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Water dissociation A remarkable property of pure water is that it dissociates to form hydrogen ions (H3O+) and hydroxide (OH−) ions. The ionic product, Kw pH Variation in Kw with temperature and pressure Acidity, basicity, and the pKa of water Weak acids Hydrogen ions Hydroxide ions Grotthuss mechanism Ionic strength 'I will employ the name "hydrogen ion exponent" and the symbol pH for the numerical value of the exponent of this power' The ionic product, Kw Water dissociation (autoionization; self-ionization) occurs endothermically d due to electric field fluctuations between neighboring molecules. Dipole librations [191], resulting from thermal effects and favorable localized hydrogen bonding [567], together with nuclear quantum effects [2025, 4456], cause these fluctuations. The process may be facilitated by exciting the O-H stretch overtone vibration [393]. Once formed (at an average concentration of about 1 M H2O-H+···OH− at femtosecond timescales, as reported by Vasily Artemov's group [1984]),h the ions may separate through the Grotthuss mechanism. Usually (>99.9%), these ion-clusters rapidly recombine (≈ 20 ps [2171]) with a frequency in the terahertz range to give the long-lived ions conventionally found. Thus the exact hydrogen ion concentrations depend on the time scale at which these are probed. Rarely (about once every eleven hours per molecule at 25 °C, or less than once a week at 0 °C), the localized hydrogen bonding arrangement breaks before allowing the separated ions to return [191]. The pair of ions (H+, OH−)g hydrate independently and continue their separate existencea for about 70 μs (this lifetimeis also dependent on the extent of hydrogen bonding, being shorter at lower temperatures). They tend to recombine when separated by only one or two water molecules. H2O H+ + OH− Kw = [H+] × [OH−] The kinetics of the process has been described using the equations, [4481] The recombination (kr2) is assumed to be controlled by diffusion (0.112 M−1 × ps−1), kd2 ≫kd1., and kr1 ≫kr2 , (kd1 =0.076 × s−1, kr1 = 3.142 × ps−1. The dissociation rate (kd2) was estimated at 2.04 × 10−5 × s−1 . The paired ions were found to be ion pairs separated by two water molecules (0.58 nm). pKw is a dimensionless number (= 13.995, 25 °C [IAPWS]) as the included concentrations are relative to the molal standard states (e.g., 1 mol × Kg−1). n This low occurrence of the ions means that at neutrality (pH 7, at 25 °C) c, similarly charged ions are, on average, separated by vast distances (≈ 0.255 μm) in molecular terms and (for example) bacteria contain only a few tens of free hydrogen ions (~ 30 in an Escherichia coli). Contributing to this effect is the high dielectric constant (encouraging charge separation) and high concentration of H2O (≈ 55.5 M; increasing the absolute amount dissociated). The mean lifetime of a hydroxonium ion (1 ps; about the same as that of a hydrogen bond) is such that the charge could be associated with over 107 molecules of water before neutralization. Although the extent of dissociation is tiny ([H+]/[H2O] = 2.8 × 10−9 at 37 °C), the dissociation and consequential changes in the tiny concentrations of hydrogen ions have absolute importance to living processes. Hydrogen and hydroxyl ions are produced already hydrated. H2O (liq) H+(aq) + OH− (aq) where the subscripts, 'liq' and 'aq', indicate that the species are in or within the aqueous liquid phase.l Hydration enthalpies of protons and hydroxides, from [1938b] The protons (H+, hydrons) initially hydrate as hydroxonium ions, H3O+ (also called oxonium or hydronium ions) and do not exist as naked protons in the gas phase, or liquid, or solid water, where they interact extremely strongly with electron clouds. All three hydrogen atoms in the hydroxonium ion are held by strong covalent bonds and are equivalent (C3v symmetry in a vacuum). The thermodynamic properties of the dissociation at 25 °C and 0.1 MPa are ΔU° = 59.5 kJ × mol−1, ΔV° = 22.13 cm3 × mol−1, ΔH° = 55.8 kJ × mol−1, ΔG° = 79.9 kJ × mol−1, ΔS° = -80.8 J × K−1 × mol−1 [1938]. The proton is never found unhydrated in an aqueous solution, and the hydroxonium ions, H3O+, also have negligible independent existence in an aqueous environment [2134]. All the hydroxonium ion protons are predominantly hydrogen-bonded, causing further hydration to H3O+(H2O)n, where n depends on the conditions such as temperature, solutes, pressure, and method of determination. [H+] is often written instead of [H3O+]. To avoid the misleading presumption of the existence of bare protons similar to other bare cations (but see [2132] for an alternative view), the above equations are better written as: 2 H2O(aq) H3O+(aq) + OH−(aq) Kw = [H3O+] × [OH−] Change in volume on water dissociation, from [1946] Both ions are ionic kosmotropes, hydrating and creating order in forming stronger hydrogen bonds with surrounding water molecules than the water molecules form between themselves and creating short chains of hydrogen-bonded water molecules [2025]. Remarkably, the volume change in this reaction 2 H2O(l) H3O+(aq) + OH−(aq) ΔV = -22.3 cm3 mol−1 at 25 °C and infinite dilution, [1946], see Figure right, due to the change in the hydration strength plus electrostriction, is about the same as one molecule of water (18.1 cm3 × mol−1); when one water molecule ionizes, its volume effectively disappears. The concentrations of H3O+ and OH− are normally taken as the total concentrations of all the singly charged small clusters including these species. As other water molecules are required to promote the hydrolysis, the equations below includes the most important. None of these hydrated ions should be considered as 'fixed' structures, with further water molecules continually coming and going in aqueous solution with timescales of picoseconds. No bare protons occur, however. 4 H2O H5O2+ + H3O2− 10 H2O H13O6+ + H7O4− The concentration of hydroxonium and hydroxide ions produced is equal to the square root of the dissociation constant (Kw). A wide range of values for Kw has been calculated using Quantum Cluster Equilibrium (QCE) theory with various ab initio and density functional methods [3025]. The reverse reaction H3O+(aq) + OH−(aq) 2 H2O(aq) Keq = 1014 ; 25 °C greatly favors the neutralization reactions of acids and bases. Aqueous OH− does not ionize further as (O2− + H2O 2 OH−, K > 1022). H3O+ does not protonate further to the tetrahedral H4O2+ ion as although H4O2+ may be metastable in the gas phase, it is thermodynamically unstable to loss of a proton [2133], and would immediately dissociate in aqueous solution. [Back to Top] pH pH of common materials The hydronium (oxonium) ion concentration (commonly called 'hydrogen ion concentration') is often given in terms of the pH, where pH = Log10(1/[H3O+]) = -Log10([H3O+]) (that is, [H3O+] = 10−pH) f with the concentration of H3O+ in mol × L−1. This equation is adequate for most solutions but may fail under higher solute concentrations. More accurately and as determined using a pH meter, pH = -Log10(aH) = -Log10(mH × λH/m°) where aH, mH, λH, and m° are the relative (molality based) activity, molality, molal activity coefficientj, and standard molality (1 mol × [kg solvent]−1) of the hydrogen ions. This equation is correct under higher solute concentrations. Proof that the use of the equation pH = -Log10([H+]) may give misleading results (and pH = -Log10(aH) is preferred) is easily shown as the pH of 0.1 M HCl decreases (i.e., it apparently becomes more acidic) when it is diluted with 5% M LiCl [1107]. Also, the -Log10([H3O+]) for average seawater at 25 °C is 8.19, but its -Log10(aH) is 8.32. As pH involves activities, the [H3O+] calculated from pH = -Log10([H+]) is often not the [H3O+] concentration experimentally determined by titration. The hydrogen ion activity cannot be evaluated thermodynamically [3376] but may be determined kinetically. Water can thus support acid-base equilibria over a range of about 16 pH units (see above right). At the low concentrations usually found, the molarity-based hydrogen ion concentration is close enough to the relative (molality based) activity for its use in most circumstances. The presence of salts and other solutes will generally reduce this activity, and the activity varies with temperature. The molal activity of hydrogen ions cannot be determined directly but may be determined using a glass electrode standardized to the response of standard buffer solutions of comparable ionic strength. o Glass electrode-determined pH values are error-prone, and calculated hydrogen ion concentrations should be treated with caution, particularly at the extremes of pH [1890]. For more information and a list of primary pH standards, see [813]. Typical pH electrode The pH scale was first introduced by Sørensen (as pH·) in 1909 [1036] using colorimetric measurements and the hydrogen electrode, which generates an electrode potential proportional to pH. Today, we commonly use the glass electrode [3377] (see right), which also gives an electrode potential dependent on the activity of the H+and proportional to pH in dilute solution, where F, R, and T are the Faraday constant, the gas constant, and absolute temperature, respectively. E refers to the potential (V) of the "unknown" solution being determined, and ES and pHS refer to the standard reference electrode solution. Once calibrated with a solution of Known pH pH ∝ E with a proportionality correction being applied for the temperature. The pH's are reasonably accurate where the pH meter is calibrated close to the pH at issue and with a solution of approximately the same ionic strength [3378]. The pH meter can be used to estimate hydrogen ion concentrations without concern for knowing activities [3376]. pH electrodes are now commonly used to determine the pH (see right).i The pH scale extends to negative numbers (for example, concentrated HCl has a pH of about -1.1) and to greater than 14 (for example, saturated NaOH has a pH of about 15.0) [1187]; although the glass electrode cannot be used at such extreme pH's. There is a review of the pH of natural water [1712]. Similarly to pH, pKw is defined by pKw = Log10(1/Kw) = -Log10(Kw) utilizing concentrations in mol × L−1. Where the solution contains significant amounts of heavy water (D2O), the measured pH will differ slightly from that expected from the sum of the amounts of the protonated species H3O+ + H2DO+ + HD2O+ + D3O+ [2953]. [Back to Top] pKw versus temperature pKw = -log10(Kw) [IAPWS] Variation in Kw with T and P Kw is very temperature dependent, increasing with temperature (that is, from 0.001 × 10−14 mol2 × L−2 at -35 °C (pH 8.5) [112], 0.112 × 10−14 mol2 × L−2 at 0 °C (pH 7.5), to 0.991 × 10−14 mol2 × L−2 at 25 °C (pH 7.0), to 9.311 × 10−14 × mol2 × L−2 at 60 °C (pH 6.5) [87]), to 10−12 × mol2 × L−2 at 300 °C (pH 6.0, ≈ 50 MPa) [456] in agreement with the high positive standard free energy. b There is a minimum at about 249 °C along the saturated pressure line for H2O and at about 257 °C for D2O (see right [1865]). The pKw H2O minimum is about 0.74 lower than that for D2O [1865]. (see also conductivity maximum). A theoretical treatment of this temperature dependence is available [763]. Variation in pKw (pKa) pKw versus pressure Temperature and density dependence of dissociation have been examined [1321]. Dissociation depends on the pressure, with Kw doubling at about 100 MPa; unsurprising given the negative ΔV associated with the dissociation, -18.1 cm3 × mol−1. pKw versus water density, changing T and P towards and past critical point, from [4121] Using the different methodology of direct, conductivity measurements, the results from the University of Guelph [4121] show discrepancies from these values between 350 °C, and 401 °C, and between 5.75 MPa and 31.15 MPa, which reach between two and five orders of magnitude near the critical point. The actual pKw of solutions is rarely 14.0 [4245] as dissociation also varies with solute concentration and ionic strength; for example, Kw goes through a maximum of about 2 × 10−14 mol2 × L−2 (minimum pKw ~13.7) at about 0.25 M ionic strength (using tetramethylammonium chloride, where possibly the change in hydrogen-bonding caused by clathrate formation encourages dissociation) before dropping to a value of about 1 × 10−16 mol2 × L−2at 5 M (with higher concentrations disrupting the hydrogen-bonding). Similar maxima occur with other salts such as NaCl (≈ 0.6 M), KCl (≈ 0.45 M), KNO3 (≈ 0.5 M) and NaClO4 (≈ 0.5 M) [2234]. Dissociation will also be different at interfaces; for example, it is greater at lipid membrane surfaces [1964]. In ice, where the local hydrogen-bonding rarely breaks to separate the continually forming and re-associating ions, the dissociation constant is much lower (for example, at -4 °C, Kw = 2 x 10−20 mol2 × L−2). [Back to Top] Acidity, basicity, and the pKa of water There has been controversy and confusion for the last 90 years over the aciditye of water and its pKa; a confusion that is yet to be fully clarified. Does the pKa of H2O equal 15.74 [2966] or 14.00 [2965]? The answer depends on the standard state used for the solvent water.m The acidity constant (Ka) of weak acid HA,k HA (aq)+ H2O (l) A− (aq) + H3O+(aq) ΔG° where HA is an acid having its conjugate base A−; also H2O is acting as a base with its conjugate acid H3O+ Ka is defined by Ka= [H3O+][A−]/[HA] pKa= -Log10(Ka) therefore, ΔG° = - RT Ln(Ka) pKa= ΔG°/(ln(10) × RT) Together with its conjugate base A−, we get, HA (aq) + H2O (l) A− (aq)+ H3O+ (aq) ΔGa° = - RT Ln(Ka) A− (aq)+ H2O (l) HA (aq) + OH− (aq) ΔGb° = - RT Ln(Kb) H2O (l) + H2O (l) H3O+(aq) + OH− (aq) ΔGw° = - RT Ln(Kw) = 79.89 kJ × mol−1 [2967] Where the ΔG° values are the standard Gibbs free energies for the equilibria. Therefore, as ΔGw° = ΔGa° + ΔGb°, Ln(Kw) = Ln(Ka) + Ln(Kb) and pKa+ pKb = pKw and Kw = Ka × Kb H2O, as a weak acid, may be treated in the same way H2O (l) + H2O (l)H3O+(aq) + OH− (aq) Its pKa has been (mistakenly) derived as Ka= [H3O+][OH−]/[H2O] = Kw/[H2O] = Kw/55.345 (at 25 °C) and pKa = pKw +1.743 (= 15.738 at 25 °C) However, in this derivation, the H2O is treated both as an acid ([H2O] in the denominator, equaling about 55.345 mol × L−1), and the solvent (internalized in the Ka definition with a value of unity). This disparity in values introduces conflict. The alternative (and correct) derivation utilizes the activity of water (equals unity) in the denominator [1321, 2965] Ka (H2O)= [H3O+][OH−] = Kw = 10−13.995 (a number without units) pKa = pKw = 13.995 (H2O, 25 °C) H2O is a very weak acid; compare with the pKas of H2Te, H2Se, and H2S that are 2.6, 3.89, and 7.04, respectively. The pKb (= pKw - pKa = 0.00) related to this Ka concerns the conjugate base (OH−), and not H2O, as commonly mistakenly cited. OH− is a strong base, whereas H2O is a very weak base. The pKb of H2O is derived exactly as pKa (above, as the equation generates both an acid and a base) and gives the same value (= 13.995 at 25 °C). Although a true ionization constant is a thermodynamic quantity related to the standard free energy change and should be independent of the concentration used for its determination, in practice, it will vary (a little) with this concentration due to interactions between the ions (i.e, their activities). H3O+ is a strong acid with associated Ka (H3O+) equaling unity exactly (see the equation below). pKa (H3O+) equals zero exactly and is invariant with temperature, as ΔG° is necessarily zero. H3O+(aq) + H2O (l) H2O (l) + H3O+(aq) ΔG° = - RT Ln(Ka (H3O+)) = 0.00 kJ × mol−1 [2967] There is a difficulty that has been ignored in these definitions as Ka and Kb would normally be expressed in terms of activities rather than concentrations [1188], and the activity of pure H2O is defined as unity, whereas that of solutes is defined relative to their standard state (1 mol × kg−1) rather than the concentration of water (≈ 55.345 mol × L−1). It is essential that the chosen value (pKa = 13.995 for H2O) fits in with the known acidity and basicity of water compared with other materials. While older published materials reported methanol as being more acidic (pKa = 15.3) than water [2107] (and so mistakenly favoring a pKa for water of 15.74), a re-analysis [2965] shows that water is 35-fold more acidic than methanol. This value fits well with the pKa of H2O being ≈ 14. This value (pKa = 14.00) may be separately determined from thermodynamic ΔG data [2967]. Where weak acids with similar pKas are adjacent (and therefore the pKa values of the H-bond donor and acceptor groups are nearly equal), they may form low-barrier hydrogen bonds with easy exchange of the proton' for example, CH3COOH + C2H5COO− CH3COO− + C2H5COOH [Back to Top] Footnotes a It follows that pure water droplets containing less than about 108 water molecules (≈ 0.1 μm radius) would usually (i.e., on average) contain no ions in the absence of surface effects. [Back] b A bulk energy diagram for the dissociation in bulk water has been described [604]. [Back] c Note that acid-base neutrality only occurs when the concentration of hydrogen ions equals the concentration of hydroxyl ions (whatever the pH). This only occurs at pH 7 in pure water when at 25 °C. A solution is acidic when the hydrogen ion concentration is greater than the hydroxide ion concentration, whatever the pH. The pH of a neutral solution is numerically equal to half the pKw of the solution. Therefore a pH of 7 at 0 °C indicates a slightly acid solution (neutrality is pH 7.5), whereas a pH of 7 at 50 °C indicates a slightly alkaline solution (neutrality is pH 6.6). [Back] d In a vacuum the reaction H2O (g) H+ (g) + OH− (g) requires over three times more energy (1.66 MJ mol−1; Kw = 1 × 10−285 mol2 × L−2 [3025]) than dissociation H2O (g) H· (g) + ·OH (g) (531 kJ × mol−1). In liquid water, the hydration of the ions (H+ ΔG° hydration -1112.5 kJ × mol−1, this includes H3O+ ΔG° hydration -461.1 kJ × mol−1; OH− ΔG° hydration -437.6 kJ × mol−1 [1067]) reduces the ΔG° of the reaction 2 H2O (l) H3O+ (aq) + OH− (aq) to +99.78 kJ × mol−1 (These calculations assume that the standard state of the solvent water is taken as 1.0 M. If the standard state of the solvent water is the unit activity or mole fraction (= 1.0), the ΔG° is +79.907 kJ × mol−1 as given above). The dissociated radicals (H·, ·OH) are also somewhat stabilized in liquid water, as shown by the occasional dissociation of water [1066, see equations]. [Back] e Note that the 'acidity' of a material is commonly its pH and depends both on its pKa and its concentration. The 'acidity' of drinks and foodstuffs, however, also depends on the response of our taste buds. [Back] f As Logarithms may only be taken of dimensionless numbers, all the concentrations (activities, partial pressures, etc.) in any Logarithmic expression are actually divided by unit values in the same units of that concentration (activity, partial pressure, etc.); thus, for example, here [H3O+] (concentration of H3O+ in mol × L−1) is actually [H3O+]/(1.0 mol × L−1). The p in pH originated as the arbitrary choice for the naming of the electrode solutions 'p' and 'q' by Sørensen [1036, 1891], but is now taken to mean the 'logarithm to the base 10 of the reciprocal of' (cologarithm) as in the function described above. [Back] g Strictly speaking, these equations should be expressed in terms of activities rather than concentrations; thus Kw = [aH+] × [aOH−] The derivations are easier to follow as given, and usually the concentrations are so small that the difference is inconsequential. [Back] h Similar concentrations are found for ice [2171]. [Back] i Different membrane glasses may be used dependent on the solution to be analyzed (e.g., high temperatures, strong alkali or HF). The electrode reaction for the Ag/AgCl/saturated KCl reference electrode is AgCl + e− Ag0 + Cl− E = +0.197 V (in saturated KCl) [Back] j The activity coefficient of hydrogen ions depends on the acid concentration, temperature, ionic strength, the dielectric constant, the size of the ions, and the density of the medium. [Back] Titration curve of a weak acid with pKa = 7 k Weak acids A weak acid is only partially dissociated, with both the undissociated acid and its dissociation product(s) being present, in solution, and in equilibrium with each other. The dissociation constant (Ka) may be determined by titration (see right). If we consider the situation where the acid is one half dissociated, in other words where [A−] is equal to [HA], then the solution's pH equals the acid's pKa. This means that an acid is half dissociated when the pH of the solution is numerically equal to the pKa of the acid. Therefore acids with the lowest pKa values are able to dissociate in solutions of low pH, i.e., even where the hydrogen ion concentration is high. Acids with higher pKa values dissociate only in solutions of high (more alkaline) pH. The pKa values of carboxylic acids are examined elsewhere as are those associated with CO2. A compilation of weak acid pKa values is available. For any weak monoprotic acid (HA) of concentration c, the equilibrium is, HA [H+] + [A−] The concentration of hydrogen ions [H+] is given by the following four equations, Ka= [H+] × [A−]/[HA] Kw = [H+] × [OH−] Balancing charges [H+] = [OH−] + [A−] Mass balance of the acid c = [A−] + [HA] Eliminating [A−], [HA] and [OH−] gives [H+]3 + Ka × [H+]2 − (Ka × c + Kw) × [H+] − Ka × Kw = 0 (A) The pH is, Comparison of actual pH with its approximation for acetic acid so long as c ≫ Ka and c × Ka > Kw. The pH, calculated using a numerical iterative method from the above exact equation (A), is compared with its approximation -0.5 × Log10(c × Ka) for acetic acid (pKa = 4.76, 25 °C) is shown on the right. It can be seen that the approximation should not be used for concentrations below about 0.1 × Ka. At very low acid concentrations (< 10−7 M), the pH cannot rise above pH 7.0. An extremely useful relationship between pH and pKa can be obtained simply by taking logarithms of Ka= [H+] × [A−]/[HA] log10(Ka) = log10[H+] + log10([A−]/[HA]) as pKa = -log10(Ka) and pH = -log10[H+], this gives the Henderson-Hasselbalch equation, This equation may break down at high (> 1 M) and low (< 1 mM) concentrations and where the pH is more than two units distant from the pKa. The most convenient form of this Henderson-Hasselbalch equation is Using pKa values, one can express the strength of an acid (i.e., its tendency to dissociate) with reference to the pH scale. A weak acid only slightly dissociates in solution and has a low Ka and high pKa. A strong acid is mostly, perhaps wholly, dissociated and therefore has a high Ka value and a low, perhaps even negative, pKa value. If the Ka is large, then pKa will have a small (or negative) numerical value. There is no generally accepted dividing line between weak and strong acids, but as a rough guide, it is suggested that a strong acid would be at least 25% dissociated in a 0.1 M solution; this correspondis to a Ka of about 0.01 (pKa ~2). It has been found that the strong acids HCl, HBr, and HI are 91%, 95%, and 99 % dissociated, respectively [3505] (see also elsewhere). At high concentrations (> ~0.1 M), the activities of the ions and water deviate increasingly from unity, and the pH is best experimentally determined. Strong bases remove protons from molecules of acid, including even a very weak acid, and they also dissociate fully in water. Examples are the hydroxides of the alkali metal ions, e.g., LiOH, NaOH, and KOH. pKa values are used both for acids and for the conjugate acids of bases. Thus NH3 has pKa for the dissociation NH4+ H+ + NH3 of about 9.3. [Back] l Auto-ionization is not restricted to water but can occur with a few other substances. An example is liquid ammonia with ionization equilibrium NH3 + NH3 NH2−(in NH3) + NH4+(in NH3) KNH3= [NH4+][NH2−] The self-ionization constant (KNH3) of ammonia (at ≈ 10−30) is sixteen orders of magnitude smaller than that of water. [Back] m Water pKa has been calculated using first-principles to a value 1.0 units different from the experimental value [3839]. [Back] n Some reports give this unit as 1 mol × L−1. [Back] o Ionic strength. The ionic strength of a solution is a measure of its ionic concentration. The ionic strength (I, mol × L−1) of a solution is defined (empirically) as, where the factor of ½ is to include both cations and anions, ci is the molar concentration of ion i (mol × L−1), zi is the charge on that ion, and the sum is taken over all ions in the solution. The term was introduced by G. N. Lewis and M. Randal in 1921 (G. N. Lewis and M. Randall, The activity coefficient of strong electrolytes, Journal of the American Chemical Society, 43 (1921) 1112-1154). For a 1:1 electrolyte such as sodium chloride, where each ion is singly-charged, the ionic strength is equal to the concentration (c). For a 1:2 electrolyte such as magnesium chloride, the ionic strength is equal to three times the concentration of the salt as I = 0.5 × {c × (−1)2 + c × (−1)2 + c × (+2)2} = 3 × c The ionic strength of the solution reflects its charge density. It affects many properties, such as the solubility and dissociation of its ionic components and the activity and solubility of contained biological molecules. As the usefulness of the concept of 'activity' diminishes with the increased understanding of the molecular structuring of water by itself and surrounding solutes, the concept of 'ionic strength still retains its usefulness in such areas as the control of biological processes. As volumes of solutions are not generally additive, it may be useful to use the molal ionic strength, where all the concentrations are in molalities (as in its original definition). [Back] Skip to main content Official websites use .gov A .gov website belongs to an official government organization in the United States. Secure .gov websites use HTTPS A lock () or https:// means you've safely connected to the .gov website. Share sensitive information only on official, secure websites. Water, Acids, and Bases The Acid-Base Chemistry of Water The chemistry of aqueous solutions is dominated by the equilibrium between neutral water molecules and the ions they form. 2 H2O(l) H3O+(aq) + OH-(aq) Strict application of the rules for writing equilibrium constant expressions to this reaction produces the following result. This is a legitimate equilibrium constant expression, but it fails to take into account the enormous difference between the concentrations of neutral H2O molecules and H3O+ and OH- ions at equilibrium. Measurements of the ability of water to conduct an electric current suggest that pure water at 25oC contains 1.0 x 10-7 moles per liter of each of these ions. [H3O+] = [OH-] = 1.0 x 10-7 M At the same temperature, the concentration of neutral H2O molecules is 55.35 molar. The ratio of the concentration of the H+ (or OH-) ion to the concentration of the neutral H2O molecules is therefore 1.8 x 10-9. In other words, only about 2 parts per billion (ppb) of the water molecules dissociate into ions at room temperature. The equilibrium concentration of H2O molecules is so much larger than the concentrations of the H3O+ and OH- ions that it is effectively constant. We therefore build the [H2O] term into the equilibrium constant for the reaction and thereby greatly simplify equilibrium calculations. We start by rearranging the equilibrium constant expression for the dissociation of water to give the following equation. [H3O+][OH-] = Kc x [H2O]2 We then replace the term on the right side of this equation with a constant known as the waterdissociation equilibrium constant, Kw. [H3O+][OH-] = Kw In pure water, at 25C, the [H3O+] and [OH-] ion concentrations are 1.0 x 10-7 M. The value of Kw at 25C is therefore 1.0 x 10-14. [1.0 x 10-7][1.0 x 10-7] = 1.0 x 10-14 (at 25C) Although Kw is defined in terms of the dissociation of water, this equilibrium constant expression is equally valid for solutions of acids and bases dissolved in water. Regardless of the source of the H3O+ and OH- ions in water, the product of the concentrations of these ions at equilibrium at 25C is always 1.0 x 10-14. Strong Acids and the H3O+ and OH- Ion Concentrations Suppose we add enough strong acid to a beaker of water to raise the H3O+ ion concentration to 0.010 M. According to LeChatelier's principle, this should drive the equilibrium between water and its ions to the left, reducing the number of H3O+ and OH- ions in the solution. 2 H2O(l) H3O+(aq) + OH-(aq) Because there are so many H3O+ ions in this solution, the change in the concentration of this ion is too small to notice. When the system returns to equilibrium, the H3O+ ion concentration is still about 0.010 M. Furthermore, when the reaction returns to equilibrium, the product of the H3O+ and OH- ion concentrations is once again equal to Kw. [H3O+][OH-] = 1 x 10-14 The solution therefore comes back to equilibrium when the dissociation of water is so small that the OH- ion concentration is only 1.0 x 10-12 M. Adding an acid to water therefore has an effect on the concentration of both the H3O+ and OH- ions. Because it is a source of this ion, adding an acid to water increases the concentration of the H3O+ ion. Adding an acid to water, however, decreases the extent to which water dissociates. It therefore leads to a significant decrease in the concentration of the OH- ion. As might be expected, the opposite effect is observed when a base is added to water. Because we are adding a base, the OH- ion concentration increases. Once the system returns to equilibrium, the product of the H3O+ and OH- ion concentrations is once again equal to Kw. The only way this can be achieved, of course, is by decreasing the concentration of the H3O+ ion. THE IONIC PRODUCT FOR WATER, Kw This page explains what is meant by the ionic product for water. It looks at how the ionic product varies with temperature, and how that determines the pH of pure water at different temperatures. The important equilibrium in water Water molecules can function as both acids and bases. One water molecule (acting as a base) can accept a hydrogen ion from a second one (acting as an acid). This will be happening anywhere there is even a trace of water - it doesn't have to be pure. A hydroxonium ion and a hydroxide ion are formed. However, the hydroxonium ion is a very strong acid, and the hydroxide ion is a very strong base. As fast as they are formed, they react to produce water again. The net effect is that an equilibrium is set up. At any one time, there are incredibly small numbers of hydroxonium ions and hydroxide ions present. Further down this page, we shall calculate the concentration of hydroxonium ions present in pure water. It turns out to be 1.00 x 10-7 mol dm-3 at room temperature. You may well find this equilibrium written in a simplified form: This is OK provided you remember that H+(aq) actually refers to a hydroxonium ion. Defining the ionic product for water, Kw Kw is essentially just an equilibrium constant for the reactions shown. You may meet it in two forms: Based on the fully written equilibrium . . . . . . or on the simplified equilibrium: You may find them written with or without the state symbols. Whatever version you come across, they all mean exactly the same thing! You may wonder why the water isn't written on the bottom of these equilibrium constant expressions. So little of the water is ionised at any one time, that its concentration remains virtually unchanged - a constant. Kw is defined to avoid making the expression unnecessarily complicated by including another constant in it. The value of Kw Like any other equilibrium constant, the value of Kw varies with temperature. Its value is usually taken to be 1.00 x 10-14 mol2 dm-6 at room temperature. In fact, this is its value at a bit less than 25°C. Chapter 6: Unit 1. I. Bonding: Basic features of ionic and covalent bonds Chapter 6: Unit 2. Octet Rule Chapter 6: Unit 3. Formation of Ionic Compounds Chapter 6: Unit 4. Formula of an ionic compound Chapter 6: Unit 5. Nomenclature of Binary Ionic Compounds Chapter 6: Unit 6. Polyatomic Ions Chapter 6: Unit 7. Properties of ionic compounds Chapter 6: Unit 9. Formation of Covalent Compound Chapter 4: Unit 10. Nomenclature of Binary Covalent Compounds Chapter 6: Unit 11. Lewis Structures Chapter 6: Unit 12. Resonance Structures Chapter 6: Unit 13. Electronegativity & Bond Polarity Chapter 6: Unit 14. Molecular Shape and VSEPR Chapter 6: Unit 15. Molecular Polarity Chapter 6: Unit 16. Intermolecular Forces Comprehensive Quiz: Module 6 Chemical compound of hydrogen and oxygen For other uses, see Water (disambiguation). "H2O" redirects here. For other uses, see H2O (disambiguation). Water The water molecule has this basic geometric structure Ball-and-stick model of a water molecule Space filling model of a water molecule Oxygen, O Hydrogen, H A drop of water falling towards water in a glass Names Preferred IUPAC name Water Systematic IUPAC name Oxidane (not in common use)[3] Other names Hydrogen oxideHydrogen hydroxide (H2O or HOH)Hydroxylic acidDihydrogen monoxide (DHMO) (parody name[1])Dihydrogen oxideHydric acidHydrohydroxic acidHydroxic acidHydrol[2]μ-Oxidodihydrogenκ1-Hydroxylhydrogen(0)AquaNeutral liquidOxygen dihydride (may be considered incorrect) Identifiers CAS Number 7732-18-5 Y 3D model (JSmol) Interactive image Beilstein Reference 3587155 ChEBI CHEBI:15377 Y ChEMBL ChEMBL1098659 Y ChemSpider 937 Y DrugBank DB09145 ECHA InfoCard 100.028.902 EC Number 231-791-2 Gmelin Reference 117 KEGG C00001 PubChem CID 962 RTECS number ZC0110000 UNII 059QF0KO0R Y CompTox Dashboard (EPA) DTXSID6026296 InChI InChI=1S/H2O/h1H2 YKey: XLYOFNOQVPJJNP-UHFFFAOYSA-N Y SMILES O Properties Chemical formula H2O Molar mass 18.01528(33) g/mol Appearance Almost colorless or white crystalline solid, almost colorless liquid, with a hint of blue, colorless gas[4] Odor Odorless Density Liquid (1 atm, VSMOW):0.99984283(84) g/mL at 0 °C[5]0.99997495(84) g/mL at 3.983035(670) °C (temperature of maximum density, often 4 °C)[5]0.99704702(83) g/mL at 25 °C[5]0.96188791(96) g/mL at 95 °C[6]Solid:0.9167 g/mL at 0 °C[7] Melting point 0.00 °C (32.00 °F; 273.15 K) [b] Boiling point 99.98 °C (211.96 °F; 373.13 K)[17][b] Solubility Poorly soluble in haloalkanes, aliphatic and aromatic hydrocarbons, ethers.[8] Improved solubility in carboxylates, alcohols, ketones, amines. Miscible with methanol, ethanol, propanol, isopropanol, acetone, glycerol, 1,4-dioxane, tetrahydrofuran, sulfolane, acetaldehyde, dimethylformamide, dimethoxyethane, dimethyl sulfoxide, acetonitrile. Partially miscible with diethyl ether, methyl ethyl ketone, dichloromethane, ethyl acetate, bromine. Vapor pressure 3.1690 kilopascals or 0.031276 atm at 25 °C[9] Acidity (pKa) 13.995[10][11][a] Basicity (pKb) 13.995 Conjugate acid Hydronium H3O+ (pKa = 0) Conjugate base Hydroxide OH– (pKb = 0) Thermal conductivity 0.6065 W/(m·K)[14] Refractive index (nD) 1.3330 (20 °C)[15] Viscosity 0.890 mPa·s (0.890 cP)[16] Structure Crystal structure Hexagonal Point group C2v Molecular shape Bent Dipole moment 1.8546 D[18] Thermochemistry Heat capacity (C) 75.385 ± 0.05 J/(mol·K)[17] Std molarentropy (S298) 69.95 ± 0.03 J/(mol·K)[17] Std enthalpy offormation (ΔfH298) −285.83 ± 0.04 kJ/mol[8][17] Gibbs free energy (ΔfG) −237.24 kJ/mol[8] Hazards Occupational safety and health (OHS/OSH): Main hazards DrowningAvalanche (as snow)Water intoxication NFPA 704 (fire diamond) 0 0 0 Flash point Non-flammable Related compounds Other anions Hydrogen sulfideHydrogen selenideHydrogen tellurideHydrogen polonideHydrogen peroxide Related solvents AcetoneEthanolMethanolHydrogen fluorideAmmonia Supplementary data page Water (data page) Except where otherwise noted, data are given for materials in their standard state (at 25 °C [77 °F], 100 kPa). Y verify (what is YN ?) Infobox references Chemical compound Water is an inorganic compound with the chemical formula H2O. It is a transparent, tasteless, odorless,[c] and nearly colorless chemical substance. It is the main constituent of Earth's hydrosphere and the fluids of all known living organisms (in which it acts as a solvent[20]). It is vital for all known forms of life, despite not providing food energy or organic micronutrients. Its chemical formula, H2O, indicates that each of its molecules contains one oxygen and two hydrogen atoms, connected by covalent bonds. The hydrogen atoms are attached to the oxygen atom at an angle of 104.45°.[21] In liquid form, H2O is also called "water" at standard temperature and pressure. Because Earth's environment is relatively close to water's triple point, water exists on Earth as a solid, a liquid, and a gas.[22] It forms precipitation in the form of rain and aerosols in the form of fog. Clouds consist of suspended droplets of water and ice, its solid state. When finely divided, crystalline ice may precipitate in the form of snow. The gaseous state of water is steam or water vapor. Water covers about 71.0% of the Earth's surface, with seas and oceans making up most of the water volume (about 96.5%).[23] Small portions of water occur as groundwater (1.7%), in the glaciers and the ice caps of Antarctica and Greenland (1.7%), and in the air as vapor, clouds (consisting of ice and liquid water suspended in air), and precipitation (0.001%).[24][25] Water moves continually through the water cycle of evaporation, transpiration (evapotranspiration), condensation, precipitation, and runoff, usually reaching the sea. Water plays an important role in the world economy. Approximately 70% of the fresh water used by humans goes to agriculture.[26] Fishing in salt and fresh water bodies has been, and continues to be, a major source of food for many parts of the world, providing 6.5% of global protein.[27] Much of the long-distance trade of commodities (such as oil, natural gas, and manufactured products) is transported by boats through seas, rivers, lakes, and canals. Large quantities of water, ice, and steam are used for cooling and heating in industry and homes. Water is an excellent solvent for a wide variety of substances, both mineral and organic; as such, it is widely used in industrial processes and in cooking and washing. Water, ice, and snow are also central to many sports and other forms of entertainment, such as swimming, pleasure boating, boat racing, surfing, sport fishing, diving, ice skating, snowboarding, and skiing. The word water comes from Old English wæter, from Proto-Germanic *watar (source also of Old Saxon watar, Old Frisian wetir, Dutch water, Old High German wazzar, German Wasser, vatn, Gothic (wato)), from Proto-Indo-European *wod-or, suffixed form of root *wed- ('water'; 'wet').[28] Also cognate, through the Indo-European root, with Greek ύδωρ (ýdor; from Ancient Greek ὕδωρ (hýdōr), whence English 'hydro-'), Russian вода́ (vodá), Irish uisce, and Albanian ujë. Main articles: Origin of water on Earth § History of water on Earth, and Properties of water § History This section is an excerpt from Origin of water on Earth § History of water on Earth.[edit] One factor in estimating when water appeared on Earth is that water is continually being lost to space. H2O molecules in the atmosphere are broken up by photolysis, and the resulting free hydrogen atoms can sometimes escape Earth's gravitational pull. When the Earth was younger and less massive, water would have been lost to space more easily.[29] Lighter elements like hydrogen and helium are expected to leak from the atmosphere continually, but isotopic ratios of heavier noble gases in the modern atmosphere suggest that even the heavier elements in the early atmosphere were subject to significant losses.[30] In particular, xenon is useful for calculations of water loss over time. Not only is it a noble gas (and therefore is not removed from the atmosphere through chemical reactions with other elements), but comparisons between the abundances of its nine stable isotopes in the modern atmosphere reveal that the Earth lost at least one ocean of water, a volume of water approximately equal to modern ocean volume, early in its history. This is likely to have occurred between the Hadean and Archean eons in cataclysmic events such as the moon forming impact.[31] Any water on Earth during the latter part of its accretion would have been disrupted by the Moon-forming impact (~4.5 billion years ago), which likely vaporized much of Earth's crust and upper mantle and created a rock-vapor atmosphere around the young planet.[32][33] The rock vapor would have condensed within two thousand years, leaving behind hot volatiles which probably resulted in a majority carbon dioxide atmosphere with hydrogen and water vapor. Afterward, liquid water oceans may have existed despite the surface temperature of 230 °C (446 °F) due to the increased atmospheric pressure of the CO2 atmosphere.[34] As the cooling continued, most CO2 was removed from the atmosphere by subduction and dissolution in ocean water, but levels oscillated wildly as new surface and mantle cycles appeared.[35] This pillow basalt on the seafloor near Hawaii was formed when magma extruded underwater. Other, much older pillow basalt formations provide evidence for large bodies of water long ago in Earth's history. Geological evidence also helps constrain the time frame for liquid water existing on Earth. A sample of pillow basalt (a type of rock formed during an underwater eruption) was recovered from the Isua Greenstone Belt and provides evidence that water existed on Earth 3.8 billion years ago.[36] In the Nuvvuagittuq Greenstone Belt, Quebec, Canada, rocks dated at 3.8 billion years old by one study[37] and 4.28 billion years old by another[38] show evidence of the presence of water at these ages.[36] If oceans existed earlier than this, any geological evidence has yet to be discovered (which may be because such potential evidence has been destroyed by geological processes like crustal recycling). More recently, in August 2020, researchers reported that sufficient water to fill the oceans may have always been on the Earth since the beginning of the planet's formation.[39][40][41] Unlike rocks, minerals called zircons are highly resistant to weathering and geological processes and so are used to understand conditions on the very early Earth. Mineralogical evidence from zircons has shown that liquid water and an atmosphere must have existed 4.404 ± 0.008 billion years ago, very soon after the formation of Earth.[42][43][44][45] This presents somewhat of a paradox, as the cool early Earth hypothesis suggests temperatures were cold enough to freeze water between about 4.4 billion and 4.0 billion years ago.[46] Other studies of zircons found in Australian Hadean rock point to the existence of plate tectonics as early as 4 billion years ago.[47] If true, that implies that rather than a hot, molten surface and an atmosphere full of carbon dioxide, early Earth's surface was much as it is today (in terms of thermal insulation). The action of plate tectonics traps vast amounts of CO2, thereby reducing greenhouse effects, leading to a much cooler surface temperature and the formation of solid rock and liquid water.[48] Main article: Properties of water See also: Water (data page) and Water model A water molecule consists of two hydrogen atoms and one oxygen atom. Water (H2O) is a polar inorganic compound. At room temperature it is a tasteless and odorless liquid, nearly colorless with a hint of blue. The simplest hydrogen chalcogenide, it is by far the most studied chemical compound and is sometimes described as the "universal solvent" for its ability to dissolve more substances than any other liquid,[49][50] though it is poor at dissolving nonpolar substances.[51] This allows it to be the "solvent of life":[52] indeed, water as found in nature almost always includes various dissolved substances, and special steps are required to obtain chemically pure water. Water is the only common substance to exist as a solid, liquid, and gas in normal terrestrial conditions.[53] The three common states of matter Along with oxidane, water is one of the two official names for the chemical compound H2O;[54] it is also the liquid phase of H2O.[55] The other two common states of matter of water are the solid phase, ice, and the gaseous phase, water vapor or steam. The addition or removal of heat can cause phase transitions: freezing (water to ice), melting (ice to water), vaporization (water to vapor), condensation (vapor to water), sublimation (ice to vapor) and deposition (vapor to ice).[56] See also: Frost weathering Water is one of only a few common naturally occurring substances which, for some temperature ranges, become less dense as they cool, and the only known naturally occurring substance which does so while liquid. In addition it is unusual as it becomes significantly less dense as it freezes, though it is not unique in that respect.[d] At 1 atm pressure, it reaches its maximum density of 999.972 kg/m3 (62.4262 lb/cu ft) at 3.98 °C (39.16 °F).[58][59] Below that temperature, but above the freezing point of 0 °C (32 °F), it expands becoming less dense until it reaches freezing point, reaching a density in its liquid phase of 999.8 kg/m3 (62.4155 lb/cu ft). Once it freezes and becomes ice, it expands by about 9%, with a density of 917 kg/m3 (57.25 lb/cu ft).[60][61] This expansion can exert enormous pressure, bursting pipes and cracking rocks.[62] As a solid, it displays the usual behavior of contracting and becoming more dense as it cools. These unusual thermal properties have important consequences for life on earth. In a lake or ocean, water at 4 °C (39 °F) sinks to the bottom, and ice forms on the surface, floating on the liquid water. This ice insulates the water below, preventing it from freezing solid. Without this protection, most aquatic organisms residing in lakes would perish during the winter.[63] In addition, this anomalous behavior is an important part of the thermohaline circulation which distributes heat around the planet's oceans. Water is a diamagnetic material.[64] Though interaction is weak, with superconducting magnets it can attain a notable interaction.[64] At a pressure of one atmosphere (atm), ice melts or water freezes (solidifies) at 0 °C (32 °F) and water boils or vapor condenses at 100 °C (212 °F). However, even below the boiling point, water can change to vapor at its surface by evaporation (vaporization throughout the liquid is known as boiling). Sublimation and deposition also occur on surfaces.[56] For example, frost is deposited on cold surfaces while snowflakes form by deposition on an aerosol particle or ice nucleus.[65] In the process of freeze-drying, a food is frozen and then stored at low pressure so the ice on its surface sublimates.[66] The melting and boiling points depend on pressure. A good approximation for the rate of change of the melting temperature with pressure is given by the Clausius–Clapeyron relation: d T d P = T (v L − v S) L f {\displaystyle {\frac {dT}{dP}}={\frac {T\left(v_{\text{L}}-v_{\text{S}}\right)}{L_{\text{f}}}}} where v L {\displaystyle v_{\text{L}}} and v S {\displaystyle v_{\text{S}}} are the molar volumes of the liquid and solid phases, and L f {\displaystyle L_{\text{f}}} is the molar latent heat of melting. In most substances, the volume increases when melting occurs, so the melting temperature increases with pressure. However, because ice is less dense than water, the melting temperature decreases.[57] In glaciers, pressure melting can occur under sufficiently thick volumes of ice, resulting in subglacial lakes.[67][68] The Clausius-Clapeyron relation also applies to the boiling point, but with the liquid/gas transition the vapor phase has a much lower density than the liquid phase, so the boiling point increases with pressure.[69] Water can remain in a liquid state at high temperatures in the deep ocean or underground. For example, temperatures exceed 205 °C (401 °F) in Old Faithful, a geyser in Yellowstone National Park.[70] In hydrothermal vents, the temperature can exceed 400 °C (752 °F).[71] At sea level, the boiling point of water is 100 °C (212 °F). As atmospheric pressure decreases with altitude, the boiling point decreases by 1 °C every 274 meters. High-altitude cooking takes longer than sea-level cooking. For example, at 1,524 metres (5,000 ft), cooking time must be increased by a fourth to achieve the desired result.[72] Conversely, a pressure cooker can be used to decrease cooking times by raising the boiling temperature.[73] In a vacuum, water will boil at room temperature.[74] Phase diagram of water On a pressure/temperature phase diagram (see figure), there are curves separating solid from vapor, vapor from liquid, and liquid from solid. These meet at a single point called the triple point, where all three phases can coexist. The triple point is at a temperature of 273.16 K (0.01 °C; 32.02 °F) and a pressure of 611.657 pascals (0.00604 atm; 0.0887 psi);[75] it is the lowest pressure at which liquid water can exist. Until 2019, the triple point was used to define the Kelvin temperature scale.[76][77] The water/vapor phase curve terminates at 647.096 K (373.946 °C; 705.103 °F) and 22.064 megapascals (3,200.1 psi; 217.75 atm).[78] This is known as the critical point. At higher temperatures and pressures the liquid and vapor phases form a continuous phase called a supercritical fluid. It can be gradually compressed or expanded between gas-like and liquid-like densities; its properties (which are quite different from those of ambient water) are sensitive to density. For example, for suitable pressures and temperatures it can mix freely with nonpolar compounds, including most organic compounds. This makes it useful in a variety of applications including high-temperature electrochemistry and as an ecologically benign solvent or catalyst in chemical reactions involving organic compounds. In Earth's mantle, it acts as a solvent during mineral formation, dissolution and deposition.[79][80] Main article: Ice The normal form of ice on the surface of Earth is ice Ih, a phase that forms crystals with hexagonal symmetry. Another with cubic crystalline symmetry, ice Ic, can occur in the upper atmosphere.[81] As the pressure increases, ice forms other crystal structures. As of 2024, twenty have been experimentally confirmed and several more are predicted theoretically.[82] The eighteenth form of ice, ice XVIII, a face-centred-cubic, superionic ice phase, was discovered when a droplet of water was subject to a shock wave that raised the water's pressure to millions of atmospheres and its temperature to thousands of degrees, resulting in a structure of rigid oxygen atoms in which hydrogen atoms flowed freely.[83][84] When sandwiched between layers of graphene, ice forms a square lattice.[85] The details of the chemical nature of liquid water are not well understood; some theories suggest that its unusual behavior is due to the existence of two liquid states.[59][86][87][88] Pure water is usually described as tasteless and odorless, although humans have specific sensors that can feel the presence of water in their mouths,[89][90] and frogs are known to be able to smell it.[91] However, water from ordinary sources (including mineral water) usually has many dissolved substances that may give it varying tastes and odors. Humans and other animals have developed senses that enable them to evaluate the potability of water in order to avoid water that is too salty or putrid.[92] Main article: Color of water See also: Electromagnetic absorption by water Pure water is visibly blue due to absorption of light in the region c. 600–800 nm.[93] The color can be easily observed in a glass of tap-water placed against a pure white background, in daylight. The principal absorption bands responsible for the color are overtones of the O–H stretching vibrations. The apparent intensity of the color increases with the depth of the water column, following Beer's law. This also applies, for example, with a swimming pool when the light source is sunlight reflected from the pool's white tiles. In nature, the color may also be modified from blue to green due to the presence of suspended solids or algae. In industry, near-infrared spectroscopy is used with aqueous solutions as the greater intensity of the lower overtones of water means that glass cuvettes with short path-length may be employed. To observe the fundamental stretching absorption spectrum of water or of an aqueous solution in the region around 3,500 cm−1 (2.85 μm)[94] a path length of about 25 μm is needed. Also, the cuvette must be both transparent around 3500 cm−1 and insoluble in water; calcium fluoride is one material that is in common use for the cuvette windows with aqueous solutions. The Raman-active fundamental vibrations may be observed with, for example, a 1 cm sample cell. Aquatic plants, algae, and other photosynthetic organisms can live in water up to hundreds of meters deep, because sunlight can reach them. Practically no sunlight reaches the parts of the oceans below 1,000 metres (3,300 ft) of depth. The refractive index of liquid water (1.333 at 20 °C (68 °F)) is much higher than that of air (1.0), similar to those of alkanes and ethanol, but lower than those of glycerol (1.473), benzene (1.501), carbon disulfide (1.627), and common types of glass (1.4 to 1.6). The refraction index of ice (1.31) is lower than that of liquid water. Tetrahedral structure of water In a water molecule, the hydrogen atoms form a 104.5° angle with the oxygen atom. The hydrogen atoms are close to two corners of a tetrahedron centered on the oxygen. At the other two corners are lone pairs of valence electrons that do not participate in the bonding. In a perfect tetrahedron, the atoms would form a 109.5° angle, but the repulsion between the lone pairs is greater than the repulsion between the hydrogen atoms.[95][96] The O–H bond length is about 0.096 nm.[97] Other substances have a tetrahedral molecular structure, for example methane (CH4) and hydrogen sulfide (H2S). However, oxygen is more electronegative than most other elements, so the oxygen atom has a negative partial charge while the hydrogen atoms are partially positively charged. Along with the bent structure, this gives the molecule an electrical dipole moment and it is classified as a polar molecule.[98] Water is a good polar solvent, dissolving many salts and hydrophilic organic molecules such as sugars and simple alcohols such as ethanol. Water also dissolves many gases, such as oxygen and carbon dioxide—the latter giving the fizz of carbonated beverages, sparkling wines and beers. In addition, many substances in living organisms, such as proteins, DNA and polysaccharides, are dissolved in water. The interactions between water and the subunits of these biomacromolecules shape protein folding, DNA base pairing, and other phenomena crucial to life (hydrophobic effect). Many organic substances (such as fats and oils and alkanes) are hydrophobic, that is, insoluble in water. Many inorganic substances are insoluble too, including most metal oxides, sulfides, and silicates. See also: Chemical bonding of water Model of hydrogen bonds (1) between molecules of water Because of its polarity, a molecule of water in the liquid or solid state can form up to four hydrogen bonds with neighboring molecules. Hydrogen bonds are about ten times as strong as the Van der Waals force that attracts molecules to each other in most liquids. This is the reason why the melting and boiling points of water are much higher than those of other analogous compounds like hydrogen sulfide. They also explain its exceptionally high specific heat capacity (about 4.2 J/(g·K)), heat of fusion (about 333 J/g), heat of vaporization (2257 J/g), and thermal conductivity (between 0.561 and 0.679 W/(m·K)). These properties make water more effective at moderating Earth's climate, by storing heat and transporting it between the oceans and the atmosphere. The hydrogen bonds of water are around 23 kJ/mol (compared to a covalent O-H bond at 492 kJ/mol). Of this, it is estimated that 90% is attributable to electrostatics, while the remaining 10% is partially covalent.[99] These bonds are the cause of water's high surface tension[100] and capillary forces. The capillary action refers to the tendency of water to move up a narrow tube against the force of gravity. This property is relied upon by all vascular plants, such as trees.[citation needed] Specific heat capacity of water[101] Main article: Self-ionization of water Water is a weak solution of hydronium hydroxide—there is an equilibrium 2H2O ⇌ H3O+ + OH−, in combination with solvation of the resulting hydronium and hydroxide ions. Pure water has a low electrical conductivity, which increases with the dissolution of a small amount of ionic material such as common salt. Liquid water can be split into the elements hydrogen and oxygen by passing an electric current through it—a process called electrolysis. The decomposition requires more energy input than the heat released by the inverse process (285.8 kJ/mol, or 15.9 MJ/kg).[102] Liquid water can be assumed to be incompressible for most purposes: its compressibility ranges from 4.4 to 5.1×10−10 Pa−1 in ordinary conditions.[103] Even in oceans at 4 km depth, where the pressure is 400 atm, water suffers only a 1.8% decrease in volume.[104] The viscosity of water is about 10−3 Pa·s or 0.01 poise at 20 °C (68 °F), and the speed of sound in liquid water ranges between 1,400 and 1,540 metres per second (4,600 and 5,100 ft/s) depending on temperature. Sound travels long distances in water with little attenuation, especially at low frequencies (roughly 0.03 dB/km for 1 kHz), a property that is exploited by cetaceans and humans for communication and environment sensing (sonar).[105] Metallic elements which are more electropositive than hydrogen, particularly the alkali metals and alkaline earth metals such as lithium, sodium, calcium, potassium and cesium displace hydrogen from water, forming hydroxides and releasing hydrogen. At high temperatures, carbon reacts with steam to form carbon monoxide and hydrogen.[citation needed] Main articles: Hydrology and Water distribution on Earth Hydrology is the study of the movement, distribution, and quality of water throughout the Earth. The study of the distribution of water is hydrography. The study of the distribution and movement of groundwater is hydrogeology, of glaciers is glaciology, of inland waters is limnology and distribution of oceans is oceanography. Ecological processes with hydrology are in the focus of ecohydrology. The collective mass of water found on, under, and over the surface of a planet is called the hydrosphere. Earth's approximate water volume (the total water supply of the world) is 1.386 billion cubic kilometres (333 million cubic miles).[24] Liquid water is found in bodies of water, such as an ocean, sea, lake, river, stream, canal, pond, or puddle. The majority of water on Earth is seawater. Water is also present in the atmosphere in solid, liquid, and vapor states. It also exists as groundwater in aquifers. Water is important in many geological processes. Groundwater is present in most rocks, and the pressure of this groundwater affects patterns of faulting. Water in the mantle is responsible for the melt that produces volcanoes at subduction zones. On the surface of the Earth, water is important in both chemical and physical weathering processes. Water, and to a lesser but still significant extent, ice, are also responsible for a large amount of sediment transport that occurs on the surface of the earth. Deposition of transported sediment forms many types of sedimentary rocks, which make up the geologic record of Earth history. Main article: Water cycle Water cycle The water cycle (known scientifically as the hydrologic cycle) is the continuous exchange of water within the hydrosphere, between the atmosphere, soil water, surface water, groundwater, and plants. Water moves perpetually through each of these regions in the water cycle consisting of the following transfer processes: evaporation from oceans and other water bodies into the air and transpiration from land plants and animals into the air. precipitation, from water vapor condensing from the air and falling to the earth or ocean. runoff from the land usually reaching the sea. Most water vapors found mostly in the ocean returns to it, but winds carry water vapor over land at the same rate as runoff into the sea, about 47 Tt per year while evaporation and transpiration happening in land masses also contribute another 72 Tt per year. Precipitation, at a rate of 119 Tt per year over land, has several forms: most commonly rain, snow, and hail, with some contribution from fog and dew.[106] Dew is small drops of water that are condensed when a high density of water vapor meets a cool surface. Dew usually forms in the morning when the temperature is the lowest, just before sunrise and when the temperature of the earth's surface starts to increase.[107] Condensed water in the air may also refract sunlight to produce rainbows. Water runoff often collects over watersheds flowing into rivers. Through erosion, runoff shapes the environment creating river valleys and deltas which provide rich soil and level ground for the establishment of population centers. A flood occurs when an area of land, usually low-lying, is covered with water which occurs when a river overflows its banks or a storm surge happens. On the other hand, drought is an extended period of months or years when a region notes a deficiency in its water supply. This occurs when a region receives consistently below average precipitation either due to its topography or due to its location in terms of latitude. Main article: Water resources Water resources are natural resources of water that are potentially useful for humans,[108] for example as a source of drinking water supply or irrigation water. Water occurs as both "stocks" and "flows". Water can be stored as lakes, water vapor, groundwater or aquifers, and ice and snow. Of the total volume of global freshwater, an estimated 69 percent is stored in glaciers and permanent snow cover; 30 percent is in groundwater; and the remaining 1 percent in lakes, rivers, the atmosphere, and biota.[109] The length of time water remains in storage is highly variable: some aquifers consist of water stored over thousands of years but lake volumes may fluctuate on a seasonal basis, decreasing during dry periods and increasing during wet ones. A substantial fraction of the water supply for some regions consists of water extracted from water stored in stocks, and when withdrawals exceed recharge, stocks decrease. By some estimates, as much as 30 percent of total water used for irrigation comes from unsustainable withdrawals of groundwater, causing groundwater depletion.[110] Main articles: Seawater and Tides Seawater contains about 3.5% sodium chloride on average, plus smaller amounts of other substances. The physical properties of seawater differ from fresh water in some important respects. It freezes at a lower temperature (about −1.9 °C (28.6 °F)) and its density increases with decreasing temperature to the freezing point, instead of reaching maximum density at a temperature above freezing. The salinity of water in major seas varies from about 0.7% in the Baltic Sea to 4.0% in the Red Sea. (The Dead Sea, known for its ultra-high salinity levels of between 30 and 40%, is really a salt lake.) Tides are the cyclic rising and falling of local sea levels caused by the tidal forces of the Moon and the Sun acting on the oceans. Tides cause changes in the depth of the marine and estuarine water bodies and produce oscillating currents known as tidal streams. The changing tide produced at a given location is the result of the changing positions of the Moon and Sun relative to the Earth coupled with the effects of Earth rotation and the local bathymetry. The strip of seashore that is submerged at high tide and exposed at low tide, the intertidal zone, is an important ecological product of ocean tides. The Bay of Fundy at high tide and low tide High tide Low tide Overview of photosynthesis (green) and respiration (red) From a biological standpoint, water has many distinct properties that are critical for the proliferation of life. It carries out this role by allowing organic compounds to react in ways that ultimately allow replication. All known forms of life depend on water. Water is vital both as a solvent in which many of the body's solutes dissolve and as an essential part of many metabolic processes within the body. Metabolism is the sum total of anabolism and catabolism. In anabolism, water is removed from molecules (through energy requiring enzymatic chemical reactions) in order to grow larger molecules (e.g., starches, triglycerides, and proteins for storage of fuels and information). In catabolism, water is used to break bonds in order to generate smaller molecules (e.g., glucose, fatty acids, and amino acids to be used for fuels for energy use or other purposes). Without water, these particular metabolic processes could not exist. Water is fundamental to both photosynthesis and respiration. Photosynthetic cells use the sun's energy to split off water's hydrogen from oxygen.[111] In the presence of sunlight, hydrogen is combined with CO2 (absorbed from air or water) to form glucose and release oxygen.[112] All living cells use such fuels and oxidize the hydrogen and carbon to capture the sun's energy and reform water and CO2 in the process (cellular respiration). Water is also central to acid-base neutrality and enzyme function. An acid, a hydrogen ion (H+, that is, a proton) donor, can be neutralized by a base, a proton acceptor such as a hydroxide ion (OH−) to form water. Water is considered to be neutral, with a pH (the negative log of the hydrogen ion concentration) of 7 in an ideal state. Acids have pH values less than 7 while bases have values greater than 7. Further information: Hydrobiology, Marine life, and Aquatic plant Earth's surface waters are filled with life. The earliest life forms appeared in water; nearly all fish live exclusively in water, and there are many types of marine mammals, such as dolphins and whales. Some kinds of animals, such as amphibians, spend portions of their lives in water and portions on land. Plants such as kelp and algae grow in the water and are the basis for some underwater ecosystems. Plankton is generally the foundation of the ocean food chain. Aquatic vertebrates must obtain oxygen to survive, and they do so in various ways. Fish have gills instead of lungs, although some species of fish, such as the lungfish, have both. Marine mammals, such as dolphins, whales, otters, and seals need to surface periodically to breathe air. Some amphibians are able to absorb oxygen through their skin. Invertebrates exhibit a wide range of modifications to survive in poorly oxygenated waters including breathing tubes (see insect and mollusc siphons) and gills (Carcinus). However, as invertebrate life evolved in an aquatic habitat most have little or no specialization for respiration in water. Some of the biodiversity of a coral reef Some marine diatoms – a key phytoplankton group Squat lobster and Alvinocarididae shrimp at the Von Damm hydrothermal field survive by altered water chemistry. This section needs additional citations for verification. Please help improve this article by adding citations to reliable sources in this section. Unsourced material may be challenged and removed. (May 2018) (Learn how and when to remove this message) Water fountain Civilization has historically flourished around rivers and major waterways; Mesopotamia, one of the so-called cradles of civilization, was situated between the major rivers Tigris and Euphrates; the ancient society of the Egyptians depended entirely upon the Nile. The early Indus Valley civilization (c. 3300 BCE – c. 1300 BCE) developed along the Indus River and tributaries that flowed out of the Himalayas. Rome was also founded on the banks of the Italian river Tiber. Large metropolises like Rotterdam, London, Montreal, Paris, New York City, Buenos Aires, Shanghai, Tokyo, Chicago, and Hong Kong owe their success in part to their easy accessibility via water and the resultant expansion of trade. Islands with safe water ports, like Singapore, have flourished for the same reason. In places such as North Africa and the Middle East, where water is more scarce, access to clean drinking water was and is a major factor in human development. An environmental science program – a student from Iowa State University sampling water Water fit for human consumption is called drinking water or potable water. Water that is not potable may be made potable by filtration or distillation, or by a range of other methods. More than 660 million people do not have access to safe drinking water.[113][114] Water that is not fit for drinking but is not harmful to humans when used for swimming or bathing is called by various names other than potable or drinking water, and is sometimes called safe water, or "safe for bathing". Chlorine is a skin and mucous membrane irritant that is used to make water safe for bathing or drinking. Its use is highly technical and is usually monitored by government regulations (typically 1 part per million (ppm) for drinking water, and 1–2 ppm of chlorine not yet reacted with impurities for bathing water). Water for bathing may be maintained in satisfactory microbiological condition using chemical disinfectants such as chlorine or ozone or by the use of ultraviolet light. Water reclamation is the process of converting wastewater (most commonly sewage, also called municipal wastewater) into water that can be reused for other purposes. There are 2.3 billion people who reside in nations with water scarcities, which means that each individual receives less than 1,700 cubic metres (60,000 cu ft) of water annually. 380 billion cubic metres (13×10^12 cu ft) of municipal wastewater are produced globally each year.[115][116][117] Freshwater is a renewable resource, recirculated by the natural hydrologic cycle, but pressures over access to it result from the naturally uneven distribution in space and time, growing economic demands by agriculture and industry, and rising populations. Currently, nearly a billion people around the world lack access to safe, affordable water. In 2000, the United Nations established the Millennium Development Goals for water to halve by 2015 the proportion of people worldwide without access to safe water and sanitation. Progress toward that goal was uneven, and in 2015 the UN committed to the Sustainable Development Goals of achieving universal access to safe and affordable water and sanitation by 2030. Poor water quality and bad sanitation are deadly; some five million deaths a year are caused by water-related diseases. The World Health Organization estimates that safe water could prevent 1.4 million child deaths from diarrhea each year.[118] In developing countries, 90% of all municipal wastewater still goes untreated into local rivers and streams.[119] Some 50 countries, with roughly a third of the world's population, also suffer from medium or high water scarcity and 17 of these extract more water annually than is recharged through their natural water cycles.[120] The strain not only affects surface freshwater bodies like rivers and lakes, but it also degrades groundwater resources. Further information: Water supply Total water withdrawals for agricultural, industrial and municipal purposes per capita, measured in cubic metres (m3) per year in 2010[121] The most substantial human use of water is for agriculture, including irrigated agriculture, which accounts for as much as 80 to 90 percent of total human water consumption.[122] In the United States, 42% of freshwater withdrawn for use is for irrigation, but the vast majority of water "consumed" (used and not returned to the environment) goes to agriculture.[123] Access to fresh water is often taken for granted, especially in developed countries that have built sophisticated water systems for collecting, purifying, and delivering water, and removing wastewater. But growing economic, demographic, and climatic pressures are increasing concerns about water issues, leading to increasing competition for fixed water resources, giving rise to the concept of peak water.[124] As populations and economies continue to grow, consumption of water-thirsty meat expands, and new demands rise for biofuels or new water-intensive industries, new water challenges are likely.[125] An assessment of water management in agriculture was conducted in 2007 by the International Water Management Institute in Sri Lanka to see if the world had sufficient water to provide food for its growing population.[126] It assessed the current availability of water for agriculture on a global scale and mapped out locations suffering from water scarcity. It found that a fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity, where there is not enough water to meet all demands. A further 1.6 billion people live in areas experiencing economic water scarcity, where the lack of investment in water or insufficient human capacity make it impossible for authorities to satisfy the demand for water. The report found that it would be possible to produce the food required in the future, but that continuation of today's food production and environmental trends would lead to crises in many parts of the world. To avoid a global water crisis, farmers will have to strive to increase productivity to meet growing demands for food, while industries and cities find ways to use water more efficiently.[127] Water scarcity is also caused by production of water intensive products. For example, cotton: 1 kg of cotton—equivalent of a pair of jeans—requires 10.9 cubic metres (380 cu ft) water to produce. While cotton accounts for 2.4% of world water use, the water is consumed in regions that are already at a risk of water shortage. Significant environmental damage has been caused: for example, the diversion of water by the former Soviet Union from the Amu Darya and Syr Darya rivers to produce cotton was largely responsible for the disappearance of the Aral Sea.[128] Water requirement per tonne of food product Water distribution in subsurface drip irrigation Irrigation of field crops On 7 April 1795, the gram was defined in France to be equal to "the absolute weight of a volume of pure water equal to a cube of one-hundredth of a meter, and at the temperature of melting ice".[129] For practical purposes though, a metallic reference standard was required, one thousand times more massive, the kilogram. Work was therefore commissioned to determine precisely the mass of one liter of water. In spite of the fact that the decreed definition of the gram specified water at 0 °C (32 °F)—a highly reproducible temperature—the scientists chose to redefine the standard and to perform their measurements at the temperature of highest water density, which was measured at the time as 4 °C (39 °F).[130] The Kelvin temperature scale of the SI system was based on the triple point of water, defined as exactly 273.16 K (0.01 °C; 32.02 °F), but as of May 2019 is based on the Boltzmann constant instead. The scale is an absolute temperature scale with the same increment as the Celsius temperature scale, which was originally defined according to the boiling point (set to 100 °C (212 °F)) and melting point (set to 0 °C (32 °F)) of water. Natural water consists mainly of the isotopes hydrogen-1 and oxygen-16, but there is also a small quantity of heavier isotopes oxygen-18, oxygen-17, and hydrogen-2 (deuterium). The percentage of the heavier isotopes is very small, but it still affects the properties of water. Water from rivers and lakes tends to contain less heavy isotopes than seawater. Therefore, standard water is defined in the Vienna Standard Mean Ocean Water specification. Main article: Drinking water A young girl drinking bottled water Water availability: the fraction of the population using improved water sources by country Roadside fresh water outlet from glacier, Nubra The human body contains from 55% to 78% water, depending on body size.[131][user-generated source?] To function properly, the body requires between one and seven litres (0.22 and 1.54 imp gal; 0.26 and 1.85 US gal)[citation needed] of water per day to avoid dehydration; the precise amount depends on the level of activity, temperature, humidity, and other factors. Most of this is ingested through foods or beverages other than drinking straight water. It is not clear how much water intake is needed by healthy people, though the British Dietetic Association advises that 2.5 liters of total water daily is the minimum to maintain proper hydration, including 1.8 liters (6 to 7 glasses) obtained directly from beverages.[132] Medical literature favors a lower consumption, typically 1 liter of water for an average male, excluding extra requirements due to fluid loss from exercise or warm weather.[133] Healthy kidneys can excrete 0.8 to 1 liter of water per hour, but stress such as exercise can reduce this amount. People can drink far more water than necessary while exercising, putting them at risk of water intoxication (hyperhydration), which can be fatal.[134][135] The popular claim that "a person should consume eight glasses of water per day" seems to have no real basis in science.[136] Studies have shown that extra water intake, especially up to 500 millilitres (18 imp fl oz; 17 US fl oz) at mealtime, was associated with weight loss.[137][138][139][140][141][142] Adequate fluid intake is helpful in preventing constipation.[143] Hazard symbol for non-potable water An original recommendation for water intake in 1945 by the Food and Nutrition Board of the U.S. National Research Council read: "An ordinary standard for diverse persons is 1 milliliter for each calorie of food. Most of this quantity is contained in prepared foods."[144] The latest dietary reference intake report by the U.S. National Research Council in general recommended, based on the median total water intake from US survey data (including food sources): 3.7 litres (0.81 imp gal; 0.98 US gal) for men and 2.7 litres (0.59 imp gal; 0.71 US gal) of water total for women, noting that water contained in food provided approximately 19% of total water intake in the survey.[145] Specifically, pregnant and breastfeeding women need additional fluids to stay hydrated. The US Institute of Medicine recommends that, on average, men consume 3 litres (0.66 imp gal; 0.79 US gal) and women 2.2 litres (0.48 imp gal; 0.58 US gal); pregnant women should increase intake to 2.4 litres (0.53 imp gal; 0.63 US gal) and breastfeeding women should get 3 liters (12 cups), since an especially large amount of fluid is lost during nursing.[146] Also noted is that normally, about 20% of water intake comes from food, while the rest comes from drinking water and beverages (caffeinated included). Water is excreted from the body in multiple forms; through urine and feces, through sweating, and by exhalation of water vapor in the breath. With physical exertion and heat exposure, water loss will increase and daily fluid needs may increase as well. Humans require water with few impurities. Common impurities include metal salts and oxides, including copper, iron, calcium and lead,[147][full citation needed] and harmful bacteria, such as Vibrio. Some solutes are acceptable and even desirable for taste enhancement and to provide needed electrolytes.[148] The single largest (by volume) freshwater resource suitable for drinking is Lake Baikal in Siberia.[149] This section is an excerpt from Washing.[edit] A woman washes her hands with soap and water. Washing is a method of cleaning, usually with water and soap or detergent. Regularly washing and then rinsing both body and clothing is an essential part of good hygiene and health.[150][151][152] Often people use soaps and detergents to assist in the emulsification of oils and dirt particles so they can be washed away. The soap can be applied directly, or with the aid of a washcloth or assisted with sponges or similar cleaning tools. In social contexts, washing refers to the act of bathing, or washing different parts of the body, such as hands, hair, or faces. Excessive washing may damage the hair, causing dandruff, or cause rough skin/skin lesions.[153][154] Some washing of the body is done ritually in religions like Christianity and Judaism, as an act of purification. Washing can also refer to washing objects. For example, washing of clothing or other cloth items, like bedsheets, or washing dishes or cookwear. Keeping objects clean, especially if they interact with food or the skin, can help with sanitation. Other kinds of washing focus on maintaining cleanliness and durability of objects that get dirty, such washing one's car, by lathering the exterior with car soap, or washing tools used in a dirty process. A private home washing machine These paragraphs are an excerpt from Maritime transport.[edit] Maritime transport (or ocean transport) or more generally waterborne transport, is the transport of people (passengers) or goods (cargo) via waterways. Freight transport by watercraft has been widely used throughout recorded history, as it provides a higher-capacity mode of transportation for passengers and cargo than land transport, the latter typically being more costly per unit payload due to it being affected by terrain conditions and road/rail infrastructures. The advent of aviation during the 20th century has diminished the importance of sea travel for passengers, though it is still popular for short trips and pleasure cruises. Transport by watercraft is much cheaper than transport by aircraft or land vehicles (both road and rail),[155] but is significantly slower for longer journeys and heavily dependent on adequate port facilities. Maritime transport accounts for roughly 80% of international trade, according to UNCTAD in 2020. Maritime transport can be realized over any distance as long as there are connecting bodies of water that are navigable to boats, ships or barges such as oceans, lakes, rivers and canals. Shipping may be for commerce, recreation, or military purposes, and is an important aspect of logistics in human societies since early shipbuilding and river engineering were developed, leading to canal ages in various civilizations. While extensive inland shipping is less critical today, the major waterways of the world including many canals are still very important and are integral parts of worldwide economies. Particularly, especially any material can be moved by water; however, water transport becomes impractical when material delivery is time-critical such as various types of perishable produce. Still, water transport is highly cost effective with regular schedulable cargoes, such as trans-oceanic shipping of consumer products – and especially for heavy loads or bulk cargos, such as coal, coke, ores or grains. Arguably, the Industrial Revolution had its first impacts where cheap water transport by canal, navigations, or shipping by all types of watercraft on natural waterways supported cost-effective bulk transport. Containerization revolutionized maritime transport starting in the 1970s. "General cargo" includes goods packaged in boxes, cases, pallets, and barrels. When a cargo is carried in more than one mode, it is intermodal or co-modal. Water is widely used in chemical reactions as a solvent or reactant and less commonly as a solute or catalyst. In inorganic reactions, water is a common solvent, dissolving many ionic compounds, as well as other polar compounds such as ammonia and compounds closely related to water. In organic reactions, it is not usually used as a reaction solvent, because it does not dissolve the reactants well and is amphoteric (acidic and basic) and nucleophilic. Nevertheless, these properties are sometimes desirable. Also, acceleration of Diels-Alder reactions by water has been observed. Supercritical water has recently been a topic of research. Oxygen-saturated supercritical water combusts organic pollutants efficiently. Water and steam are a common fluid used for heat exchange, due to its availability and high heat capacity, both for cooling and heating. Cool water may even be naturally available from a lake or the sea. It is especially effective to transport heat through vaporization and condensation of water because of its large latent heat of vaporization. A disadvantage is that metals commonly found in industries such as steel and copper are oxidized faster by untreated water and steam. In almost all thermal power stations, water is used as the working fluid (used in a closed-loop between boiler, steam turbine, and condenser), and the coolant (used to exchange the waste heat to a water body or carry it away by evaporation in a cooling tower). In the United States, cooling power plants is the largest use of water.[156] In the nuclear power industry, water can also be used as a neutron moderator. In most nuclear reactors, water is both a coolant and a moderator. This provides something of a passive safety measure, as removing the water from the reactor also slows the nuclear reaction down. However other methods are favored for stopping a reaction and it is preferred to keep the nuclear core covered with water so as to ensure adequate cooling. Water is used for fighting wildfires. Water has a high heat of vaporization and is relatively inert, which makes it a good fire extinguishing fluid. The evaporation of water carries heat away from the fire. It is dangerous to use water on fires involving oils and organic solvents because many organic materials float on water and the water tends to spread the burning liquid. Use of water in fire fighting should also take into account the hazards of a steam explosion, which may occur when water is used on very hot fires in confined spaces, and of a hydrogen explosion, when substances which react with water, such as certain metals or hot carbon such as coal, charcoal, or coke graphite, decompose the water, producing water gas. The power of such explosions was seen in the Chernobyl disaster, although the water involved in this case did not come from fire-fighting but from the reactor's own water cooling system. A steam explosion occurred when the extreme overheating of the core caused water to flash into steam. A hydrogen explosion may have occurred as a result of a reaction between steam and hot zirconium. Some metallic oxides, most notably those of alkali metals and alkaline earth metals, produce so much heat in reaction with water that a fire hazard can develop. The alkaline earth oxide quicklime, also known as calcium oxide, is a mass-produced substance that is often transported in paper bags. If these are soaked through, they may ignite as their contents react with water.[157] Main article: Water sport (recreation) San Andrés island, Colombia Humans use water for many recreational purposes, as well as for exercising and for sports. Some of these include swimming, waterskiing, boating, surfing and diving. In addition, some sports, like ice hockey and ice skating, are played on ice. Lakesides, beaches and water parks are popular places for people to go to relax and enjoy recreation. Many find the sound and appearance of flowing water to be calming, and fountains and other flowing water structures are popular decorations. Some keep fish and other flora and fauna inside aquariums or ponds for show, fun, and companionship. Humans also use water for snow sports such as skiing, sledding, snowmobiling or snowboarding, which require the water to be at a low temperature either as ice or crystallized into snow. The water industry provides drinking water and wastewater services (including sewage treatment) to households and industry. Water supply facilities include water wells, cisterns for rainwater harvesting, water supply networks, and water purification facilities, water tanks, water towers, water pipes including old aqueducts. Atmospheric water generators are in development. Drinking water is often collected at springs, extracted from artificial borings (wells) in the ground, or pumped from lakes and rivers. Building more wells in adequate places is thus a possible way to produce more water, assuming the aquifers can supply an adequate flow. Other water sources include rainwater collection. Water may require purification for human consumption. This may involve the removal of undissolved substances, dissolved substances and harmful microbes. Popular methods are filtering with sand which only removes undissolved material, while chlorination and boiling kill harmful microbes. Distillation does all three functions. More advanced techniques exist, such as reverse osmosis. Desalination of abundant seawater is a more expensive solution used in coastal arid climates. The distribution of drinking water is done through municipal water systems, tanker delivery or as bottled water. Governments in many countries have programs to distribute water to the needy at no charge. Reducing usage by using drinking (potable) water only for human consumption is another option. In some cities such as Hong Kong, seawater is extensively used for flushing toilets citywide in order to conserve freshwater resources. Polluting water may be the biggest single misuse of water; to the extent that a pollutant limits other uses of the water, it becomes a waste of the resource, regardless of benefits to the polluter. Like other types of pollution, this does not enter standard accounting of market costs, being conceived as externalities for which the market cannot account. Thus other people pay the price of water pollution, while the private firms' profits are not redistributed to the local population, victims of this pollution. Pharmaceuticals consumed by humans often end up in the waterways and can have detrimental effects on aquatic life if they bioaccumulate and if they are not biodegradable. Municipal and industrial wastewater are typically treated at wastewater treatment plants. Mitigation of polluted surface runoff is addressed through a variety of prevention and treatment techniques. A water-carrier in India, 1882. In many places where running water is not available, water has to be transported by people. A manual water pump in China Water purification facility Reverse osmosis (RO) desalination plant in Barcelona, Spain Many industrial processes rely on reactions using chemicals dissolved in water, suspension of solids in water slurries or using water to dissolve and extract substances, or to wash products or process equipment. Processes such as mining, chemical pulping, pulp bleaching, paper manufacturing, textile production, dyeing, printing, and cooling of power plants use large amounts of water, requiring a dedicated water source, and often cause significant water pollution. Water is used in power generation. Hydroelectricity is electricity obtained from hydropower. Hydroelectric power comes from water driving a water turbine connected to a generator. Hydroelectricity is a low-cost, non-polluting, renewable energy source. The energy is supplied by the motion of water. Typically a dam is constructed on a river, creating an artificial lake behind it. Water flowing out of the lake is forced through turbines that turn generators. Three Gorges Dam is the largest hydro-electric power station in the world. Pressurized water is used in water blasting and water jet cutters. High pressure water guns are used for precise cutting. It works very well, is relatively safe, and is not harmful to the environment. It is also used in the cooling of machinery to prevent overheating, or prevent saw blades from overheating. Water is also used in many industrial processes and machines, such as the steam turbine and heat exchanger, in addition to its use as a chemical solvent. Discharge of untreated water from industrial uses is pollution. Pollution includes discharged solutes (chemical pollution) and discharged coolant water (thermal pollution). Industry requires pure water for many applications and uses a variety of purification techniques both in water supply and discharge. Water can be used to cook foods such as noodles. Sterile water for injection Boiling, steaming, and simmering are popular cooking methods that often require immersing food in water or its gaseous state, steam.[158] Water is also used for dishwashing. Water also plays many critical roles within the field of food science. Solutes such as salts and sugars found in water affect the physical properties of water. The boiling and freezing points of water are affected by solutes, as well as air pressure, which is in turn affected by altitude. Water boils at lower temperatures with the lower air pressure that occurs at higher elevations. One mole of sucrose (sugar) per kilogram of water raises the boiling point of water by 0.51 °C (0.918 °F), and one mole of salt per kg raises the boiling point by 1.02 °C (1.836 °F); similarly, increasing the number of dissolved particles lowers water's freezing point.[159] Solutes in water also affect water activity that affects many chemical reactions and the growth of microbes in food.[160] Water activity can be described as a ratio of the vapor pressure of water in a solution to the vapor pressure of pure water.[159] Solutes in water lower water activity—this is important to know because most bacterial growth ceases at low levels of water activity.[160] Not only does microbial growth affect the safety of food, but also the preservation and shelf life of food. Water hardness is also a critical factor in food processing and may be altered or treated by using a chemical ion exchange system. It can dramatically affect the quality of a product, as well as playing a role in sanitation. Water hardness is classified based on concentration of calcium carbonate the water contains. Water is classified as soft if it contains less than 100 mg/L (UK)[161] or less than 60 mg/L (US).[162] According to a report published by the Water Footprint organization in 2010, a single kilogram of beef requires 15 thousand litres (3.3×10^3 imp gal; 4.0×10^3 US gal) of water; however, the authors also make clear that this is a global average and circumstantial factors determine the amount of water used in beef production.[163] Water for injection is on the World Health Organization's list of essential medicines.[164] Band 5 ALMA receiver is an instrument specifically designed to detect water in the universe.[165] Much of the universe's water is produced as a byproduct of star formation. The formation of stars is accompanied by a strong outward wind of gas and dust. When this outflow of material eventually impacts the surrounding gas, the shock waves that are created compress and heat the gas. The water observed is quickly produced in this warm dense gas.[166] On 22 July 2011, a report described the discovery of a gigantic cloud of water vapor containing "140 trillion times more water than all of Earth's oceans combined" around a quasar located 12 billion light years from Earth. According to the researchers, the "discovery shows that water has been prevalent in the universe for nearly its entire existence".[167][168] Water has been detected in interstellar clouds within the Milky Way.[169] Water probably exists in abundance in other galaxies, too, because its components, hydrogen, and oxygen, are among the most abundant elements in the universe. Based on models of the formation and evolution of the Solar System and that of other star systems, most other planetary systems are likely to have similar ingredients. Water is present as vapor in: Atmosphere of the Sun: in detectable trace amounts[170] Atmosphere of Mercury: 3.4%, and large amounts of water in Mercury's exosphere[171] Atmosphere of Venus: 0.002%[172] Earth's atmosphere: ≈0.40% over full atmosphere, typically 1–4% at surface Atmosphere of the Moon: in trace amounts[173] Atmosphere of Mars: 0.03%[174] Atmosphere of Ceres[175] Atmosphere of Jupiter: 0.0004%[176] – in ices only; and that of its moon Europa[177] Atmosphere of Saturn – in ices only; Enceladus: 91%[178] and Dione (exosphere)[citation needed] Atmosphere of Uranus – in trace amounts below 50 bar Atmosphere of Neptune – found in the deeper layers[179] Extrasolar planet atmospheres: including those of HD 189733 b[180] and HD 209458 b,[181] Tau Boötis b,[182] HAT-P-11b,[183][184] XO-1b, WASP-12b, WASP-17b, and WASP-19b.[185] Stellar atmospheres: not limited to cooler stars and even detected in giant hot stars such as Betelgeuse, Mu Cephei, Antares and Arcturus.[184][186] Circumstellar disks: including those of more than half of T Tauri stars such as AA Tauri[184] as well as TW Hydrae,[187][188] IRC +10216[189] and APM 08279+5255,[167][168] VY Canis Majoris and S Persei.[186] Further information: List of largest lakes and seas in the Solar System and Extraterrestrial liquid water Liquid water is present on Earth, covering 71% of its surface.[23] Liquid water is also occasionally present in small amounts on Mars.[190] Scientists believe liquid water is present in the Saturnian moons of Enceladus, as a 10-kilometre thick ocean approximately 30–40 kilometers below Enceladus' south polar surface,[191][192] and Titan, as a subsurface layer, possibly mixed with ammonia.[193] Jupiter's moon Europa has surface characteristics which suggest a subsurface liquid water ocean.[194] Liquid water may also exist on Jupiter's moon Ganymede as a layer sandwiched between high pressure ice and rock.[195] Water is present as ice on: Water ice in the Korolev crater on MarsMars: under the regolith and at the poles.[196][197] Earth–Moon system: mainly as ice sheets on Earth and in Lunar craters and volcanic rocks[198] NASA reported the detection of water molecules by NASA's Moon Mineralogy Mapper aboard the Indian Space Research Organization's Chandrayaan-1 spacecraft in September 2009.[199] Ceres[200][201][202] Jupiter's moons: Europa's surface and also that of Ganymede[203] and Callisto[204][205] Saturn: in the planet's ring system[206] and on the surface and mantle of Titan[207] and Enceladus[208] Pluto–Charon system[206] Comets[209][210] and other related Kuiper belt and Oort cloud objects[211] And is also likely present on: Mercury's poles[212] Tethys[213] Water and other volatiles probably comprise much of the internal structures of Uranus and Neptune and the water in the deeper layers may be in the form of ionic water in which the molecules break down into a soup of hydrogen and oxygen ions, and deeper still as superionic water in which the oxygen crystallizes, but the hydrogen ions float about freely within the oxygen lattice.[214] Further information: Water distribution on Earth and Planetary habitability The existence of liquid water, and to a lesser extent its gaseous and solid forms, on Earth are vital to the existence of life on Earth as we know it. The Earth is located in the habitable zone of the Solar System; if it were slightly closer to or farther from the Sun (about 5%, or about 8 million kilometers), the conditions which allow the three forms to be present simultaneously would be far less likely to exist.[215][216] Earth's gravity allows it to hold an atmosphere. Water vapor and carbon dioxide in the atmosphere provide a temperature buffer (greenhouse effect) which helps maintain a relatively steady surface temperature. If Earth were smaller, a thinner atmosphere would allow temperature extremes, thus preventing the accumulation of water except in polar ice caps (as on Mars).[citation needed] The surface temperature of Earth has been relatively constant through geologic time despite varying levels of incoming solar radiation (insolation), indicating that a dynamic process governs Earth's temperature via a combination of greenhouse gases and surface or atmospheric albedo. This proposal is known as the Gaia hypothesis.[citation needed] The state of water on a planet depends on ambient pressure, which is determined by the planet's gravity. If a planet is sufficiently massive, the water on it may be solid even at high temperatures, because of the high pressure caused by gravity, as it was observed on exoplanets Gliese 436 b[217] and GJ 1214 b.[218] Main articles: Water law, Water right, and Water scarcity This section needs to be updated. Please help update this article to reflect recent events or newly available information. (June 2022) An estimate of the proportion of people in developing countries with access to potable water 1970–2000 Water politics is politics affected by water and water resources. Water, particularly fresh water, is a strategic resource across the world and an important element in many political conflicts. It causes health impacts and damage to biodiversity. Access to safe drinking water has improved over the last decades in almost every part of the world, but approximately one billion people still lack access to safe water and over 2.5 billion lack access to adequate sanitation.[219] However, some observers have estimated that by 2025 more than half of the world population will be facing water-based vulnerability.[220] A report, issued in November 2009, suggests that by 2030, in some developing regions of the world, water demand will exceed supply by 50%.[221] 1.6 billion people have gained access to a safe water source since 1990.[222] The proportion of people in developing countries with access to safe water is calculated to have improved from 30% in 1970[223] to 71% in 1990, 79% in 2000, and 84% in 2004.[219] A 2006 United Nations report stated that "there is enough water for everyone", but that access to it is hampered by mismanagement and corruption.[224] In addition, global initiatives to improve the efficiency of aid delivery, such as the Paris Declaration on Aid Effectiveness, have not been taken up by water sector donors as effectively as they have in education and health, potentially leaving multiple donors working on overlapping projects and recipient governments without empowerment to act.[225] The authors of the 2007 Comprehensive Assessment of Water Management in Agriculture cited poor governance as one reason for some forms of water scarcity. Water governance is the set of formal and informal processes through which decisions related to water management are made. Good water governance is primarily about knowing what processes work best in a particular physical and socioeconomic context. Mistakes have sometimes been made by trying to apply 'blueprints' that work in the developed world to developing world locations and contexts. The Mekong river is one example; a review by the International Water Management Institute of policies in six countries that rely on the Mekong river for water found that thorough and transparent cost-benefit analyses and environmental impact assessments were rarely undertaken. They also discovered that Cambodia's draft water law was much more complex than it needed to be.[226] In 2004, the UK charity WaterAid reported that a child dies every 15 seconds from easily preventable water-related diseases, which are often tied to a lack of adequate sanitation.[227][228] Since 2003, the UN World Water Development Report, produced by the UNESCO World Water Assessment Programme, has provided decision-makers with tools for developing sustainable water policies.[229] The 2023 report states that two billion people (26% of the population) do not have access to drinking water and 3.6 billion (46%) lack access to safely managed sanitation.[230] People in urban areas (2.4 billion) will face water scarcity by 2050.[229] Water scarcity has been described as endemic, due to overconsumption and pollution.[231] The report states that 10% of the world's population lives in countries with high or critical water stress. Yet over the past 40 years, water consumption has increased by around 1% per year, and is expected to grow at the same rate until 2050. Since 2000, flooding in the tropics has quadrupled, while flooding in northern mid-latitudes has increased by a factor of 2.5.[232] The cost of these floods between 2000 and 2019 was 100,000 deaths and $650 million.[229] Organizations concerned with water protection include the International Water Association (IWA), WaterAid, Water 1st, and the American Water Resources Association. The International Water Management Institute undertakes projects with the aim of using effective water management to reduce poverty. Water related conventions are United Nations Convention to Combat Desertification (UNCCD), International Convention for the Prevention of Pollution from Ships, United Nations Convention on the Law of the Sea and Ramsar Convention. World Day for Water takes place on 22 March[233] and World Oceans Day on 8 June.[234] Main article: Water and religion See also: Sacred waters People come to Inda Abba Hadera spring (Inda Sillasie, Ethiopia) to wash in holy water. Water is considered a purifier in most religions. Faiths that incorporate ritual washing (ablution) include Christianity,[235] Hinduism, Islam, Judaism, the Rastafari movement, Shinto, Taoism, and Wicca. Immersion (or aspersion or affusion) of a person in water is a central Sacrament of Christianity (where it is called baptism); it is also a part of the practice of other religions, including Islam (Ghusl), Judaism (mikvah) and Sikhism (Amrit Sanskar). In addition, a ritual bath in pure water is performed for the dead in many religions including Islam and Judaism. In Islam, the five daily prayers can be done in most cases after washing certain parts of the body using clean water (wudu), unless water is unavailable (see Tayammum). In Shinto, water is used in almost all rituals to cleanse a person or an area (e.g., in the ritual of misogi). In Christianity, holy water is water that has been sanctified by a priest for the purpose of baptism, the blessing of persons, places, and objects, or as a means of repelling evil.[236][237] In Zoroastrianism, water (āb) is respected as the source of life.[238] Icosahedron as a part of Spinoza monument in Amsterdam The Ancient Greek philosopher Empedocles saw water as one of the four classical elements (along with fire, earth, and air), and regarded it as an ylem, or basic substance of the universe. Thales, whom Aristotle portrayed as an astronomer and an engineer, theorized that the earth, which is denser than water, emerged from the water. Thales, a monist, believed further that all things are made from water. Plato believed that the shape of water is an icosahedron – flowing easily compared to the cube-shaped earth.[239] The theory of the four bodily humors associated water with phlegm, as being cold and moist. The classical element of water was also one of the five elements in traditional Chinese philosophy (along with earth, fire, wood, and metal). Some traditional and popular Asian philosophical systems take water as a role-model. James Legge's 1891 translation of the Dao De Jing states, "The highest excellence is like (that of) water. The excellence of water appears in its benefiting all things, and in its occupying, without striving (to the contrary), the low place which all men dislike. Hence (its way) is near to (that of) the Tao" and "There is nothing in the world more soft and weak than water, and yet for attacking things that are firm and strong there is nothing that can take precedence of it—for there is nothing (so effectual) for which it can be changed."[240] Guanzi in the "Shui di" 水地 chapter further elaborates on the symbolism of water, proclaiming that "man is water" and attributing natural qualities of the people of different Chinese regions to the character of local water resources.[241] "Living water" features in Germanic and Slavic folktales as a means of bringing the dead back to life. Note the Grimm fairy-tale ("The Water of Life") and the Russian dichotomy of living [ru] and dead water [ru]. The Fountain of Youth represents a related concept of magical waters allegedly preventing aging. In the significant modernist novel Ulysses (1922) by Irish writer James Joyce, the chapter "Ithaca" takes the form of a catechism of 309 questions and answers, one of which is known as the "water hymn".[242]:91 According to Richard E. Madtes, the hymn is not merely a "monotonous string of facts", rather, its phrases, like their subject, "ebb and flow, heave and swell, gather and break, until they subside into the calm quiescence of the concluding 'pestilential fens, faded flowerwater, stagnant pools in the waning moon.'"[242]:79 The hymn is considered one of the most remarkable passages in Ithaca, and according to literary critic Hugh Kenner, achieves "the improbable feat of raising to poetry all the clutter of footling information that has accumulated in schoolbooks."[242]:91 The literary motif of water represents the novel's theme of "everlasting, everchanging life," and the hymn represents the culmination of the motif in the novel.[242]:91 The following is the hymn quoted in full.[243] What in water did Bloom, waterlover, drawer of water, watercarrier returning to the range, admire?Its universality: its democratic equality and constancy to its nature in seeking its own level: its vastness in the ocean of Mercator's projection: its unplumbed profundity in the Sundam trench of the Pacific exceeding 8,000 fathoms: the restlessness of its waves and surface particles visiting in turn all points of its seaboard: the independence of its units: the variability of states of sea: its hydrostatic quiescence in calm: its hydrokinetic turgidity in neap and spring tides: its subsidence after devastation: its sterility in the circumpolar icecaps, arctic and antarctic: its climatic and commercial significance: its preponderance of 3 to 1 over the dry land of the globe: its indisputable hegemony extending in square leagues over all the region below the subequatorial tropic of Capricorn: the multisecular stability of its primeval basin: its luteofulvous bed: its capacity to dissolve and hold in solution all soluble substances including millions of tons of the most precious metals: its slow erosions of peninsulas and downwardtending promontories: its alluvial deposits: its weight and volume and density: its imperturbability in lagoons and highland tarns: its gradation of colours in the torrid and temperate and frigid zones: its vehicular ramifications in continental lakecontained streams and confluent oceanflowing rivers with their tributaries and transoceanic currents: gulfstream, north and south equatorial courses: its violence in seaquakes, waterspouts, artesian wells, eruptions, torrents, eddies, freshets, spates, groundswells, watersheds, waterpartings, geysers, cataracts, whirlpools, maelstroms, inundations, deluges, cloudbursts: its vast circumterrestrial ahorizontal curve: its secrecy in springs, and latent humidity, revealed by rhabdomantic or hygrometric instruments and exemplified by the well by the hole in the wall at Ashtown gate, saturation of air, distillation of dew: the simplicity of its composition, two constituent parts of hydrogen with one constituent part of oxygen: its healing virtues: its buoyancy in the waters of the Dead Sea: its persevering penetrativeness in runnels, gullies, inadequate dams, leaks on shipboard: its properties for cleansing, quenching thirst and fire, nourishing vegetation: its infallibility as paradigm and paragon: its metamorphoses as vapour, mist, cloud, rain, sleet, snow, hail: its strength in rigid hydrants: its variety of forms in loughs and bays and gulfs and bights and guts and lagoons and atolls and archipelagos and sounds and fjords and minches and tidal estuaries and arms of sea: its solidity in glaciers, icebergs, icefloes: its docility in working hydraulic millwheels, turbines, dynamos, electric power stations, bleachworks, tanneries, scutchmills: its utility in canals, rivers, if navigable, floating and graving docks: its potentiality derivable from harnessed tides or watercourses falling from level to level: its submarine fauna and flora (anacoustic, photophobe) numerically, if not literally, the inhabitants of the globe: its ubiquity as constituting 90% of the human body: the noxiousness of its effluvia in lacustrine marshes, pestilential fens, faded flowerwater, stagnant pools in the waning moon.The vast "water hymn" in James Joyce's novel Ulysses is occasioned when the protagonist Leopold Bloom fills a kettle with water from a kitchen faucet.[243] Painter and activist Fredericka Foster curated The Value of Water, at the Cathedral of St. John the Divine in New York City,[244] which anchored a year-long initiative by the Cathedral on our dependence on water.[245][246] The largest exhibition to ever appear at the Cathedral,[247] it featured over forty artists, including Jenny Holzer, Robert Longo, Mark Rothko, William Kentridge, April Gornik, Kiki Smith, Pat Steir, Alice Dalton Brown, Teresita Fernandez and Bill Viola.[248][249] Foster created Think About Water,[250][full citation needed] an ecological collective of artists who use water as their subject or medium. Members include Basia Irland,[251][full citation needed] Aviva Rahmani, Betsy Damon, Diane Burko, Leila Daw, Stacy Levy, Charlotte Coté,[252] Meridel Rubenstein, and Anna Macleod. To mark the 10th anniversary of access to water and sanitation being declared a human right by the UN, the charity WaterAid commissioned ten visual artists to show the impact of clean water on people's lives.[253][254] Main article: Dihydrogen monoxide parody 'Dihydrogen monoxide' is a technically correct but rarely used chemical name of water. This name has been used in a series of hoaxes and pranks that mock scientific illiteracy. This began in 1983, when an April Fools' Day article appeared in a newspaper in Durand, Michigan. The false story consisted of safety concerns about the substance.[255] The word "Water" has been used by many Florida based rappers as a sort of catchphrase or adlib. Rappers who have done this include BLP Kosher and Ski Mask the Slump God.[256] To go even further some rappers have made whole songs dedicated to the water in Florida, such as the 2023 Danny Towers song "Florida Water".[257] Others have made whole songs dedicated to water as a whole, such as XXXTentacion, and Ski Mask the Slump God with their hit song "H2O". Oceans portalRenewable energy portalWater portalWeather portal Outline of water – Overview of and topical guide to water Water (data page) – Chemical data page for water is a collection of the chemical and physical properties of water. Aquaphobia – Persistent and abnormal fear of water Blue roof – Roof of a building that is designed to provide temporary water storage Catchwater – Runoff catching or channeling device Human right to water and sanitation Hydroelectricity – Electricity generated by hydropower List of waterfalls Marine current power – Extraction of power from ocean currents Marine energy – Energy available from oceans Mpemba effect – Natural phenomenon that hot water freezes faster than cold Oral rehydration therapy – Type of fluid replacement used to prevent and treat dehydration Osmotic power – Energy available from the difference in the salt concentration between seawater and river water Oxyhydrogen – Explosive mixture of hydrogen and oxygen gases Properties of water – Physical and chemical properties of pure water Rainwater tank Thirst – Craving for potable fluids experienced by animals Tidal power – Technology to convert the energy from tides into useful forms of power Water pinch analysis – systematic technique for reducing water consumption and wastewater generationPages displaying wikidata descriptions as a fallback Wave power – Transport of energy by wind waves, and the capture of that energy to do useful work Water filter – Device that removes impurities in water Water heat recycling – Use of a heat exchanger to recover energy and reuse heat from drain water Water recycling shower – Showers that use a basin and a pump to re-use the showering water Water-sensitive urban design – Integrated approach to urban water cycle

^ A commonly quoted value of 15.7 used mainly in organic chemistry for the pKa of water is incorrect.[12][13] ^ a b Vienna Standard Mean Ocean Water (VSMOW), used for calibration, melts at 273.1500089(10) K (0.000089(10) °C), and boils at 373.1339 K (99.9839 °C). Other isotopic compositions melt or boil at slightly different temperatures. ^ see the taste and odor section ^ Other substances with this property include bismuth, silicon, germanium and gallium.[57] ^ "naming molecular compounds". www.iun.edu. Archived from the original on 24 September 2018. Retrieved 1 October 2018. Sometimes these compounds have generic or common names (e.g., H2O is "water") and they also have systematic names (e.g., H2O, dihydrogen monoxide). ^ "Definition of Hydrol". Merriam-Webster. Archived from the original on 13 August 2017. Retrieved 21 April 2019. ^ Leigh, Favre & Metanomski 1998, p. 99. ^ Braun CL, Smirnov SN (1 August 1993). "Why is water blue?" (PDF). Journal of Chemical Education. 70 (8): 612. 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The New York Times (15 April 2016) water at Wikipedia's sister projects Definitions from WiktionaryMedia from CommonsNews from WikinewsQuotations from WikiquoteTexts from WikisourceTextbooks from WikibooksResources from Wikiversity The World's Water Data Page FAO Comprehensive Water Database, AQUASTAT The Water Conflict Chronology: Water Conflict Database Archived 16 January 2013 at the Wayback Machine Water science school (USGS) Portal to The World Bank's strategy, work and associated publications on water resources America Water Resources Association Archived 24 March 2018 at the Wayback Machine Water on the web Water structure and science Archived 28 December 2014 at the Wayback Machine "Why water is one of the weirdest things in the universe", Ideas, BBC, Video, 3:16 minutes, 2019 The chemistry of water Archived 19 June 2020 at the Wayback Machine (NSF special report) The International Association for the Properties of Water and Steam H2O: The Molecule That Made Us, a 2020 PBS documentary Retrieved from "

2One hundred years, from 1901 to 2000 For other uses, see 20th century (disambiguation). Earthrise, taken on December 24, 1968 by astronaut William "Bill" Anders during the Apollo 8 space mission. It was the first photograph taken of Earth from lunar orbit. Millennia 2nd millennium Centuries 19th century 20th century 21st century Timelines 19th century 20th century 21st century State leaders 19th century 20th century 21st century Decades 1900s 1910s 1920s 1930s 1940s 1950s 1960s 1970s 1980s 1990s Categories: Births – Deaths Establishments – Disestablishments vte The 20th century was the century that began on 1 January 1901 (MCMI), and ended on 31 December 2000 (MM).[1][2] It was the 10th and last century of the 2nd millennium and was marked by new models of scientific understanding, unprecedented scopes of warfare, new modes of communication that would operate at nearly instant speeds, and new forms of art and entertainment. Population growth was also unprecedented,[3] as the century started with around 1.6 billion people, and ended with around 6.2 billion.[4] The 20th century was dominated by significant geopolitical events that reshaped the political and social structure of the globe: World War I, the Spanish flu pandemic, World War II and the Cold War. Unprecedented advances in science and technology defined the century, including the advent of nuclear weapons and nuclear power, space exploration, the shift from analog to digital computing and the continuing advancement of transportation, including powered flight and the automobile. The Earth's sixth mass extinction event, the Holocene extinction, continued, and human conservation efforts increased. Major themes of the century included decolonization, nationalism, globalization and new forms of intergovernmental organizations. Democracy spread, and women were given the right to vote in many countries in the world. Cultural homogenization began through developments in emerging transportation and information and communications technology, with popular music and other influences of Western culture, international corporations, and what is arguably a truly global economy by the end of the 20th century. Poverty was reduced and the century saw rising standards of living, world population growth, awareness of environmental degradation and ecological extinction.[5][6] Automobiles, airplanes, and home appliances became common, and video and audio recording saw mass adoption. These developments were made possible by the exploitation of fossil fuel resources, which offered energy in an easily portable form, but also caused concern about pollution and long-term impact on the environment. Humans started to explore space, taking their first footsteps on the Moon. Great advances in electricity generation and telecommunications allowed for near-instantaneous worldwide communication, ultimately leading to the Internet. Meanwhile, advances in medical technology resulted in the near-eradication and eradication of many infectious diseases, as well as opening the avenue of biological genetic engineering. Scientific discoveries, such as the theory of relativity and quantum physics, profoundly changed the foundational models of physical science, forcing scientists to realize that the universe is more complex than previously believed, and dashing the hopes (or fears) at the end of the 19th century that the last few details of scientific knowledge were about to be filled in. At the beginning of the period, the British Empire is the world's most powerful nation,[7] having acted as the world's policeman for the past century. World powers and empires in 1914, just before the First World War. Technological advancements during World War I changed the way war is fought, as new inventions such as tanks, chemical weapons, and aircraft modified tactics and strategy. After more than four years of trench warfare in Western Europe, and up to 17 million dead, the powers that had formed the Triple Entente (France, Britain, and Russia, later replaced by the United States and joined by Italy and Romania) emerged victorious over the Central Powers (Germany, Austria-Hungary, the Ottoman Empire and Bulgaria). In addition to annexing many of the colonial possessions of the vanquished states, the Triple Entente exacted punitive restitution payments from them, plunging Germany in particular into economic depression. The Austro-Hungarian and Ottoman empires were dismantled at the war's conclusion. The Russian Revolution resulted in the overthrow of the Tsarist regime of Nicholas II and the onset of the Russian Civil War. The victorious Bolsheviks then established the Soviet Union, the world's first communist state. Fascism, a movement which grew out of post-war angst and which accelerated during the Great Depression of the 1930s, gained momentum in Italy, Germany, and Spain in the 1920s and 1930s, culminating in World War II, sparked by Nazi Germany's aggressive expansion at the expense of its neighbors. Meanwhile, Japan had rapidly transformed itself into a technologically advanced industrial power and, along with Germany and Italy, formed the Axis powers. Japan's military expansionism in East Asia and the Pacific Ocean brought it into conflict with the United States, culminating in a surprise attack which drew the US into World War II. After some years of dramatic military success, Germany is defeated in 1945, having been invaded by the Soviet Union and Poland from the East and by the United States, the United Kingdom, Canada, and France from the West. After the victory of the Allies in Europe, the war in Asia ended with the Soviet invasion of Manchuria and the dropping of two atomic bombs on Japan by the US, the first nation to develop nuclear weapons and the only one to use them in warfare. In total, World War II left some 60 million people dead. The mushroom cloud of the detonation of Little Boy, the first nuclear attack in history, on 6 August 1945 over Hiroshima, igniting the nuclear age with the international security dominating thread of mutual assured destruction in the latter half of the 20th century. Following World War II, the United Nations, successor to the League of Nations, is established as an international forum in which the world's nations could discuss issues diplomatically. It enacted resolutions on such topics as the conduct of warfare, environmental protection, international sovereignty, and human rights. Peacekeeping forces consisting of troops provided by various countries, with various United Nations and other aid agencies, helped to relieve famine, disease, and poverty, and to suppress some local armed conflicts. Europe slowly united, economically and, in some ways, politically, to form the European Union, which consisted of 15 European countries by the end of the 20th century. After the war, Germany is occupied and divided between the Western powers and the Soviet Union. East Germany and the rest of Eastern Europe became Soviet puppet states under communist rule. Western Europe is rebuilt with the aid of the American Marshall Plan, resulting in a major post-war economic boom, and many of the affected nations became close allies of the United States. With the Axis defeated and Britain and France rebuilding, the United States and the Soviet Union were left standing as the world's only superpowers. Allies during the war, they soon became hostile to one another as their competing ideologies of communism and democratic capitalism proliferated in Europe, which became divided by the Iron Curtain and the Berlin Wall. They formed competing military alliances (NATO and the Warsaw Pact) which engaged in a decades-long standoff known as the Cold War. The period is marked by a new arms race as the USSR became the second nation to develop nuclear weapons, which were produced by both sides in sufficient numbers to end most human life on the planet had a large-scale nuclear exchange ever occurred. Mutually assured destruction is credited by many historians as having prevented such an exchange, each side being unable to strike first at the other without ensuring an equally devastating retaliatory strike. Unable to engage one another directly, the conflict played out in a series of proxy wars around the world—particularly in China, Korea, Cuba, Vietnam, and Afghanistan—as the USSR sought to export communism while the US attempted to contain it. The technological competition between the two sides led to substantial investment in research and development which produced innovations that reached far beyond the battlefield, such as space exploration and the Internet. The international community grew in the second half of the century significantly due to a new wave of decolonization, particularly in Africa. Most of the newly independent states, were grouped together with many other so called developing countries. Developing countries gained attention, particularly due to rapid population growth, leading to a record world population of nearly 7 billion people by the end of the century. In the latter half of the century, most of the European-colonized world in Africa and Asia gained independence in a process of decolonization. Meanwhile, globalization opened the door for several nations to exert a strong influence over many world affairs. The US's global military presence spread American culture around the world with the advent of the Hollywood motion picture industry and Broadway, jazz, rock music, and pop music, fast food and hippy counterculture, hip-hop, house music, and disco, as well as street style, all of which came to be identified with the concepts of popular culture and youth culture.[8][9][10] After the Soviet Union collapsed under internal pressure in 1991, most of the communist governments it had supported around the world were dismantled—with the notable exceptions of China, North Korea, Cuba, Vietnam, and Laos—followed by difficult transitions into market economies.[11] Due to continuing industrialization and expanding trade, many significant changes of the century were, directly or indirectly, economic and technological in nature. Inventions such as the light bulb, the automobile, mechanical computers, and the telephone in the late 19th century, followed by supertankers; airliners; motorways; radio communication and broadcasting; television; digital computers; air conditioning; antibiotics; nuclear power; frozen food; microcomputers; the Internet and the World Wide Web; and mobile telephones affected people's quality of life across the developed world. The quantity of goods consumed by the average person expanded massively. Scientific research, engineering professionalization and technological development—much of it motivated by the Cold War arms race—drove changes in everyday life. Martin Luther King Jr., an African American civil rights movement leader (ishington, August 1963) Starting from the century, strong discrimination based on race and sex is significant in most societies. Although the Atlantic slave trade had ended in the 19th century, movements for equality for non-white people in the white-dominated societies of North America, Europe, and South Africa continued. By the end of the 20th century, in many parts of the world, women had the same legal rights as men, and racism had come to be seen as unacceptable, a sentiment often backed up by legislation.[12] When the Republic of India is constituted, the disadvantaged classes of the caste system in India became entitled to affirmative action benefits in education, employment and government. Attitudes toward pre-marital sex changed rapidly in many societies during the sexual revolution of the 1960s and 1970s. Attitudes towards homosexuality also began to change in the later part of the century.[13][14] Trauma brought on by events like World War I and World War II, with their military death tolls alone at bare minimum being 29,697,963, and the Spanish Flu, whose death count alone exceeded that, helped make society in many countries more egalitarian and less neglectful of the poor.[15] The Blue Marble, Earth as seen from Apollo 17 in December 1972. The photograph is taken by LMP Harrison Schmitt. The second half of the 20th century saw humanity's first space exploration.Economic growth and technological progress had radically altered daily lives. Europe appeared to be at a sustainable peace for the first time in recorded history[citation needed]. The people of the Indian subcontinent, a sixth of the world population at the end of the 20th century, had attained an indigenous independence for the first time in centuries. China, an ancient nation comprising a fifth of the world population, is finally open to the world, creating a new state after the near-complete destruction of the old cultural order. With the end of colonialism and the Cold War, nearly a billion people in Africa were left in new nation states. The world is undergoing its second major period of globalization; the first, which started in the 18th century, having been terminated by World War I. Since the US is in a dominant position, a major part of the process is Americanization. The influence of China and India is also rising, as the world's largest populations were rapidly integrating with the world economy. Terrorism, dictatorship, and the spread of nuclear weapons were pressing global issues. The world is still blighted by small-scale wars and other violent conflicts, fueled by competition over resources and by ethnic conflicts. Disease threatened to destabilize many regions of the world. New viruses such as the West Nile virus continued to spread. Malaria and other diseases affected large populations. Millions were infected with HIV, the virus which causes AIDS. The virus is becoming an epidemic in southern Africa. Based on research done by climate scientists, the majority of the scientific community consider that in the long term environmental problems pose a serious threat.[16] One argument is that of global warming occurring due to human-caused emission of greenhouse gases, particularly carbon dioxide produced by the burning of fossil fuels.[17] This prompted many nations to negotiate and sign the Kyoto treaty, which set mandatory limits on carbon dioxide emissions. World population increased from about 1.6 billion people in 1901 to 6.1 billion at the century's end.[18][19] Main articles: International relations of the Great Powers (1814–1919), Diplomatic history of World War I, International relations (1919–1939), Diplomatic history of World War II, Cold War, and International relations since 1989 Map of territorial changes in Europe after World War I (as of 1923). The number of people killed during the century by government actions is in the hundreds of millions. This includes deaths caused by wars, genocide, politicide and mass murders. The deaths from acts of war during the two world wars alone have been estimated at between 50 and 80 million.[citation needed] Political scientist Rudolph Rummel estimated 262,000,000 deaths caused by democide, which excludes those killed in war battles, civilians unintentionally killed in war and killings of rioting mobs.[20] According to Charles Tilly, "Altogether, about 100 million people died as a direct result of action by organized military units backed by one government or another over the course of the century. Most likely a comparable number of civilians died of war-induced disease and other indirect effects."[21] It is estimated that approximately 70 million Europeans died through war, violence and famine between 1914 and 1945.[22] Russo-Japanese War, between the Russian Empire and the Empire of Japan during 1904 and 1905 over rival imperial ambitions in Manchuria and the Korean Empire. Russian Revolution of 1905, a wave of mass political and social unrest then began to spread across the vast areas of the Russian Empire. The unrest is directed primarily against the Tsar, the nobility, and the ruling class. It included worker strikes, peasant unrest, and military mutinies. Sinking of the Titanic, RMS Titanic sank on 15 April 1912 in the North Atlantic Ocean. The largest ocean liner in service at the time, Titanic is four days into her maiden voyage from Southampton, England, to New York City, with an estimated 2,224 people on board when she struck an iceberg at 23:40 (ship's time)[a] on 14 April. The Armenian, Assyrian and Greek genocide were the systematic destruction, mass murder and expulsion of the Armenians, Assyrians and Greeks in the Ottoman Empire during World War I, spearheaded by the ruling Committee of Union and Progress (CUP).[23][24] The Alliance of Eight Nations (Austro-Hungarian Empire, French Republic, German Empire, Kingdom of Italy, Empire of Japan, Russian Empire, United Kingdom of Great Britain and Ireland and United States of America) formed in 1900 to invade the Qing China represented the club of great powers in the early 20th century. Rising nationalism and increasing national awareness were among the many causes of World War I (1914–1918), the first of two wars to involve many major world powers including Germany, France, Italy, Japan, Russia/USSR, the British Empire and the United States. At the time, it is said by many to be the "war to end all wars". The Arab Revolt of 1916 is an armed uprising against the Ottoman Empire done by the Arabs in agreement with the British and French empires. The revolt is led by Sharif Hussein bin Ali who is promised by Henry McMahon, the British High Commissioner in Egypt and the French government, that in exchange for fighting the Ottoman Empire, Sharif Hussein would gain control over all Arab lands under the Ottoman Empire. A promise the British and French did not honor.[25][26][27] During World War I, in the Russian Revolution of 1917, 300 years of Tsarist reign were ended and the Bolsheviks, under the leadership of Vladimir Lenin, established the world's first Communist state. The end of World War I saw the collapse of the central powers, the German Empire, the Austrian-Hungarian Empire, the Kingdom of Bulgaria, and the Ottoman Empire into several independent sovereign states throughout Central Europe, the Balkans, and the Middle East. After gaining political rights in the United States and much of Europe in the first part of the century, and with the advent of new birth control techniques, women became more independent throughout the century. Industrial warfare greatly increased in its scale and complexity during the first half of the 20th century. Notable developments included chemical warfare, the introduction of military aviation and the widespread use of submarines. The introduction of nuclear warfare in the mid-20th century marked the definite transition to modern warfare. The Revolutions of 1917–1923 occurred during and World War I inspired by the Russian Revolution which saw many political changes in Europe and in Asia. The Osage Murders of 1918-1931 were a series of killings of members of the Native American Osage Nation, who were the richest people per capita in the world at that time.[28] The 1921 Tulsa Race Massacre, is a racist anti black terrorist attack in the Greenwood District in Tulsa, Oklahoma, which is home to many successful and wealthy Black Americans. The attack is perpetrated by white residents and local white deputies. The perpetrators were armed by local government officials.[29][30] The 1923 Beer Hall Putsch failed coup d'état by Nazi Party leader Adolf Hitler. The Great Depression in the 1930s led to the rise of Fascism (especially Nazism) in Europe. Holodomor, man-made famine in Soviet Ukraine from 1932 to 1933 that killed millions of Ukrainians. Night of the Long Knives, purge that took place in Nazi Germany from 30 June to 2 July 1934. The 1934 to 1935 Long March, military retreat by the Chinese Red Army and Chinese Communist Party (CCP) from advancing Kuomintang forces. A violent civil war broke out in Spain in 1936 when General Francisco Franco rebelled against the Second Spanish Republic. Many consider this war as a testing battleground for World War II, as the fascist armies bombed some Spanish territories. Great Purge, political purge in the Soviet Union that took place from 1936 and 1938. The 1938 Kristallnacht, pogrom against Jews carried out by the Nazi Party's Sturmabteilung (SA) and Schutzstaffel (SS) paramilitary forces World War II (1939–1945) became the deadliest conflict in human history involving primarily the axis, Nazi Germany, Fascist Italy, and the Empire of Japan against the allies, China, France, the United Kingdom, the Soviet Union, and the United States. Many atrocities occurred, particularly the Holocaust killing approximately 11 million victims. It ended with the atomic bombings on Hiroshima and Nagasaki in Japan. The two world wars led to efforts to increase international cooperation, notably through the founding of the League of Nations after World War I, and its successor, the United Nations, after World War II. The creation of Israel in 1948, a Jewish state in the Middle East, at the end of the British Mandate for Palestine, fueled many conflicts between Israelis and Palestinians in addition to regional conflicts. These were also influenced by the vast oil fields in many of the other countries of the predominantly Arab region. In 1948 The Nakba is, according to several historians, a targeted ethnic cleansing campaign against Arabs in Palestine perpetrated by Jewish Militias under Plan Delta, a plan ordered by Ben-Gurion. The campaign utilized methods of intimidation, violent attacks, and the destruction of several Arab villages.[31][32][33] After the Soviet Union's involvement in World War II, communism became a major force in global politics, notably in Eastern Europe, China, Indochina and Cuba, where communist parties gained near-absolute power. Richard Nixon and Leonid Brezhnev aboard the USS Sequoia, June 19, 1973 The Cold War (1947–1991) involved an arms race and increasing competition between the two major players in the world: the Soviet Union and the United States. This competition included the development and improvement of nuclear weapons and space technology. This led to the proxy wars with the Western bloc, including wars in Korea (1950–1953) and Vietnam (1957–1975). The Soviet authorities caused the deaths of millions of their own citizens to eliminate domestic opposition.[34] More than 18 million people passed through the Gulag, with a further 6 million being exiled to remote areas of the Soviet Union.[35] Nationalist movements in the Indian subcontinent led to the independence and partition of Jawaharlal Nehru-led India and Muhammad Ali Jinnah-led Pakistan, although would lead to conflicts between the two nations such as border and territorial disputes. After a long period of civil wars and conflicts with western powers, China's last imperial dynasty ended in 1912. The resulting republic is replaced, after another civil war, by the communist People's Republic of China in 1949. At the end of the 20th century, though still ruled by a communist party, China's economic system had largely transformed to capitalism. Mahatma Gandhi's nonviolence and Indian independence movement against the British Empire influenced many political movements around the world, including the civil rights movement in the United States, and freedom movements in South Africa against apartheid challenging racial segregation The end of colonialism led to the independence of many African and Asian countries, from the two largest colonial empires in the world, the British and French colonial empires. During the Cold War, many of these aligned with the United States, the USSR, or China for defense. Hong Kong, under British administration from 1842 to 1997, is one of the original Four Asian Tigers. 1956 Poznań protests, the first of several massive protests against the communist government of the Polish People's Republic. Hungarian Revolution of 1956, attempted countrywide revolution against the government of the Hungarian People's Republic (1949–1989) and the policies caused by the government's subordination to the Soviet Union (USSR). Mao Zedong's radical policy of modernization leads to the Great Chinese Famine causing the death of tens of millions of Chinese peasants between 1959 and 1962. It is thought to be the largest famine in human history.[36] Cuban Missile Crisis, 13-day confrontation between the governments of the United States and the Soviet Union, when American deployments of nuclear missiles in Italy and Turkey were matched by Soviet deployments of nuclear missiles in Cuba. The Vietnam War caused two million deaths, changed the dynamics between the Eastern and Western Blocs, and altered global North-South relations.[37] The 1967 Six-Day War, fought between Israel and a coalition of Arab states, primarily Egypt, Syria, and Jordan. The 1968 Prague Spring, period of political liberalization and mass protest in the Czechoslovak Socialist Republic. 1970 Polish protests, protests were sparked by a sudden increase in the prices of food and other everyday items while wages remained stagnant. Yom Kippur War, fought from 6 to 25 October 1973 between Israel and a coalition of Arab states led by Egypt and Syria. Iranian revolution, series of events that culminated in the overthrow of the Pahlavi dynasty in 1979. The Soviet invasion of Afghanistan caused an estimated two million deaths and contributed to the dissolution of the Soviet Union along with complete political turmoil in Afghanistan[36] The 1981 Martial law in Poland, the government of the Polish People's Republic drastically restricted everyday life by introducing martial law and a military junta in an attempt to counter political opposition, in particular the Solidarity movement. The 1986 Chernobyl disaster, the worst nuclear disaster in history. The revolutions of 1989 released Eastern and Central Europe from Soviet control. Soon thereafter, the Soviet Union, Czechoslovakia, and Yugoslavia dissolved; the former having many states seceded and the latter violently over several years, into successor states, with many rife with ethnic nationalism. Meanwhile, East Germany and West Germany were reunified in 1990. The Tiananmen Square protests of 1989, culminating in the deaths of hundreds of civilian protesters and thousands of wounded, were a series of demonstrations in and near Tiananmen Square in Beijing, China. Led mainly by students and intellectuals, the protests occurred in a year that saw the collapse of a number of communist governments around the world. 1991 Soviet coup attempt, a failed attempt by hardliners of the Communist Party of the Soviet Union (CPSU) to forcibly seize control of the country from Mikhail Gorbachev, who is Soviet President and General Secretary of the CPSU at the time. Bosnian War, international armed conflict that took place in Bosnia and Herzegovina between 1992 and 1995. The 1994 Rwandan genocide, over a span of around 100 days, members of the Tutsi ethnic group, as well as some moderate Hutu and Twa, were systematically killed by Hutu militias. European integration began in earnest in the 1950s in France and Germany, and eventually led to the European Union, a political and economic union that comprised 15 countries at the end of the 20th century. Main article: 20th century in literature I and the Village, 1911, by Marc Chagall, a modern painter As the century began, Paris is the artistic capital of the world, where both French and foreign writers, composers and visual artists gathered. By the middle of the century New York City had become the artistic capital of the world. Theater, films, music and the media had a major influence on fashion and trends in all aspects of life. As many films and much music originate from the United States, American culture spread rapidly over the world. 1953 saw the coronation of Queen Elizabeth II, an iconic figure of the century. Visual culture became more dominant not only in films but in comics and television as well. During the century a new skilled understanding of narrativist imagery is developed. Computer games and internet surfing became new and popular form of entertainment during the last 25 years of the century. In literature, science fiction, fantasy (with well-developed fictional worlds, rich in detail), and alternative history fiction gained popularity. Detective fiction gained popularity in the interwar period. In the United States in 1961 Grove Press published Tropic of Cancer a novel by Henry Miller redefining pornography and censorship in publishing in America. Main article: 20th-century music Elvis Presley in 1956, a leading figure of rock and roll and rockabilly. The invention of music recording technologies such as the phonograph record, and dissemination technologies such as radio broadcasting, massively expanded the audience for music. Prior to the 20th century, music is generally only experienced in live performances. Many new genres of music were established during the 20th century. Igor Stravinsky revolutionized classical composition. In the 1920s, Arnold Schoenberg developed the twelve-tone technique, which became widely influential on 20th-century composers. In classical music, composition branched out into many completely new domains, including dodecaphony, aleatoric (chance) music, and minimalism. Tango is created in Argentina and became extremely popular in the rest of the Americas and Europe. Blues and jazz music became popularized during the 1910s, 1920s and 1930s in the United States. Bebop develops as a form of jazz in the 1940s. Country music develops in the 1920s and 1930s in the United States. Blues and country went on to influence rock and roll in the 1950s, which along with folk music, increased in popularity with the British Invasion of the mid-to-late 1960s. Rock soon branched into many different genres, including folk rock, heavy metal, punk rock, and alternative rock and became the dominant genre of popular music. This is challenged with the rise of hip hop in the 1980s and 1990s. Other genres such as house, techno, reggae, and soul all developed during the latter half of the century and went through various periods of popularity. Synthesizers began to be employed widely in music and crossed over into the mainstream with new wave music in the 1980s. Electronic instruments have been widely deployed in all manners of popular music and has led to the development of such genres as house, synth-pop, electronic dance music, and industrial. Charlie Chaplin in his 1921 film The Kid, with Jackie Coogan. See also: History of film Film as an artistic medium is created in the 20th century. The first modern movie theatre is established in Pittsburgh in 1905.[38] Hollywood developed as the center of American film production. While the first films were in black and white, technicolor is developed in the 1920s to allow for color films. Sound films were developed, with the first full-length feature film, The Jazz Singer, released in 1927. The Academy Awards were established in 1929. Animation is also developed in the 1920s, with the first full-length cel animated feature film Snow White and the Seven Dwarfs, released in 1937. Computer-generated imagery is developed in the 1980s, with the first full-length CGI-animated film Toy Story released in 1995. Julie Andrews, Harry Belafonte, Humphrey Bogart, Marlon Brando, James Cagney, Charlie Chaplin, Sean Connery, Tom Cruise, James Dean, Robert De Niro, Harrison Ford, Clark Gable, Cary Grant, Audrey Hepburn, Katharine Hepburn, Bruce Lee, Marilyn Monroe, Paul Newman, Jack Nicholson, Al Pacino, Sidney Poitier, Meryl Streep, Elizabeth Taylor, James Stewart, Jane Fonda and John Wayne are among the most popular Hollywood stars of the 20th century. Madhubala, Jean-Paul Belmondo, Karel Roden, Sean Connery, Marcello Mastroianni, Salah Zulfikar, Marlene Dietrich, Brigitte Bardot, Omar Sharif, Catherine Deneuve, Alain Delon, Soad Hosny, Fernanda Montenegro, Sophie Marceau, Fatima Rushdi, Amitabh Bachchan, Jean Gabin, Toshiro Mifune, Shoukry Sarhan, Lars Mikkelsen, Sophia Loren, Youssef Wahbi, Claudia Cardinale, Klaus Kinski, Gérard Depardieu, Max von Sydow, Faten Hamama, Rutger Hauer and Toni Servillo are among the most popular movie stars of the 20th century. Sergei Eisenstein, D. W. Griffith, Cecil B. DeMille, Frank Capra, Howard Hawks, John Ford, Orson Welles, Martin Scorsese, John Huston, Alfred Hitchcock, Akira Kurosawa, Spike Lee, Ingmar Bergman, Federico Fellini, Walt Disney, Stanley Kubrick, Steven Spielberg, Sergey Parajanov, Ridley Scott, Woody Allen, Quentin Tarantino, James Cameron, William Friedkin, Ezz El-Dine Zulficar and George Lucas are among the most important and popular filmmakers of the 20th century. In theater, sometimes referred to as Broadway in New York City, playwrights such as Eugene O'Neill, Samuel Beckett, Edward Albee, Arthur Miller and Tennessee Williams introduced innovative language and ideas to the idiom. In musical theater, figures such as Rodgers and Hammerstein, Lerner and Loewe, Mohammed Karim, and Irving Berlin had an enormous impact on both film and the culture in general. Modern dance is born in America as a 'rebellion' against centuries-old European ballet. Dancers and choreographers Alvin Ailey, Isadora Duncan, Vaslav Nijinsky, Ruth St. Denis, Mahmoud Reda, Martha Graham, José Limón, Doris Humphrey, Merce Cunningham, and Paul Taylor re-defined movement, struggling to bring it back to its 'natural' roots and along with Jazz, created a solely American art form. Alvin Ailey is credited with popularizing modern dance and revolutionizing African-American participation in 20th-century concert dance. His company gained the nickname "Cultural Ambassador to the World" because of its extensive international touring. Ailey's choreographic masterpiece Revelations is believed to be the best known and most often seen modern dance performance. See also: History of Television Ralph Baer's Magnavox Odyssey, the first video game console, released in 1972. Main article: History of video games Video games—due to the great technological steps forward in computing since the second post-war period—are one of the new forms of entertainment that emerged in the 20th century alongside films. While already conceptualized in the 1940s–50s, video games only emerged as an industry during the 1970s, and then exploded into social and cultural phenomena in the late 1970s and early 1980s with the golden age of arcade video games, with notable releases such as Taito's Space Invaders, Atari, Inc.'s Asteroids, Nintendo's Donkey Kong, Namco's Pac-Man and Galaga, Konami's Frogger, Capcom's 1942 and Sega's Zaxxon,[39] the worldwide success of Nintendo's Super Mario Bros.[40] and the release in the 1990s of Sony PlayStation console, the first one to break the record of 100 million units sold, with Gran Turismo being the system's best selling video game.[41] Video game design becomes a discipline. Some game designers in this century stand out for their work, such as Shigeru Miyamoto, Hideo Kojima, Sid Meier and Will Wright. The Empire State Building is an iconic building of the 1930s. Main article: 20th-century art The art world experienced the development of new styles and explorations such as fauvism, expressionism, Dadaism, cubism, de stijl, surrealism, abstract expressionism, color field, pop art, minimal art, lyrical abstraction, and conceptual art. The modern art movement revolutionized art and culture and set the stage for both Modernism and its counterpart postmodern art as well as other contemporary art practices. Art Nouveau began as a form of architecture and design but fell out of fashion after World War I. The style is dynamic and inventive but unsuited to the depression of the Great War. In Europe, modern architecture departed from the decorated styles of the Victorian era. Streamlined forms inspired by machines became commonplace, enabled by developments in building materials and technologies. Before World War II, many European architects moved to the United States, where modern architecture continued to develop. The automobile increased the mobility of people in the Western countries in the early-to-mid-century, and in many other places by the end of the 20th century. City design throughout most of the West became focused on transport via car. The popularity of sport increased considerably—both as an activity for all and as entertainment, particularly on television. The modern Olympic Games, first held in 1896, grew to include tens of thousands of athletes in dozens of sports. The FIFA World Cup is first held in 1930 and is held every four years after World War II. American League Baseball is formed in 1900 and in 1903, both National and American agreed to play in the first World Series with over 100,000 in attendance.[42] Boxing, also known as "Prize Fighting" became popular over this decade although bare-knuckle fighting is still popular. Main article: 20th century in science See also: Big Science The pioneer of computer science, Alan Turing Multiple new fields of mathematics were developed in the 20th century. In the first part of the 20th century, measure theory, functional analysis, and topology were established, and significant developments were made in fields such as abstract algebra and probability. The development of set theory and formal logic led to Gödel's incompleteness theorems. Later in the 20th century, the development of computers led to the establishment of a theory of computation.[43] Computationally-intense results include the study of fractals[44] and a proof of the four color theorem in 1976.[45] New areas of physics, like special relativity, general relativity, and quantum mechanics, were developed during the first half of the century. In the process, the internal structure of atoms came to be clearly understood, followed by the discovery of elementary particles. It is found that all the known forces can be traced to only four fundamental interactions. It is discovered further that two forces, electromagnetism and weak interaction, can be merged in the electroweak interaction, leaving only three different fundamental interactions. Discovery of nuclear reactions, in particular nuclear fusion, finally revealed the source of solar energy. Radiocarbon dating is invented, and became a powerful technique for determining the age of prehistoric animals and plants as well as historical objects. A much better understanding of the evolution of the universe is achieved, its age (about 13.8 billion years) is determined, and the Big Bang theory on its origin is proposed and generally accepted. The age of the Solar System, including Earth, is determined, and it turned out to be much older than believed earlier: more than 4 billion years, rather than the 20 million years suggested by Lord Kelvin in 1862.[46] The planets of the Solar System and their moons were closely observed via numerous space probes. Pluto is discovered in 1930 on the edge of the Solar System, although in the early 21st century, it is reclassified as a dwarf planet instead of a planet proper, leaving eight planets. No trace of life is discovered on any of the other planets orbiting the Sun (or elsewhere in the universe), although it remained undetermined whether some forms of primitive life might exist, or might have existed, somewhere in the Solar System. Extrasolar planets were observed for the first time. Wheat yields greatly increased from the Green Revolution in the world's least developed countries. Norman Borlaug fathered the Green Revolution, the set of research technology transfer initiatives occurring between 1950 and the late 1960s that increased agricultural production in parts of the world, beginning most markedly in the late 1960s, and is often credited with saving over a billion people worldwide from starvation. Genetics is unanimously accepted and significantly developed. The structure of DNA is determined in 1953 by James Watson,[47][48] Francis Crick,[47][48] Rosalind Franklin[48] and Maurice Wilkins,[47][48] following by developing techniques which allow to read DNA sequences and culminating in starting the Human Genome Project (not finished in the 20th century) and cloning the first mammal in 1996. The role of sexual reproduction in evolution is understood, and bacterial conjugation is discovered. The convergence of various sciences for the formulation of the modern evolutionary synthesis (produced between 1936 and 1947), providing a widely accepted account of evolution. A stamp commemorating Alexander Fleming. His discovery of penicillin changed the world of medicine by introducing the age of antibiotics. Placebo-controlled, randomized, blinded clinical trials became a powerful tool for testing new medicines. Antibiotics drastically reduced mortality from bacterial diseases. A vaccine is developed for polio, ending a worldwide epidemic. Effective vaccines were also developed for a number of other serious infectious diseases, including influenza, diphtheria, pertussis (whooping cough), tetanus, measles, mumps, rubella (German measles), chickenpox, hepatitis A, and hepatitis B. Epidemiology and vaccination led to the eradication of the smallpox virus in humans. X-rays became a powerful diagnostic tool for a wide spectrum of diseases, from bone fractures to cancer. In the 1960s, computerized tomography is invented. Other important diagnostic tools developed were sonography and magnetic resonance imaging. Development of vitamins virtually eliminated scurvy and other vitamin-deficiency diseases from industrialized societies. New psychiatric drugs were developed. These include antipsychotics for treating hallucinations and delusions, and antidepressants for treating depression. The role of tobacco smoking in the causation of cancer and other diseases is proven during the 1950s (see British Doctors Study). New methods for cancer treatment, including chemotherapy, radiation therapy, and immunotherapy, were developed. As a result, cancer could often be cured or placed in remission. The development of blood typing and blood banking made blood transfusion safe and widely available. The invention and development of immunosuppressive drugs and tissue typing made organ and tissue transplantation a clinical reality. New methods for heart surgery were developed, including pacemakers and artificial hearts. Cocaine and heroin were widely illegalized after being found to be addictive and destructive. Psychoactive drugs such as LSD and MDMA were discovered and subsequently prohibited in many countries. Prohibition of drugs caused a growth in the black market drug industry, and expanded enforcement led to a larger prison population in some countries.[49] Contraceptive drugs were developed, which reduced population growth rates in industrialized countries, as well as decreased the taboo of premarital sex throughout many western countries. The development of medical insulin during the 1920s helped raise the life expectancy of diabetics to three times of what it had been earlier. Vaccines, hygiene and clean water improved health and decreased mortality rates, especially among infants and the young. An influenza pandemic, Spanish Flu, killed anywhere from 17 to 100 million people between 1918 and 1919. A new viral disease, called the Human Immunodeficiency Virus, or HIV, arose in Africa and subsequently killed millions of people throughout the world. HIV leads to a syndrome called Acquired Immunodeficiency Syndrome, or AIDS. Treatments for HIV remained inaccessible to many people living with AIDS and HIV in developing countries, and a cure has yet to be discovered. Because of increased life spans, the prevalence of cancer, Alzheimer's disease, Parkinson's disease, and other diseases of old age increased slightly. Changes in food production, along with sedentary lifestyles due to labor-saving devices and the increase in home entertainment, contributed to an "epidemic" of obesity, at first in the rich countries, but by the end of the 20th century spreading to the developing world. Oil field in California, 1938. The first modern oil well is drilled in 1848 by Russian engineer F.N. Semyonov, on the Apsheron Peninsula north-east of Baku. Fossil fuels and nuclear power were the dominant forms of energy sources. Widespread use of petroleum in industry—both as a chemical precursor to plastics and as a fuel for the automobile and airplane—led to the geopolitical importance of petroleum resources. The Middle East, home to many of the world's oil deposits, became a center of geopolitical and military tension throughout the latter half of the century. (For example, oil is a factor in Japan's decision to go to war against the United States in 1941, and the oil cartel, OPEC, used an oil embargo of sorts in the wake of the Yom Kippur War in the 1970s). The increase in fossil fuel consumption also fueled a major scientific controversy over its effect on air pollution, global warming, and global climate change. Pesticides, herbicides and other toxic chemicals accumulated in the environment, including in the bodies of humans and other animals. Population growth and worldwide deforestation diminished the quality of the environment. In the last third of the century, concern about humankind's impact on the Earth's environment made environmentalism popular. In many countries, especially in Europe, the movement is channeled into politics through Green parties. Increasing awareness of global warming began in the 1980s, commencing decades of social and political debate. First flight of the Wright brothers' Wright Flyer on December 17, 1903, in Kitty Hawk, North Carolina; Orville piloting with Wilbur running at wingtip. One of the prominent traits of the 20th century is the dramatic growth of technology. Organized research and practice of science led to advancement in the fields of communication, electronics, engineering, travel, medicine, and war. Basic home appliances including ishing machines, clothes dryers, furnaces, exercise machines, dishwashers, refrigerators, freezers, electric stoves and vacuum cleaners became popular from the 1920s through the 1950s. Radios were popularized as a form of entertainment during the 1920s, followed by television during the 1950s. The first airplane, the Wright Flyer, is flown in 1903. With the engineering of the faster jet engine in the 1940s, mass air travel became commercially viable. The assembly line made mass production of the automobile viable. By the end of the 20th century, billions of people had automobiles for personal transportation. The combination of the automobile, motor boats and air travel allowed for unprecedented personal mobility. In western nations, motor vehicle accidents became the greatest cause of death for young people. However, expansion of divided highways reduced the death rate. The triode tube is invented, laying the foundation for amplification and switching technologies that led to silicon-based solid-state transistors, which revolutionized modern electronics. Air conditioning of buildings became common New materials, most notably stainless steel, Velcro, silicone, teflon, and plastics such as polystyrene, PVC, polyethylene, and nylon came into widespread use for many various applications. These materials typically have tremendous performance gains in strength, temperature, chemical resistance, or mechanical properties over those known prior to the 20th century. Aluminum became an inexpensive metal and became second only to iron in use. Thousands of chemicals were developed for industrial processing and home use. Digital computers came into use, they greatly increased productivity and paved the way for the Internet, which revolutionized global communication and information sharing. Photo of American astronaut Buzz Aldrin during the first moonwalk in 1969, taken by Neil Armstrong. The relatively young aerospace engineering industries rapidly grew in the 66 years after the Wright brothers' first flight. The Space Race between the United States and the Soviet Union gave a peaceful outlet to the political and military tensions of the Cold War, leading to the first human spaceflight with the Soviet Union's Vostok 1 mission in 1961, and man's first landing on another world—the Moon—with America's Apollo 11 mission in 1969. Later, the first space station is launched by the Soviet space program. The United States developed the first reusable spacecraft system with the Space Shuttle program, first launched in 1981. As the century ended, a permanent crewed presence in space is being founded with the ongoing construction of the International Space Station. In addition to human spaceflight, uncrewed space probes became a practical and relatively inexpensive form of exploration. The first orbiting space probe, Sputnik 1, is launched by the Soviet Union in 1957. Over time, a massive system of artificial satellites is placed into orbit around Earth. These satellites greatly advanced navigation, communications, military intelligence, geology, climate, and numerous other fields. Also, by the end of the 20th century, uncrewed probes had visited or flown by the Moon, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, and various asteroids and comets, with Voyager 1 being the farthest manufactured object from Earth at 23,5 billion kilometers away from Earth as of 6 September 2022, and together with Voyager 2 both carrying The Voyager Golden Record containing sounds, music and greetings in 55 languages as well as 116 images of nature, human advancement, space and society. The Hubble Space Telescope, launched in 1990, greatly expanded our understanding of the Universe and brought brilliant images to TV and computer screens around the world. The Global Positioning System, a series of satellites that allow land-based receivers to determine their exact location, is developed and deployed.[50] See also: List of 20th-century religious leaders 1900s – A number of related revival movements mark the start of Pentecostalism. 1904 – Aleister Crowley dictates The Book of the Law, the foundational text of Thelema. 1922 – The Soviet Union establishes a doctrine of state atheism. 1924 – Mustafa Kemal Pasha abolishes the Islamic Caliphate, in favor of secularism. This marks the last widely recognized Muslim Caliphate. 1930 – Wallace Fard Muhammad founds the Nation of Islam. The Seventh Lambeth Conference allows for the possibility of birth control within Anglicanism, the first example of a modern Christian church supporting such a position.[51] 1940s – Wicca is formalized by Gerald Gardner and Doreen Valiente. 1950s – Sayyid Qutb articulates Qutbism, a violent variety of Islamism that would later become foundational to jihadist ideology. Maharishi Mahesh Yogi begins to teach Transcendental Meditation. 1953 – L. Ron Hubbard founds the Church of Scientology, which has a unique cosmology based on science fiction and his older system of Dianetics. 1956 – B. R. Ambedkar launches the Dalit Buddhist movement. 1960 – The charismatic movement starts within Anglicanism, quickly spreading to other Christian sects. 1962–65 – The Second Vatican Council is held, resulting in significant changes in the Catholic Church. 1970s – New Age beliefs and practices are popularized. 1979 – In Shia Islam, the Islamic Revolution establishes a theocratic state within Iran. 1988 – Al-Qaeda, a network of Islamic extremists, is founded among Arab members of the Afghan mujahideen. It engages in a number of terror attacks throughout the 1990s, leading up to the September 11 attacks in 2001. 1999 – Falun Gong, a Chinese new religious movement dating to the early 1990s, begins to be persecuted by the Chinese government. The Great Depression is a worldwide economic slowdown that lasted throughout the early 1930s. The Soviet Union implemented a series of five-year plans for industrialization and economic development. Most countries abandoned the gold standard for their currency. The Bretton Woods system involved currencies being pegged to the United States dollar; after the system collapsed in 1971 most major currencies had a floating exchange rate. Economics is divided into two general economic schools: Keynesian and neoclassical The 1970s energy crisis occurred when the Western world, particularly the United States, Canada, Western Europe, Australia, and New Zealand, faced substantial petroleum shortages as well as elevated prices. The two worst crises of this period were the 1973 oil crisis and the 1979 energy crisis, when, respectively, the Yom Kippur War and the Iranian Revolution triggered interruptions in Middle Eastern oil exports. Modern history portal 19th Century 21st Century 20th-century inventions Death rates in the 20th century Infectious disease in the 20th century Modern art Short twentieth century Timelines of modern history List of 20th-century women artists List of notable 20th-century writers List of battles 1901–2000 List of stories set in a future now in the past

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