Basic data on water

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Links to further data on water:

http://www.wissenschaft-technik-ethik.de/wasser_dichte.html
(density tables of water, ice and vapor]
http://www.wissenschaft-technik-ethik.de/wasser_dampfdruck.html
(vapor pressure tables of water and ice]
http://www.wissenschaft-technik-ethik.de/wasser_loesung.html
(dissolving properties of water, solubilities, ph value]
http://www.wissenschaft-technik-ethik.de/wasser_ph.html
(determination of pH value by means of Hägg diagram]

1. Occurrence and general physical properties

Two thirds of the surface of the planet earth is covered with water. More than 97 percent of the total water supply of the earth are salt water and only 2.5 percent are fresh water. Two thirds of fresh water are in turn the ice at the poles and thus not available as drinking water. Thus, only one third of global fresh water supplies is available as drinking water.

The amount of water existing on earth is approximately 1.386 billion km^3. Approximately 12,900 km^3 of water exist as vapor in the atmosphere. The entire Lake Constance vaporizes into the atmosphere 18 times every day, app. 90% of which pours down as rain into the oceans.

Distribution:

- salt water 97.5 percent
- fresh water 2.5 percent, of which
  - 0.01 percent are clouds, rain, snow and hail
  - 0.3 percent are rivers, streams, lakes
  - 30.8 percent are groundwater
  - 68.9 percent are glaciers

occurrence	volume x 10³ km³	% of total volume	% fresh water	recharge time in years
ocean	1,370,323	93.94	-	3,000
deep groundwater	60,000	4.11	-	5,000
rechargeable groundwater	4,000	0.27	14.09	330
ice (glaciers)	24,000	1.65	84.57	8,000
lakes	280	0.02	0.99	7
soil moisture	85	0.01	0.30	1
atmosphere	14	0.00	0.05	0.03
rivers	1.2	0.00	0.00	0.03
fresh water total	28,380	1.95	100	-
water total	1,458,703	100		2,800

According to Lvovitch 1979, quoted in Schwoebel: Einführung in die Limnologie 6. Auflage Stuttgart 1987

Converted into masses, this corresponds to:

- amount of water on earth, free and fixed in lithosphere: app. 2.4*10^21 kg
- mass of hydrosphere: 1.664*10^21 kg
- (for comparison: mass of atmosphere: 5.136*10^18 kg)
- total surface of oceans and seas: 3.61*10^14 m² = 70.8% of earth surface
- mean depths of oceans: 3794 m

Drinking water refers to all water that is used for drinking and cooking, for personal hygiene as well as for cleaning of dishes and other things and the water that we use in connection with foods.

For what in particular is drinking water used?

According to the United Nations the average water consumption of a US American is 30 liters per day; in contrast, it is only 22 liters in Egypt (as of 2002). In Germany one person uses app. 124 liters of water a day. In detail:

- showering and personal hygiene: app. 46 liters
- toilet flush: 35 liters
- laundry: 15 liters
- cleaning and garden: 8 liters
- dishwasher: 8 liters
- drinking and cooking: 5 liters

The global water consumption has increased tenfold in the past 100 years, while the earth population has “only” quadrupled.

Agriculture accounts for two thirds and thus for the largest share of global fresh water consumption. While Europe and North America use two thirds of their extracted water for the industries and households and one third for agriculture, other regions of the earth, like Asia and Latin America, use 80 percent of their water for agriculture.

The increase of global water consumption is the result of growing industrialization and the increased demand of predominantly urban households.

In addition to the direct water consumption there is the consumption of “virtual water”. “Virtual water” refers to the amount of water contained in a product or a service or used in the respective production process. For example, in order to produce a 32-megabyte computer chip app. 34 liters are used, and in the course of the production of a car a total of 400,000 liters of water are used; one cup of breakfast coffee requires app. 100 liters of water if that water is taken into consideration as well that is required for the growing and processing of the coffee beans! The production of a cotton T-shirt requires more than 1000 liters of water. And the production of a single pair of shoes uses 8000 liters!

A German citizen consumes app. 4,000 liters of virtual water a year.

2. Properties of water

- chemical formula
  H_2O

- molecular weight
  $M(H_2O)$ = 18.01534 g/Mol

- melting point at standard pressure
  $Smp(H_2O)$ = 0°C
- boiling point at standard pressure
  Sdp (H_2O) = 100°C

- heat of fusion at constant pressure (“enthalpy of fusion”) under standard pressure
  Delta H(Sm) = 6.007 kJ/Mol = 333.4 kJ/kg at 0°C

- heat of evaporation at constant pressure (“enthalpy of evaporation”) under standard pressure
  Delta H(V) = 40.66 kJ/Mol = 2257 kJ/kg at 100°C

- standard enthalpy of formation of liquid water
  Delta H(B) = -285.9 kJ/Mol = -15.87 MJ/kg

- triple point
  T(Trp) = 0.01°C

- the water molecule
  distance between the centers of the atoms:
  - H-O = 0.1013 nm
  - H-H = 0.153 nm
  - angle between O-H bonds: 105.05°

Enthalpy of fusion and evaporation is temperature-dependent. This has to be considered especially in case of enthalpy of evaporation as, due to the strong dependence of the boiling temperature from pressure, evaporation or condensation often happen at temperatures that deviate very much from the boiling point under standard conditions. Evaporation and condensate formation also occur at very different temperatures at standard pressure (see Table 1).

Table 1: vapor pressures, enthalpies of liquid phase and the enthalpies of vaporization given at different temperatures at the respective saturation pressure

temperature [°C]	pressure p [bar]	enthalpy of liquid phase [kJ/kg]	enthalpy of vaporization H(V) [kJ/kg]
0	0.0061	0.00	2500.5
5	0.0087	21.05	2488.6
10	0.0123	42.03	2476.9
15	0.0170	62.96	2465.1
20	0.0234	83.86	2453.4
25	0.0317	104.74	2441.7
30	0.0424	125.61	2429.9
40	0.0737	167.34	2406.2
50	0.1233	209.11	2382.2
60	0.1992	250.91	2357.9
70	0.3116	292.78	2333.1
80	0.4736	334.72	2307.8
90	0.7011	376.75	2268.8
100	1.0132	418.88	2255.5
110	1.4326	461.13	2228.5
120	1.9853	503.5	2200.7
140	3.614	588.90	2142.9
160	6.180	675.20	2081.3
180	10.027	762.70	2014.9
200	15.551	851.80	1941.9
220	23.201	943.00	1860.4
240	33.48	1036.90	1768.2
260	46.94	1134.30	1663.1
280	64.19	1236.10	1542.5
300	85.92	1344.20	1403.6
320	112.90	1461.30	1241.3
340	146.08	1593.50	1026.7
350	165.37	1670.30	892.2
360	186.74	1762.20	720.9
365	198.30	1817.90	608.0
370	210.52	1893.70	446.2
372	215.62	1938.10	349.0
373	218.22	1972.00	280.4
374	220.86	2043.20	144.4
374.15	221.29	2099.70	0.00

3. Critical data

If water [this is also true for other substances!] is continuously heated in a closed pressure vessel more and more water evaporates with the temperature increase causing the pressure in the vessel to rise. The physical properties of water and vapor become more and more similar with rising temperature. If a certain temperature is reached the properties of water and vapor are the same. This temperature is called critical temperature T[krit]. This can be seen, among others, in the fact that the phase boundary between liquid and vapor that is still visible below the critical temperature [due to the then still different refraction indices] disappears when the critical temperature is reached [from this temperature on the refraction indices, like all other properties, are the same]. Pressure and density at the critical temperature are called critical pressure p[crit] and critical density D[krit].

Critical data of water:

- T[krit] = 374.15 °C
- p[krit] = 216.9 bar
- D[krit] = 315 kg/m³

4. Specific heat

Table 2: specific heat capacity of water, ice and water vapor at constant pressure, dependent from temperature

temperature [°C]	specific heat c(p) [kJ/kg/K]	state of matter
-100	1.377	solid (ice)
-60	1.64	solid (ice)
-32	1.86	solid (ice)
-25	1.93	solid (ice)
-21	1.95	solid (ice)
-15	2.00	solid (ice)
-11	2.04	solid (ice)
-5	2.06	solid (ice)
-2	2.10	solid
0	4.218	liquid
10	4.192	liquid
20	4.182	liquid
30	4.179	liquid
40	4.179	liquid
50	4.181	liquid
60	4.184	liquid
70	4.190	liquid
80	4.196	liquid
90	4.205	liquid
100	4.216	liquid
110	2.014	gas (vapor)
120	1.997	gas (vapor)
150	1.976	gas (vapor)
200	1.963	gas (vapor)
250	1.980	gas (vapor)
300	1.997	gas
400	2.052	supercritical
500	2.119	supercritical

Table 3 For comparison: specific heat of other solids and liquids

substance	temperature [°C]	specific heat c(p) [kJ/kg/K]
aluminum	20	0.896
lead	0	0.128
copper	0	0.381
sheet glass	20	0.8 (app.)
oak wood	20	2.39
pinewood	20	2.7
rubber	0	1.4
dry sand	20	0.8
concrete	20	0.9
sugar	0	1.26
ammonia	0	4.65 (at saturation pressure)
ammonia	20	4.77 (at saturation pressure)
hydrazine	25	2.90
hydrogen cyanide	25	2.62
sulfuric acid	20	1.38
methanol	25	2.54
ethanol	25	2.45
acetone	25	2.17
acetic acid	25	2.05
n-octane	25	2.22
i-octane	25	2.07
benzol	20	1.73
spindle oil	20	1.85
chloroform	25	0.97
mercury	0	0.140
mercury	80	0.138

5. Heat conductivity of water, ice and water vapor, dependent from temperature and pressure

Table 4

temperature [°C]	Lambda [W/m/K]	state of matter
-100	3.5	ice
-60	2.8	ice
0	2.2	ice
0	0.569	
20	0.604	
40	0.632	
60	0.654	
80	0.670	
100	0.681	
140	0.688	saturation pressure
180	0.677	saturation pressure
220	0.648	saturation pressure
300	0.541	saturation pressure
340	0.460	saturation pressure
374	0.238	saturation pressure
30	0.611	1 bar
30	0.649	1000 bar
30	0.707	2500 bar
300	4.35	vapor, 1 bar
400	5.40	[supercritical, 1 bar]
300	4.75	[vapor, 20 bar]
400	5.60	[supercritical, 20 bar]
300	5.30	[vapor, 50 bar]
400	5.94	[supercritical, 50 bar]

For comparison: heat conductivity of other liquids and solids:

substance	temperature [°C]	Lambda [W/m/K]
acetone	16	0.190
benzol	22.5	0.158
toluol	27	0.1340
CCl4	27	0.1036
glycerin	20	0.294
mercury	0	7.9
V2A steel	20	15
iron	25	80.4
copper	25	401
aluminum	25	237
Diamond type I	25	990
Diamond type IIa	25	2320
diamond type IIb	25	1360
pyrolytic graphite	25	
- parallel to layers		1960
- perpendicular to layers		5.73
sulfur, crystalline	25	0.27
pinewood	20	0.14
cork	20	0.05
concrete	20	1

6. Dynamic viscosity of water, depending on pressure and temperature:

temperature [°C]	Eta [N*s/m²]	
	1bar	100bar
liquid:		
0	0.001792	0.001770
10	0.001307	0.001296
20	0.001002	0.001000
30	0.000797	0.000789
40	0.000653	0.000654
50	0.000546	0.000549
60	0.000466	0.000469
70	0.000404	0.000408
80	0.000355	0.000361
90	0.000315	0.000324
100	0.000282	0.000293
120	0.000245	
140	0.000207	
200	0.000141	
300	0.000094	
gas:		
100	0.0000124	
120	0.0000132	
140	0.0000140	
160	0.0000148	
180	0.0000155	
200	0.0000163	
300	0.0000202	
supercritical:		
400	0.0000240	0.0000289
500	0.0000277	0.0000322

In comparison: dynamic viscosity of other liquids:

substance	temperature [°C]	Eta [N*s/m²]
acetone	25	0.000316
acetic acid	18	0.00130
methanol	25	0.000547
ethanol	20	0.001200
	30	0.001003
isopropanol	30	0.00177
chloroform	25	0.000542
diethyl ether	25	0.000222
benzol	20	0.000652
	50	0.000442
toluol	20	0.000590
ethylene glycol	20	0.0199
	40	0.00913
	80	0.00302
glycerin	20	1.490
	30	0.629
hydrazine	20	0.00097
hexane	25	0.000294
olive oil	20	0.0840
	40	0.0363

	70	0.0124
sulfuric acid	20	0.0254
	30	0.0157
mercury	20	0.001554
	100	0.001240
	200	0.001052

conversion into other units:

1 P [Poise] = 0.1 N*s/m²

1 cP = 0.001 N*s/m²

1 N*s/m² = 1 kg/m/s

7. Electric conductivity of pure water, dependent from temperature:

temperature [°C]	Chi [yS/m]
-2	1.47
0	1.58
2	1.80
4	2.12
10	2.85
18	4.41
26	6.70
34	9.62
50	18.9

8. Isothermal compressibility of water, dependent from pressure and temperature:

It holds:

V = V0*[1-Chi*p]
[V: volume, V0: initial volume, Chi: isothermal coefficient of compressibility, p: pressure]

temperature [°C]	Chi [10^-5 per bar] in pressure range:			
	1..50	50..100	100..200	1000..2000bar
0	5.0	4.9	4.7	3.3
10		4.8		
20	4.6	4.5	4.3	3.2
30	4.5			
40	4.4	4.4	4.2	3.1
50	4.4			
60	4.4	4.4	4.2	
70	4.5			
80	4.6			
90	4.7			
100	4.8	4.7	4.6	

means at 20°C:

p [bar]	Chi [10^-5 per bar]
1	4.59
100	4.52
200	4.46
300	4.39
500	4.27
750	4.12
1000	3.98
1250	3.85
1500	3.73

For comparison: isothermal compressibility of some other liquids:

liquid	Chi [10^-5 per bar]	
	20°C	80°C
acetone	12	
acetic acid	9	14
glycol	3.7	4.6
mercury	0.40	0.42
methanol	12	
ethanol	11	17

9. The relation between wavelength ans spectral color ranges meant as orientation for the following optical properties of water:

wavelength	spectral color ranges	
<400nm	ultraviolet	
400..425nm	violet	blue-violet
470..500nm	blue	blue-green
520..560nm	green	yellow-green
580..600nm	yellow	orange
680..800nm	red	
>800nm	infrared	

9.1 Absorption of electromagnetic radiation of different wavelengths in water:

I: intensity after passage through water layer of x m thickness
I0: initial intensity before passage
k: absorption coefficient

It holds:

$I = I0 * e^{[-k*x]}$

The k values were taken from /4/, which lists absorption data from different references that differ in part exorbitantly, especially in the UV range. The values presented here are mainly means from a selection of those values that are similar to each other at least to some extent. Those who need more than an orienting overview are strongly recommended to review the original literature.

Concerning the values of 1000 nm and above the values from the individual references in general differ just a little from each other. Here, the mean values of up to four individual references are given.

x [0.001] is the calculated thickness of the water layer weakening the respective radiation to 1/1000 of its initial value.

[1]: corresponding radiation maximum at app. 1200°C
[2]: corresponding radiation maximum at app. 700°C
[3]: corresponding radiation maximum at app. 200°C
[4]: corresponding radiation maximum at app. 0°C
[5]: 300-GHz waves [1mm waves]
[6]: 300-MHz radio waves [1m waves]

Lambda [nm]	k [1/m]	X [0.001][m]
200	app. 7	1
250	app. 1	7
300	app. 0.2	35
350	app. 0.2	35
400	app. 0.06	110
450	app. 0.02	350
500	app. 0.025	280
550	app. 0.05	140
600	app. 0.2	35

650	app. 0.32	22
700	app. 0.65	11
750	app. 2.6	2.7
800	app. 2.0	3.5
1000	37	0,19
2000 [1]	6,800	0.0010
3000 [2]	1,150,000	
4000	14,300	
5000	31,300	
6000 [3]	180,000	
7000	575,000	
8000	54,000	
9000	56,000	
1*10^4 [4]	66,000	
2*10^4	246,000	
5*10^4	126,000	
1*10^5	66,200	
2*10^5	31,400	
5*10^5	18,600	
1*10^6 [5]	12,800	
5*10^6	5,860	
1*10^7	3,640	
5*10^7	372	0.019
1*10^8	93	0.074
1*10^9 [6]	1.0	6.9

9.2 Refractive index n of water against air of equal temperature at standard pressure, depending from temperature:

wavelength	n [20°C]	n [30°C]	n [40°C]
235	1.3854	1.3838	
280	1.3644	1.3631	1.3614
366	1.3470	1.3458	1.3442
405	1.3427	1.3417	1.3402
447	1.3394	1.3383	1.3370
502	1.3364	1.3353	1.3339
546	1.3345	1.3334	1.3321
589 [1]	1.3330	1.3319	1.3306
656	1.3312	1.3301	1.3288
707	1.3300	1.3290	1.3277
808	1.3282		
871	1.3270		
943	1.3258		
1028	1.3245		
1500	1.316		
2000	1.300		

Refractive index of ice at the sodium D line at 0°C:
1.3091 [ordinary beam]
1.3105 [extraordinary beam]

[1]: Sodium D line, wavelength Lambda = 589.3 nm
For comparison: refractive indices n[25] D of other liquids at 25°C and the Sodium D line:

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substance	**n[25]D**
sulfuric acid	1.427
bromine	1.661
hydrazine	1.470 [22°C]
CS2	1.628
CSe2	1.845 [20°C]
methanol	1.326
ethanol	1.359
1-Propanol	1.383
1-Butanol	1.397
1-Pentanol	1.408
n-Hexane	1.372
n-Octane	1.395
n-Decane	1.409
n-Dodecane	1.400
cyclohexane	1.424
acetone	1.357
acetic acid	1.370
diethyl ether	1.352
chloroform	1.444
CCl4	1.460
benzol	1.498
styrol	1.545
nitrobenzene	1.550
diiodomethane	1.749

10. Static dielectric constant of water, dependent from temperature:

temperature [°C]	Epsilon
0	87.69
10	83.82
20	80.08
25	78.25
30	76.94
40	73.02
50	69.70
60	66.51
70	63.45
80	60.54
90	57.77
100	55.15

For comparison: dielectric constants of other liquids [at temperatures above boiling point: value at saturation pressure]:

substance	temp.[°C]	Epsilon
ammonia	-33.4	22.4
	25	16.9
hydrazine	20	52
bromine	20	3.09
H_2O_2	0	84.2
CO_2	0	1.60
HCN	0	158
	20	114
methanol	25	32.63
ethanol	25	24.30
acetic acid	20	6.15
n-Hexane	20	1.89
benzol	20	2.28
nitrobenzol	25	34.8
formamide	20	109
formic acid	16	58
glycerin	25	42.5
glycol	25	37
diethyl ether	20	4.34
cyclohexane	20	2.02
styrol	25	2.43

11. Sonic velocity c in distilled water at 750 Hz, dependent from temperature:

temperature [°C]	c [m/s]
0	1403
10	1448
20	1483
30	1509
40	1529
50	1543
60	1551
70	1555
80	1555
90	1551
100	1543

For comparison: sonic velocity of other liquids at 25°C:

substance	c [m/s]
sea water	1531
aceton	1174
benzol	1295
methanol	1103
ethanol	1207
mercury	1450
diethyl ether	985
glycol	1658
glycerin	1904
chloroform	987

12. Surface tension of water against air, depending from temperature:

temperature [°C]	Sigma [N/m]
-5	0.0764
0	0.0756
10	0.0742
20	0.0728
30	0.0712
40	0.0696
50	0.0679
60	0.0662
80	0.0626
100	0.0589

For comparison: surface tension of other liquids against air at 20°C:

substance	Sigma [N/m]
benzol	0.0289
glycerin	0.0634
glycol	0.0477
methanol	0.0226
n-Hexane	0.0184
N_2 (-183°C)	0.0066 [against vapor]
He (-269°C)	0.00012 [against vapor]
H_2SO_4 (98.5%)	0.0551
mercury	0.476

13. References:

/1/ D'Ans-Lax, Taschenbuch für Chemiker und Physiker, Bd.1, 3.Aufl., Springer, Berlin-Heidelberg 1967

/2/ Weast, Handbuch für Chemiker und Physiker, 64th Edition 1983-84, CRC Press

/3/ Meyer/Schiffner, Technische Thermodynamik, VEB Fachbuchverlag, Leipzig 1989

/4/ http://omlc.ogi.edu/spectra/water/