www.symbols.net/christian |
| R.9.3.2 | p. 415 / 416: Church Symbols – What Do They Really Mean?  
Rita Green  
www.epworthsteeble.org/symbols.htm |
| R.9.3.3a | p. 415 / 416: Rudolf Koch: Christian Symbols  
catholic-resources.org/Art/Koch-christiansymbols.htm |
| R.9.3.3b | p. 415 / 416: „The Meaning of Water in Christianity”  
Alexander Pokhilko  
http://www.st-johnnesbaptist.de/Heiligengeschichte/heiligengeschichte.html |
| R.9.3.4 | p. 417: John the Baptist: Biography from Answers.com  
http://www.answers.com/topic/john-the-baptist |
| R.9.3.5 | p. 418: The Baptism of Jesus – Wikipedia, the free encyclopedia  
Amazon.com: The Baptism of Jesus in the Jordan: The Trinitarian and Cosmic Order of Salvation: Kilian McDonald Books  
www.amazon.com/Baptism-Jesus-Jordan |
| R.9.3.6 | p. 419: Jesus walking upon the Lake and rescuer at high Sea  
Parallel Texts in Mathew, Mark and Luke (synoptic: presenting or taking the same point of view)  
http://www2.ev-theol.uni-bonn.de/replaced/wunder/meditatseew.html |

R.9.3.7 | A meditation about Petrus (and Jesus) walking upon the Sea  
(Eine Meditation zum Seewandel des Petrus)  
Eugen Drewermann  
http://www2.ev-theol.uni-bonn.de/repaed/wunder/meditatseew.html |
| R.9.3.8 | Eugen Drewermann  
http://en.wikipedia.org/wiki/Eugen_Drewermann |
| R.9.3.9 | Eugen Drewermann: Taten der Liebe. Meditationen über die Wunder Jesu  
„Meditations about the miracles of Jesus”, Freiburg 1995  
http://www2.ev-theol.uni-bonn.de/replaced/wunder/meditatseew.html |
| R.9.3.10 | p. 420: After the baptism of a baby  
Ref. R.9.1.5, p. 15 |
http://en.wikipedia.org/wiki/Lourdes |
| R.9.3.12 | p. 422: Jesus and the Samaritan at the Fountain  
Painting from Angelika Kaufmann (1741 – 1807)  
Christ said to the samaritan: „If you knew the gift of God, and who it is that says to you, Give me to drink; you would have asked of him, and he would given you living water (4:10)“  
| R.9.3.13 | p. 423: Holy Bible  
(King James Version)  
„The Relevance” of St. John: 22: 1 – 2; p. 268 |
Wikipedia, the free encyclopedia  
en.wikipedia.org/wiki/Canticle_of_the_Sun |
| R.9.3.15 | 9-A-3-1: The washing of the feet of Jesus by Maria Magdalena  
Johann Christof Haas (1753 – 1829)  
9-A-3-2: The Baptism in Sainte Chapelle - Paris  
de.wikipedia.org/wiki/Wasser |

9 – 30
9.4 Water in Islam

R.9.4.1 In Islam water is important for cleansing and purifying. Muslims must be ritually pure before approaching God in prayer. Some mosques (Moscheen) have a courtyard (enclosed area, often a space enclosed by a building that is open to sky) with a pool of clear water in the centre, but in most mosques the ablutions (Waschungen) are found outside the walls. Fountains symbolising purity are also sometimes found in mosques. In Islam purity (called tahara) is required before carrying out religious duties, especially salat (worship: the adoring acknowledgment of all that lies beyond us - the glory that fills heaven and earth).

There are three kinds of ablutions: the most important is ghul (an Arabic term referring to the major ablation (ritual washing) requested in Islam for various rituals and prayers), is the washing of the whole body in pure water, after declaring the intention to do so. Muslims are obliged to perform ghul after sex which incurs a state of major ritual impurity. Ghul is also recommended before the Friday prayer, the two main feasts, and before touching the Koran. Ghul must be done for the dead before they are buried.

R.9.4.2 p. 427: Ritual washing of one's hands: Ref: R.9.1.5: p. 44

9.5 Water in Buddhism

R.9.5.1 To “Water in Buddhism” see:
Zen - Mind - Beginner's Mind
Shunryu Suzuki
in: Nirvana; The Water fall (Der Wasserfall)

R.9.5.2 p. 429: For Buddhists, symbolism and ritual are less important because they seek spiritual enlightenment that comes from seeing the reality of unreality. Bodhidharma, thought to be the first Zen Buddhism said this in the 5th Century CE.

9.6 Water in Hinduism

R.9.6.1 p. 434: Water is imbued with powers of spiritual purification for Hindus, for whom morning cleansing is an everyday obligation. All temples are located near a water source, and followers must bathe before entering the temple. Many pilgrimage sites are found on river banks; sites where two, or even three, rivers converge are considered particularly sacred.

There are seven sacred rivers: The Ganges, and the Godavari, Kaveri, Narmada, Saravati, Sindhu and Yamuna Rivers. According to Hindu beliefs, those who bath in the Ganges or who leave part of themselves (hair, bones of the dead) on the left bank of the river will reach Svarga, the paradise of Indra, storm god. Funeral rites are always held near rivers; the son of the deceased pours water on the burning funeral pyre so that the soul cannot escape and return to Earth as a ghost. The ashes are collected three days after cremation, and several days later, are thrown into a holy river.
9.7 Water in Psychology and in Philosophy

Photo of C.G. Jung from Internet under „Carl Gustav Jung“: „Pictures“

R.9.7.2 According to C.G. Jung, Water is the most well-known symbol for the collective unconscious. The descent into the depth seems always to precede the ascent. In Psychologically, water is therefore a symbol for spirit which became unconscious.

R.9.7.3 p. 442: Thales of Miletus
[Internet URL]
It is said that Thales of Miletos, one of the seven wise men, was the first to undertake the study of physical philosophy. He said that the beginning (the first principle) and the end of all things is water.

R.9.7.4 H₂O - THE MYSTEREY, ART, AND SCIENCE OF WATER
Chris Witcombe and Sang Hwang
Sweet Briar College
[Internet URL]
10. Water in the Solar System and in the Universe
10.1 Our Solar System

The Solar System - 1

Inner Planets (right from left to right): Mercury, Venus, Earth with Moon, and Mars

Asteroid belt: Large number of small spots located between Mars and Jupiter

Outer Planets (left from left to right): (Pluto), Neptune, Uranus, Saturn and Jupiter
The Solar System - 2

The earth is located in the habitable zone of the solar system; if it were about 5% or about 8 million kilometers closer to or further from the sun, the conditions which allow the three forms of water to be present simultaneously (liquid, solid, and gaseous) would be far less likely to exist.
10.2 Water on the Sun!

The Sun God Apollo

Head of the Sun god Apollo

Apollo, the Sun god, brings life – giving heat and light to Earth
Water vapour on the Sun spots Umbra!

Sun with sunspots: the mean temperature of the surface of the Sun is about 5500°C.

In the sunspots (Umbra) the temperature is “only” about 3000 to 3500°C. In such “oasis”, water vapour can survive in a highly excited state without decomposition.

Detection with Infrared spectroscopy and Computer simulations

Water on the Sun: Experiments and Theory

• Experimental: observation of the emission spectrum of the sun
• In this experiment also the water vapour of the atmosphere is an inevitably observed complication!
• But in the infrared spectrum of atmospheric water vapor there exist “windows” which allow the observation of the spectrum of the umbras.
• A careful experimental and theoretical analysis clearly demonstrates the existence of water vapor in the Umbras, but the water molecules are thermally highly excited: “hot molecules”; these hot molecules give rise to a much more complicated infrared spectrum than that known from the “cold molecules” on the Earth.
• The infrared spectrum of the water vapor of the Umbras are compared with very hot water prepared on the Earth and good agreement is obtained!
• The theoretical analysis of the IR–spectrum of “hot water molecules” is extremely complicated (quantum mechanics, coupling of electronic and atomic motions, relativistic treatment of electrons …).
10.3 The inner Solar System

- The planets Mercury, Venus, Earth, and Mars belong to the terrestrial or “rocky” planets.
- They are characterized by a relative clearly defined interface between their surfaces and their atmospheres.
- Compared to the outer planets, they are very small.

The God Mercury

Mercury: Herald of the Roman Empire and the Ambassador of Roman Gods
Since the planet Mercury is closest to the Sun, its highest temperature can rise up to 430 °C, its lowest temperature can, however, be as low as -170 °C.

One would therefore assume that the existence of water–ice is relatively improbable.

Space flight pictures from Mariner 10 show, however, many craters and suggest the presence of ice in deep craters.

Radar–signals taken from the earth (left) show red spots: strong radar signals → eventually from water–ice in craters.

Yellow, green and blue areas: progressively weaker reflections.

→ small amounts of water–ice in these areas

Venus (meaning “Love” or “sexual desire” in Latin) was a major Goddess principally associated with love, beauty and fertility. From the third century BC, the increasing Hellenization of Roman upper classes identified her as the equivalent of the Greek Goddess Aphrodite (see p. 458).
No water on the Venus!

Today, Venus has no water! In the past there existed eventually oceans, which evaporated due to the enrichment of CO₂ in the atmosphere. It is believed that this was the consequence of a self-enhancing greenhouse effect.

Michelangelo: Godfather
Creator of the Earth and of Water
Aphrodite: Goddess of Love and Beauty

Robert Fowler (1853 – 1926)

Gaia: The Goddess of the Earth

Gaia, the Jung mother of the Earth: Her suffering expression reflects the tortured Earth.
The Goddess

In the beginning, before the world was created, God was wandering around through the nothingness trying to find something. He had almost given up hope and was dead tired when suddenly he came to a big shed. He knocked. A Goddess opened the door and asked him to come in.

She said she was just busy working on Creation but he should take a seat for a while and watch what she was doing. At the moment she was planting various water plants in an aquarium.

God was astonished at what he saw. He would never have come up with the idea of creating a substance like water. It is precisely this, the Goddess said smilingly, that was, so to speak, the basis of life.

After a while God asked if perhaps he could help a bit and the Goddess said she would be very grateful if he could take the water and the things she had created so far to one of the planets that she had set up a little further in the back. She would like to start with the least significant one as a test.

So God began to deliver the Goddess' creations one after the other from her shed to the Earth, and it is not a surprise that later, people on this planet knew only about the God who had brought it all and who they assumed was the actual creator of all.

Of the Goddess who had thought it all up, however, they knew nothing, and therefore it's high time she gets mentioned.

Franz Hohler
translated from „Die blau Amsel“
The **Dry – Land Hemisphere** is defined as that part of the Globe which contains the largest part of land. It contains Europe, Africa, North–America and Greenland as well as about 95% of Asia and two third of South America. From the total surface of the Dry – Land Hemisphere, 53% is covered by water and 47% by land. Note that from the global surface, 29% is Dry – Land and 71% is Water.

The **Water – Hemisphere** constitutes that part of the Globe which contains the largest water content. Its center is located in the Pacific near New Zealand. From the continents and there land areas it contains only Australia, the Antarctic and some per cents of Asia. The surface of the Water – Hemisphere is covered by 89% of water and by 11% of dry – land.

**Poseidon** (Greek)

or

**Neptun** (Roman):

God of Water

or the Sea
The Moon of our Earth

Comparision of Earth and Moon

<table>
<thead>
<tr>
<th></th>
<th>Earth</th>
<th>Moon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (km)</td>
<td>12.742</td>
<td>3.476</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>5.974 * 10^{24}</td>
<td>7.349 * 10^{22}</td>
</tr>
<tr>
<td>Surface Gravity (m/s^2)</td>
<td>9.78</td>
<td>1.62</td>
</tr>
</tbody>
</table>

Why could water have been present on the Moon?

Answer: for the same reason as on the Earth: by Impacts of Comets and asteroids about 4 billions years ago.

But: the surface gravity on the Moon is about 6 times smaller than on the Earth ➔ Most of the water vapour can not be attracted ➔ Evaporation into space!
Apollo space crafts of NASA (1968 – 1972) confirm that the surface of the Moon has suffered a large number of impacts of comets and asteroids.

Observation of $H_2$, but no water has been found until very recently! (see p. 467)

A continuous current of hydrogen ions $H^+$ could be the source of the water on the Moon.

Several space crafts have discovered water at the surface of the Moon. The $H_2O$ – molecules are found in a very thin layer at the surface. (NZZ: September 2009).
Observation of impact craters by means of NASA’s LCROSS:
(LCROSS = Lunar Crater Observing and Sensing Satellite)

In October 2009, NASA deliberately crashed its LCROSS experiment on the south pole of the Moon, creating two impact craters. One of them was caused by the spent Centaurus rocket stage that the LCROSS instrument was carrying, while the second was made by the $78 million spacecraft itself, as it fell to its demise while snapping photos of the Centaurus impact site.

An artist’s conception shows the LCROSS probe of NASA, observing the crash of its Centaur upper stage into the Lunar surface.

Water absorption bands on the Moon discovered!

Data from the down-looking near-infrared spectrometer of the Lunar Crater Observation and Sensor Satellite (LCROSS).
The red curve shows how the spectra would look for a “grey” or “colourless” warm (230 °C) dust cloud. The yellow areas indicate the water absorption bands.
Mars – The Roman God of War

Mars in readiness of battle

Mars in full speed towards war

Water – Ice on the North – Pole of Mars

Discovered by “European Space Agency” (ESA) (July 28, 2005)

The diameter of the crater is about 35 km and its maximum depth is about 2 km. The circular blue area in the centre is residual water–ice!

It has been possible to prove that the blue area is not composed of CO₂ (dry ice).
The Outer Solar System

General Remarks about the outer Solar System

• The “Outer Solar System” contains the giant planets Jupiter, Saturn, Uranus and Neptun. Since the discovery of the Kuiper belt (Kuiper-Gürtel), the outermost parts of the Solar System are considered a distinct region consisting of the objects beyond Neptun.

• The giant planets possess a liquid or metallic core. The largest part of their mass consist, however, of Hydrogen and Helium with traces of Water vapor and other gases. Therefore, they are referred to as “gas giants”.

• In contrast to the “rocky” planets, the “gas giants” do not have a well-defined surface; their atmospheres gradually increase by approaching their cores. They are possibly interspersed by liquid or even solid matter.

• Uranus and Neptun form a separate class of “gas giants”; they are often called “ice giants”, since they contain large quantities of ice and water vapor at very high pressures. It is speculated that they contain super-ionic or even metallic ice.
**Jupiter, Father of the Gods**

In Greek mythology: Zeus

The interior of Jupiter

- 10'000 km below H\(_2\) layer: P about 1'000'000 atm, T about 6000 K!
- Liquid and metallic hydrogen: H \(\rightarrow\) protons and electrons
- Electric currents produce very strong magnetic fields!
- Within nucleus: glowing water-ice at extremely high pressures and temperatures.
Water on Jupiter and its ring system

* NASA 2000 : The atmosphere contains methane (CH\textsubscript{4}), ammonia (NH\textsubscript{3}) and water vapor. Condensation of water vapor \(\rightarrow\) clouds, rain, thunderstorms! There exist dry and humid areas.

**Jupiter's Jovian ring system**

showing four main components. This ring system is faint and consists mainly on dust and rocks.

It comprises mainly four components:
- a thick inner torus known as "halow ring"
- a relatively bright "main ring"
- two wide, thick and faint outer rings, called "grossamer rings".

**Running red rings around Jupiter**

Jupiter's rings are darker and appear as fine particles or rocks.
The six pictures at the right were taken in infrared light from the Infrared Telescope Facility in 1994, and cover a time span of two hours.
The origin of Jupiter's rings remains unknown.

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Wolfgang Amadeus Mozart (1756 - 1791)

Fourth mouvement (Molto allegro) of the Jupiter-Symphony, KV 551

Primary theme:
The Jupiter Moon Europe

Photo of a small part of the ice–crust (70 km x 30 km) of the Conamara-region of Jupiter’s Moon Europe, taken with the space probe Galileo.

Note the ruptures in the ice crust; they can be produced by several plausible reasons.

Interior of Jupiter’s Moon Europe, based on several independent observations.

Saturn with Ice-Ring-System - 1

Pictures taken from the spacecraft Telescope Hubble: The planet with his rings has been viewed from different angles (2001). Saturn is composed of about 75% hydrogen and 25% helium.

The rings of Saturn seem to be composed primarily of water–ice but they may also include rocky particles with ice coatings. The water–ice particles are swirling due to the gravitational field of the planet. Therefore, they can not condense to a moon.
Saturn with ring – system - 2

- Discovered by Galileo (1610)!

- Visits by: NASA's Pioneer 11 (1979), Voyager 1 and 2. Cassini approached Saturn in 2004 and is still circling around it.

- As Jupiter, Saturn is a “giant-gas” planet with a similar atmosphere (75% H₂ und 25% He).

- The interior of Saturn has the same structure as Jupiter: a glowing nucleus of H₂O-ice, liquid and metallic H₂ and H₂-gas.

Saturn: God of Harvest and Time

Saturn: (Caravaggio in 16th Century)
The Gods Uranus and Neptune

Uranus is the earlier Greek God of the sky.

Neptune is the Roman god of the Oceans;
In Greek mythology: Posseidon.

The diameter of Neptune is 49'248 km (smaller than Uranus). Its colour is blue–green, which is due to methane in its atmosphere. For an orbit around the sun it takes about 165 years. The interior of Neptune is similar to that of Uranus: a rocky nucleus, covered by an ice-layer, a mantle contained of water, methane, and ammonia, followed by a thick atmosphere.

As Uranus, but in contrast to Jupiter and Saturn, Neptune consists probably on clearly distinguishable layers. Its surface temperature is -218 °C. Neptun seems to possess an internal heat source. The velocity of the wind can reach values up to 2'000 km/h, which is due to the inner heat source just mentioned. This is the highest velocity of wind in the solar system.
Possible internal structure of Neptune and Uranus (*)

“Gas”: molecular hydrogen ($H_2$) and helium (He) as well as methan ($CH_4$)

“Ice”: hot ice (glowing !) mixed with $H_2$ and $CH_4$ at very high temperatures (about 1700 °C) and at very high pressures (10 GPa = 100’000 atm)

“Rock”: rocks and ice at about 7700 °C and at pressures of 800 GPa = 8 millions atm (!)

(*) Uranus and Neptune have a very similar structure and are often referred to as “giant - ice” - planets.

Superionic conducting water in Neptune and Uranus ??

The extreme conditions that exist deep within Uranus and Neptun could be ideal for water in the superionic state in which the molecules have been broken into oxygen and hydrogen ions (*)

In fact, the results from computer models strongly suggest that a layer of (solid) superionic water should extend out to about halfway to the surface (red area). The simulations assume temperatures up to 6000 °C at pressures of 7 millions atm (**).

The observed curious magnetic fields of Uranus and Neptun are consistent with nearby patches of the surface of liquid ionic water (brown area) having fields of opposite polarity.

(*) The Physics of Superionic Conductors is outlined in detail by P. Brüesch (see Ref. R.10.4.15).

(**) The Computer models have been studied by a team led by Ronald Redmer at the University of Rostock (References R.10.4.13 and R.10.4.14).
Pluto, Greek god of wealth (ninth planet from the Sun).

Modern astronomers have abolished God Pluto from his base!

Reason: it has been realized, that Pluto has to be considered as a “dwarf planet”; in addition it became clear that there exist many similar planets having the same size and structure.
10.5 Extra – Solar Water

L'Universe populaire: Camille Flammarion, Wood engraving, Paris 1888 (*)
(*) A composition ("Montage") of C. Flammarion for his art work
"L'Astronomie populaire", created 1880.
Our Milky-Way Galaxy

Diameter:
about $10^5$ light years
($9.5 \times 10^{17}$ km)

Thickness:
about $10^3$ light years
($9.5 \times 10^{15}$ km)

Age:
about $13.6$ billions of years
($13.6 \times 10^9$ years)

Number of stars:
about $300$ billions
($300 \times 10^9$ stars)

The observable Universe contains $100 - 400$ billions ($100 - 400 \times 10^9$) of Galaxies similar to that of our Milky Way system shown in this Figure. One light year (ly) is equal to $9.46 \times 10^{12}$ km! The age of the oldest known star is about $13.2$ billion years ($13.2 \times 10^9$ years).

Our Milky–Way Galaxy is a stellar disk - 1

Our Milky–Way Galaxy is a stellar disk.
Our Milky–Way Galaxy

The Milky–Way Galaxy is a vanishingly small part of the Universe; its dimension is of the order of about 100,000 light years.

The Figure at p. 490 shows the shape and the dimension of the Milky–Way System: a spiral–shaped Galaxy containing at least 200 billions of stars.

Our Sun is deeply hidden in the Orion–Arm, the distance of which is about 26,000 light years from the galactic center.

Approaching the center of the Galaxy, the density of Stars is much larger as in the vicinity of our Sun.

In the Figure of p. 490 we can observe the existence of small spherical star–clusters as well as the presence of a dwarf–Galaxy, the so–called Sagittarius dwarf, which is slowly swallowed by our Galaxy.

Edwin Hubble studied Galaxies and classified them into various types of elliptical, lenticular, and spiral Galaxies. The spiral Galaxies were characterized by disc shapes with spiral arms as shown in Figures 489 and 490 for the example of the Milky Way System.

[An elliptical Galaxy is a Galaxy having an approximately ellipsoidal shape and a smooth, nearly featureless brightness profile. They range in shape from nearly spherical to highly flattened. A lenticular Galaxy is a type of Galaxy which is intermediate between an elliptical Galaxy and a spiral Galaxy].
The Milky Way, or simply the Galaxy, is the Galaxy in which our Solar System is located. It is a barred spiral galaxy that is part of the Local Group of Galaxies. It is one of billions of galaxies in the observed Universe.

The stellar disk of the Milky Way (s. pp 489, 490 and 492) is approximately 100'000 light-years (ly) (9.5 \times 10^{17} \text{ km}) in diameter, and is considered to be, on average, about 1'000 (ly) (9.5 \times 10^{13} \text{ km}) thick. It is estimated to contain at least 200 billion of stars and possibly up to 400 billion stars, the exact figure depending on the number of very low-mass stars, which is highly uncertain.

As a guide to the relative physical scale of the Milky Way, if it were reduced to 10 m in diameter, our Solar System, including the Oort cloud (spherical cloud of Comets), would be no more than 0.1 mm in width! This is a factor of 100'000 (!).

By including the estimated age of the stars in the globular cluster (about 13.4 billion years), the age of the oldest stars in the Milky System has been estimated to about 13.6 billion years. Based upon this newest scientific result, the Galactic thin disk is estimated to have been formed between 6.5 and 10.1 billion years ago.

The galactic disk, which bulges outward at the galactic center, has a diameter between 70'000 and 100'000 ly. The distance from our Sun to the galactic center is now estimated at 26'000 1400 ly.

The galactic center harbors a compact object of very large mass as determined by the motion of material around the center. The intense radio source named Sagittarius A*, thought to mark the center of the Milky Way, is newly confirmed to be a supermassive black hole. Most Galaxies are believed to have a supermassive black hole at their center.

The Effelsberg - and the Green Bank Radio Telescope

Radio Telescope Effelsberg (Germany)
putting into operation : 1972
Mirror diameter : 100 m
focal length : 30 m

Green Bank Telescope : GRT - Telescope
(West - Virginia, USA)
putting into operation : 2001
Mirror : 100 x 110 m
The aperture is not blocked by the excentrically arranged detector!
The Hubble – Space Telescope (HST) is a Telescope, which circles around the Earth in an altitude of 590 km within 97 minutes. The operation of a Telescope outside the Earth's atmosphere is a big advantage since no filtering action for specific wavelengths of the electromagnetic spectrum, i.e. in the UV and IR range, is necessary.

In 1789, Frederick William Herschel constructed a Telescope with a mirror diameter of 126 cm and a focal length of 12 m. At May 14, 2009, the William Herschel Telescope, named to honor of Herschel, has been startet into space. Herschel will reache the so called second Lagrange-Point at a distance of 1.5 millions km from the Earth. Synchronously with the Earth, it will then circle around the sun. All the three perturbations arising from the Sun, the Moon, and the Earth, are approximately in line as viewed from the Lagrange-Point and are therefore hidden by a „sun shad“. Herschel can therefore observe under conditions free from perturbing temperature- and radiation conditions which originate from the Sun, the Earth, and the Moon.

The Herschel Telescope observes the emission of the extremely cold objects of the Galaxies in the wavelength range between the far infrared (FIR) and the sub–millimeter range (60 to 570 microns). With observations reaching deep into space, it is aimed to explore the formation and development of the Galaxies since the beginning of the Universe. It is the aime of scientists to explore the physical and chemical properties of interstellar space, thereby gaining new insight into the formation of stars which have been formed from molecular clouds.

With the help of the Herschel Telescope it is possible to observe water molecules at very low temperatures – between 10 and 20 degrees Kelvin (-263 bis -253 °C). (In this temperature range, no photons in the optical region can be observed).
The emission (or absorption lines) characteristic of water vapor can be identified if the observation of an object yields at least the three fundamental vibrations of the $\text{H}_2\text{O}$-molecule (s. Chapter 2, pp 37 and 64). Besides molecular hydrogen ($\text{H}_2$) and carbon oxide ($\text{CO}$), water ($\text{H}_2\text{O}$), is one of the most important and most stable molecules in the Universe. Due to the disturbing water vapor of the atmosphere of the Earth, water vapor in the Universe cannot be directly observed. With the aid of the Space Telescope Herschel, however (p. 496), it is now possible for the first time to observe water in the Universe and to explore its genesis and its implications for the formation of the planets.

Water plays an important role for the energy balance of stars since it regulates the temperature and cools down the stars. The existence and properties of water could also be responsible for the formation of heavy-mass and low-mass planets. This is because water plays an important role for the accumulation of matter during the formation of planets (accretion = growth of a massiv object by gravitationally attracting more matter, typically gaseous matter). On the other hand, dust grains are surrounded by ice layers, thereby limiting the coagulation to larger boulders.

Remark: The Telescope of the next Generation is in the planning stage: the „European Extremely Large Telescope (E-ELT)”; its main mirror will have a diameter of 42 meters which is composed on 900 hexagonal mirror elements. Its construction will probably be started at 2011 and is expected to come to completion in 2020.

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**Observation of extrasolar Water**

Observations of Comets such as for example Hale–Bopp, have shown that its water–ice contains many organic compounds.

Many scientists believe that in its earliest stage our Earth was hot, dry and sterile.

Therefore, it is possible that the origin of terrestrial life goes back to the complex organic molecules which have been formed in the „icy hart“ of interstellar clouds.

---

**Comet Hale–Bop and terrestrial Life**

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Many scientists believe that in its earliest stage our Earth was hot, dry and sterile.

Therefore, it is possible that the origin of terrestrial life goes back to the complex organic molecules which have been formed in the „icy hart“ of interstellar clouds.

The Hale–Bopp Comet

From the 3 $\mu$m absorption band of water it follows that the comet looses water–ice by sublimation.
The Comet Hartley 2

The NASA spacecraft “Deep Impact” has passed the Comet Hartley at November 4 2010. The photograph shows one of the most closest observed pictures.

The length of the comet corresponds to the distance between the Capital building and the Washington Monument in Washington.

The small Comet consists of a mixture of Ice, rockets and dust.

NASA has photographed the Comet Hartley 2 from different directions and from a distance of about 700 km.

At the time when spacecraft “Deep Impact” passed Hartley 2, the distance to the Earth was about 21 million km.

The Water - Planet HD 189733b in front of his Sun

Using the Spitzer Space Telescope, it has been possible to detect water vapor in the atmosphere of the gas-giant HD 189733b. An article about these findings has been published in „Nature“.

The planet studied circles around a Sun in the constellation of „Vulpera“, the distance of which is 63 light years from the Earth. The gas-giant is somewhat larger than Jupiter, but it is moving about 30 times closer around his Sun than the Earth, and for this reason it is extremely hot.

Based on the Spitzer – Telescope from NASA, an international Team of astronomers have been able to analyze in detail the wavelengths of the Sun light which have been absorbed by the atmosphere of the Planet. By analyzing the absorption spectrum in the infrared region, they found the signature of Water, i.e. the absorption lines of Water vapor.

Parts of the atmosphere are very hot - about 2'000 °C. Therefore, the Water molecules are highly excited producing an extremely complicated vibrational and translational spectrum, a spectrum which is much more complicated than that shown in the Figure of pp 37, 64. The complication is due to the extremely strong anharmonic vibrations and the strong coupling between vibrational and rotational motions.
The dwarf star Gliese is approximately at a distance of 33 light-years from the Earth. Stellar models from the Star give an estimated size of about 42% of the Sun's radius and predicts a temperature of about 3300 K.

The star is orbited by the planet designated Gliese 436b (at the left of the Figure). The planet has an orbital period of 2.8 Earth days and transits the Star as viewed from Earth. It has a mass of 22.2 times the Earth's mass.

The planet is thought to be largely composed of hot ices with an outer envelope of hydrogen and helium (see p. 484) and is termed a „hot Neptun”.

Scale comparison of the relative size of the Earth and the Water-Planet Gliese 436b.

Mass: 132.6 * 10²⁴ kg (≈ 22.2 times the mass of the Earth).

Orbital period about its Sun Gliese 436: 2.8 Earth days.

Based on its width, the mass and the proximity from its Star Gliese 436, the planet 436 b is now thought to be made mostly of hot, pressurized water ice in exotic forms (ices VII and X, see pp 48, 49; 55-56).

The composition of the atmosphere (yellow ring) is uncertain but may contain hydrogen, helium and water vapor.

The Figure shows the cross-section of the proposed structure and composition of Planet Gliese 436 b.

When the radius became better known, ice alone was not enough to account for the composition of the Planet. Another layer of hydrogen and helium up to 10% in mass would be needed on top of the ice. It has been suggested that this might even obviate the need for an ice core: alternatively, the planet may be a super-earth.
Astronomers have found the most distant signs of water in the Universe to date. According to Dr. Violetta Impellizzeri et al. from the University of Bonn, water has been found in a distance of 11.1 billion light-years from the Earth. However, because the Universe has expanded like a inflating balloon in the time, stretching out the distances between points, the Galaxy in which the water was detected is about 19.8 billion light-years away. The water emission is seen as a MASER, where molecules in the gas amplify and emit beams of microwave radiation in much the same way as a LASER emits beams of light. (MASER stands for Microwave Amplification by Stimulated Emission of Radiation).

The water vapour is thought to be contained in a jet ejected from a supermassive black hole at the centre of a Galaxy, named MG J0414+0534. The faint MASER – signal is only detectable by using a technique called gravitational lensing, where the gravity of a massive Galaxy in the foreground acts as a cosmic telescope, bending and magnifying light from the distant Galaxy to make a clover-leaf (Kleeblatt) pattern of our images of MG J0414+0534. The spectrum of water vapour (s. p. 504) has been observed with the Radio – Telescope Effelsberg.
Water - Maser Emission in Quasar MG J0414+0534

Astronomers have found the most distant Water yet seen in the Universe, in a Galaxy more than 11 billion light-years from Earth. Previously, the most distant Water had been seen in a Galaxy less than 7 billion light-years from the Earth.

The spectrum shown in the Figure at p. 504 is a “fingerprint” that revealed radio emission from Water Masers in the distant Quasar MG J0414+0534. The background image is an infrared image of the Quasar, made with the Hubble Space Telescope. The Quasar appears broken up into four components by a foreground Galaxy (diffuse object in the center), acting as gravitational lens and strengthening the signal by a factor 35. The inset with the Galaxy M87 shows how the Quasar might be seen from nearby.

The soggy Galaxy, dappled MG J0414+0534, harbors a Quasar - a supermassive black hole powering bright emission - at its core. In the region near the core, the Water molecules are acting as Masers, the radio equivalent of Lasers, to amplify radio waves at a specific frequency.

The astronomers say their discovery indicates that such giant Water Masers were more common in the early Universe than they are today. MG J0414+0534 is seen as it was when the Universe was roughly one-sixth of its current age.

At the Galaxy’s great distance, even the strengthening of the radio wave done by the Maser’s would not by itself have made them strong enough to detect with the radio telescope. However, the scientists got help from nature in the form of another Galaxy, nearly 8 billion light-years away, located directly in the line of sight from MG J0414+0534 to Earth. That foreground Galaxy’s gravity served as a lens to further brighten the more-distant Galaxy and make the emission from Water molecules visible to the radio telescope.

The detection of water from MG J0414+0534 with the Effelsberg radio telescope also occurred to a touch of fortune. The object is within just the right redshift interval (Doppler shift) to stretch the line emission of the H$_2$O molecule from the original 22 GHz to 6 GHz and so within the tuning range of the 6 GHz receiver installed in the Telescope.

The Eagle Nebula in the Serpent Constellation

The „Eagle Nebula“ belong to the Serpent Constellation or „Serpens Clouds“.

The Eagle Nebula constitute a young and open cluster of Stars in the constellation Serpens.

The distance from the Earth is about 23 billion light-years.
**Giant water quantity around a black hole**

According to estimates from NASA, the amount of the discovered water is about 140 billion times larger than the total water on the Earth.

This water surrounds a giant quasar, the quasar APM 08279+5255 - a black hole, which absorbs matter in its surrounding.

The huge mass of water is located at a distance of about 12 billions light years from the Earth.

According to NASA, this quasar is about 20 billion times larger than our Sun.

During his absorption of mass, the quasar produces a giant energy. This energy is equivalent to the energy of thousand billions of suns.

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**Aliens need Water desperately, too!!**

Believe it or believe it not: "Extended theoretical and practical investigations have revealed that extraterrestrial aliens are also heavily dependent on water and use to drink at least three gallons per day !!!"

(Text and Picture composed from P. Brüesch)
Did NASA find Liquid Water on the surface of Mars?

Images from NASA satellite have detected dark patterns that ebb and flow on Mars – evidence, perhaps, of a salty brine water.

Observations by High-Resolution Imaging Science Experiments (HiRISE) camera aboard the orbiting Mars Reconnaissance Orbiter (MRO) have captured recurring features on several steep slopes in Mars’ southern hemisphere, which researchers believe could be evidence of water.
10. Water in the Solar System and in the Universe

10.1 Our Solar System (general)

R.10.1.1 THE SOLAR SYSTEM
Thérèse Encrenaz, J.P. Bibring, M.A. Barucci, F. Roques, Ph. Zarka
Springer – Verlag Berlin Heidelberg
Third Edition, 2004

R.10.1.2 OUR SOLAR SYSTEM
Seymour Simon
Amazon.com

R.10.1.3 THE NEW SOLAR SYSTEM
J. Kelley Beatle
Amazon.com

R.10.1.4 THE SOLAR SYSTEM
T. Encrenaz, J.P. Bibring, M. Blanc, M.A. Barucci, F. Roques, and Ph. Zarka
A&A Library
Third Edition
Springer, 2004

R.10.1.5 SOLAR SYSTEM
Wikipedia, the free encyclopedia

R.10.1.6 p. 445: The Solar System -1
www.nasastockphotography.com/

R.10.1.7 p. 446: The Solar System - 2
www.aerospaceweb.org/.../astronomy/q0247

R.10.1.8 p. 447: Habitable zone in the solar system
en.wikipedia.org/wiki/Habitable_zone
10.2 Water on the Sun

R.10.2.1 WATER ON THE SUN: THE SUN YIELDS MORE SECRETS TO SPECTROSCOPY
Jonathan Tennyson and Oleg L. Polyansky
Contemporary Physics, 39, No. 4, 283-294 (1998)

R.10.2.2 WATER ON THE SUN
Grace Cavalleri and Maria Enrico
Uebersetzt von Maria Enrico
Published by Lightning Source Inc. 2006
108 pages

R.10.2.3 WATER ON THE SUN: LINE ASSIGNMENTS BASED ON VARIATIONAL CALCULATIONS
O.L. Polyansky, N.F. Zobov, S. Viti, J. Tennyson, P.F. Bernath, and L. Wallance

R.10.2.4 Water on the Sun: Molecules Everywhere

R.10.2.5 p. 449: The Sun – God Apollo
left-hand picture: http://www.snailcrawls/eril.net/plan7.htm
right-hand picture: http://www.wordsources.info/apollo.html

R.10.2.6 p. 450: Water vapour on the Sun - Spots
left-hand picture: http://www.geolinde.musin.de/aktuell/sonnenflecken1/20040723_1600_mdi_igr.gif
right-hand picture: http://www.heise.de/tp/r4/artikel/23/23563/1.html

R.10.2.7 p. 451: Experiments and Theory for the proof of Water on the Sun

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10.3 Water in the inner planetary System

R.10.3.1 p. 453: Mercury: Ambassador of Roman Gods
left-hand Figure: http://img.search.com/thumb/7/76/Mercury god.jpg/
right-hand Figure: http://www.wordsources.info/mercury

R.10.3.2 p. 454: Water on the Mercury?
http://www.nrao.edu/pr/2000/vla20/background/mercuryice/

R.10.3.3 p. 455: Birth of Venus (Sandro Botticelli)

R.10.3.4 p. 456: No Water on Venus!
left-hand side: View of the CO2 – atmosphere of Venus:
http://www.solarspace.co.uk/Planet/Pics/Venus-venus.jpg
middle-hand side: The Goddess of Love
http://de.wikipedia.org/wiki/Bild_The_Seven_Planets_-_Venus.jpg
right-hand side: Radar topography of one hemisphere of Venus
http://www.solarviews.com/eng/venus.htm

R.10.3.5 p. 457: Michelangelo: „God – Father”
http://www.romaculta.it/Images/Images_det/herc1bg.jpg

R.10.3.6 p. 458: Aphrodite: Goddess of Love and Beauty
http://www.paleofthea.com/Gallery/AphroditeFowler.html

R.10.3.7 p. 459: Gaia: The mother of the Earth
left-hand Figure: Gaia, The jung mother of Life
http://www.gods-heros-myth.com/graphics/gaea.png
right-hand Figure: Gaia, the suffering mother of the Earth
http://www.windows.ucar.edu/mythology/images/Gaea_frame.jpg
R.10.3.8 p. 460: The Goddess
Franz Hohler
translated from "Die blaue Amsel"
München: Luchterhand 1995
translated by Andrew Rushton in: Bergli Books
"At Home" (A selection of stories by Franz Hohler); p. 34

R.10.3.9 p. 461: The Blue Planet
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R.10.3.10 p. 462: Land-Hemisphere and Water-Hemisphere of the Earth
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right: Water - Hemisphere
http://www.texas.net/geographie/halbkugeln.asp

R.10.3.11 p. 463: Poseidon / Neptun: God of the Water or the Sea
http://www.hellenica.de/Griechenland/Mythos/Poseidon.html/

R.10.3.12 p. 464: The Moon of the Earth
http://www.squidoo.com/earthsmoon

R.10.3.13 p. 465: Water - layer on the Moon (!)
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http://science.nasa.gov/Headlines/y2005/14apr_moonwater.htm
right-hand side: Moon crater Copernicus
http://www.mond.de/Mondkarte/detail_copernikus.htm

R.10.3.14 p. 466: Apollo - und Lunar - Prospector Moon travels
upper right-hand Figure: Impacts on the surface of the Moon
http://www.daviddarling.info/images/Clavius.jpg
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http://science.nasa.gov/headlines/y2005/14apr_moonwater.htm

R.10.3.15 p. 467: The human layer on the Earth (Die feuchte Hülle des Mondes)
Neue Zürcher Zeitung (NZZ); Mittwoch, 30. September 2009 - Nr. 226
Forschung und Technik, p. 59

R.10.3.16 Traces of water detected on the Moon
p. 468: (upper Figure): LCROSS: http://lcross.arc.nasa.gov/
p. 468: (lower Figure): LCROSS: hitting the Moon:
www.msnbc.msn.com/id/33912611/ns/technology_and_science-space

R.10.3.17 p. 469: LCROSS: Absorption bands of Water from the Moon
www.nasa.gov/mission_pages/LCROSS/main/prelim_water_results.htm

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http://library.thinkquest.org/03oct/01859/images/aboutmars-myth.gif

R.10.3.19 p. 471: Water – ice at the north - pole of Mars
http://www.esa.int/SPECIALS/Mars_Express/SEMOKA809BE_0.html

R.10.3.20 Appendix 10-A-3:1: Did NASA find liquid Water on Surface of Mars?
http://www.bbc.co.uk/science/solotech/2011/08/110804/did-nasa-find-liquid-water...

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10.4 The Outer Solar System

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R.10.4.2 p. 474: Jupiter: Father of the Gods
left-hand Figure: [http://wordinfo.info/words/images/planet-jupiter.gif](http://wordinfo.info/words/images/planet-jupiter.gif)

R.10.4.3 p. 475: The interior of Jupiter

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Figure below: [http://apod.nasa.gov/apod/ap970205.html](http://apod.nasa.gov/apod/ap970205.html)

R.10.4.5 p. 477: Wolfgang Amadeus Mozart - Wikipedia, the free encyclopedia

R.10.4.6 p. 478: The Jupiter Moon Europe
left-hand side: Photo of the ice crust in Conamara – region (Space craft Galileo)
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[http://images.google.ch/imgres](http://images.google.ch/imgres)

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[celestialdelights.info/saturn/sweetspot.html](http://celestialdelights.info/saturn/sweetspot.html)

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R.10.4.11 p. 483: The planet Neptune
[http://www.hs.uni-hamburg.de/DE/Ins/Bib/neptun.html](http://www.hs.uni-hamburg.de/DE/Ins/Bib/neptun.html)
(Figure adapted to English by P. Brüesch)

R.10.4.12 p. 484: Possible - internal structure of Uranus and Neptune - Eis
[http://www.hs.uni-hamburg.de/DE/Ins/Bib/neptun.html](http://www.hs.uni-hamburg.de/DE/Ins/Bib/neptun.html)

New Scientist, 4 September 2010, p. 15
p. 485: Giant planets may host superionic water
Published online 22 March 2005/Nature doi:10.1038/news050321-4
(Figure - Texts rewritten for the sake of better readability by P. Brüesch)

R.10.4.14 p. 486: Pluto is a Dwarf Planet
[http://images.google.ch/imgres](http://images.google.ch/imgres)

R.10.4.15 Concerning p. 485:
The Physics of Superionic Conductors is described in detail in:
P. Brüesch
PHONONS: THEORY AND EXPERIMENTS III
Springer Series in Solid State Physics 96
Springer Verlag Berlin Heidelberg 1997
Chapter 7: Ion Dynamics in Superionic Conductors, pp 167 - 199
10.5 Extra Solar System

R.10.5.1 The Milky-Way System
Ludwig Kühn
Verlag: Hirzel, Stuttgart

R.10.5.2 DAS GESCHENKTE UNIVERSUM: see Referenz R.1.1.5
Arnold Benz: Astrophysik und Schöpfung
pp 24, 38–39: Origin of the Universe
p. 119: Origin of Life on Earth: three and a half billions of years after its origin
p. 72: It is estimated that in about 1.2 Billion years all water at the Earth will have vaporized.

R.10.5.3 see Reference R.1.1.6: SEARCHING FOR WATER IN THE UNIVERSE
Thérèse Encrenaz

R.10.5.4 pp. 488: L’Univère populaire: A composition of Camille Flammarion
http://en.wikipedia.org/wiki/Camille_Flammarion

R.10.5.5 p. 490: Our Milky-Way Galaxy
http://home.arcor.de/hpj/IMG/galaxis2.jpg

R.10.5.6 p. 491: The Milky-Way Galaxy
p. 492: http://www.atlasoftheuniverse.com/galaxy.htm/

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R.10.5.8 p. 494: Radio-Telescopes
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http://www.mpifr-bonn.mpg.de/div/effelsberg
right-hand side: Green-Bank Telescope (GBT)
http://www.gb.nrao.edu/gbt/
images-nrao.edu >…Gallery > See_the_Universe > Telescope

R.10.5.9 p. 495: The Hubble – Space Telescope
http://de.wikipedia.org/wiki/Hubble_Weltraumteleskop

R.10.5.10 p. 496: The Herschel Space Telescope
Herschel Space Observatory: Wikipedia, for the free encyclopedia and References given therein

R.10.5.11 p. 497: Observation of extrasolar Water
General Remarks

R.10.5.12 p. 498: Comet Hale – Bopp
M.P. Bernstein et al., Scientific American, July 199, p. 26
Figure from: http://www.mpifr-bonn.mpg.de/public/Dir_Jan_Thomas/Bilder/halebopp.gleason.jpg

R.10.5.13 p. 499: Comet Hartley 2
http://epoxy.umd.edu/3gallery/20101104_Sunshine3.shtml

R.10.5.14 p. 500: The Planet HD 189733b in front of his Sun

R.10.5.15 p. 501: The Water – planet Gliese with hot Ice

R.10.5.16 p. 502: Gliese 436b - Wikipedia, the free encyclopedia, and References given therein: planet containing hot Water – Ice!
(For clarity of reading, the Figures have been slightly adjusted by P. Brüesch.)
R.10.5.17  p. 503: Most distant detection of water in the Universe
Wasser in 11.1 Milliarden Lichtjahre Entfernung wurde entdeckt!
(Dr. Violetta Impellizzeri et al., Universität Bonn)
http://www.spiegel.de/wissenschaft/weltall/0,1518,597100,00.html

R.10.5.18  p. 504: Water detected in Quasar MG J0414+0534
www.raumfahrer.net/forum/smf/index.php?topic=526.15

R.10.5.19  p. 505: Most distant Water in the Universe – Text to Figure at p. 497

R.10.5.20  p. 506: Eagle Nebula
from: Eagle Nebula → Bilder „thereisfuninmypocket.blockspot.com“ → (“God's penis?”)

R.10.5.21  Water in the Universe
Arnold Hanslmeier
Springer Netherlands (2010)
ISBN 9048199832

R.10.5.22  Das Schicksal des Universums:
„Eine Reise vom Anfang zum Ende“
Günther Hasinger
Wilhelm Goldmann Verlag, München
Copyright © der Originalausgabe 2007
by Verlag C.H. Beck oHG, München

R.10.5.23  p. 507: Giant water quantity around a black hole
22. July 2011; http://www.bz-berlin.de/aktuell/welt/riesige-wassermenge-weltall...
s. also: http://bauletter.wordpress.com/2011/07/31/riesiges-wasserreservoir-im-weltall-entdeckt

R.10.5.24  p. 508: Aliens need Water desoperately, too!
Picture composed by P. Brüesch from:
Figure at the left: www.topnews.in/aliens-do-exist-us-govt-hides...
Figure at the right: Internet search for: female aliens
merveser.blogspot.com/

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