Limnology: Lecture 1

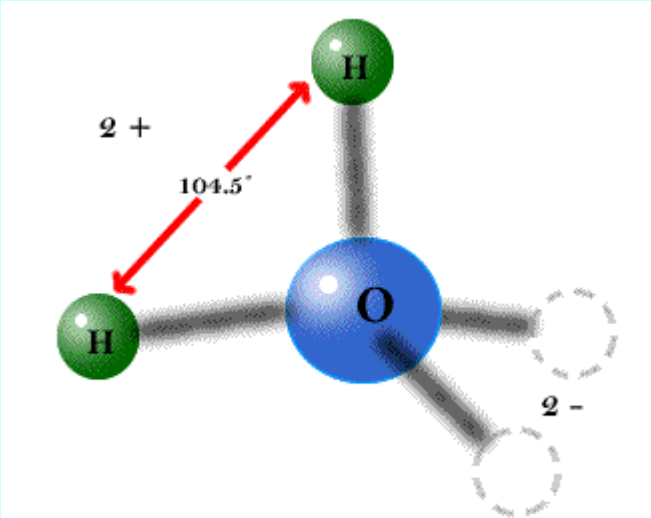
Physical Limnology: Properties of Water

I. Introduction

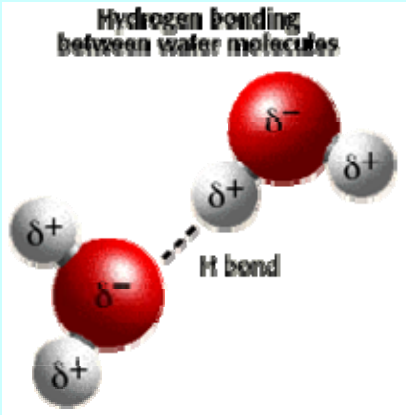
- A. Required by all living organisms
- B. Three major properties have major consequences
  - 1. Thermal-density properties
  - 2. High specific heat
  - 3. Liquid-solid characteristics

II. Molecular Structure - Basis of Properties

- A. At equilibrium - H2O molecule forms isosceles triangle with obtuse angle of 104.5° at oxygen atom
  - 1. Bond length (O-H) is 0.96 x 10-8 cm (0.96 Angstrom)
  - 2. Continual state of vibration
  - 3. Valences of approximately 56% of all molecules are balanced
  - 4. Several ionized states
    - a. H3O+ (hydronium cation)
    - b. OH- (hydroxyl anion)
    - c. H4O++
    - d. O=
- B. Weak Coulombic characteristics of hydrogen bonded to weakly electronegative oxygen
  - 1. Both ionized and covalent states occur
  - 2. Water is almost the only known compound that exhibits these characteristics



Ball and stick model of water.



III. Density Relationships

(See Figure 1.1)

- A. Specific gravity - ratio of the mass of a substance to the mass of an equal volume of a reference substance (usually water)
  - 1. Specific gravity of pure ice at 0°C - 0.91680 (g/ml)
  - 2. Specific gravity of water at 0°C - 0.99987 (g/ml)
  - 3. From 0°C, specific gravity of water increases to a max of 1.0000 g/ml at 3.98°C and then decreases above this temperature
- B. Density per degree lowering - the difference in density between water at a given temperature and water at a temperature 1°C lower
  - 1. Physical work is required to mix fluids of different density and work is proportional to difference in density
  - 2. Work required to mix water between 29°C and 30°C is 40 times greater than work required mixing water between 4°C and 5°C (24°C & 25°C - 30X)

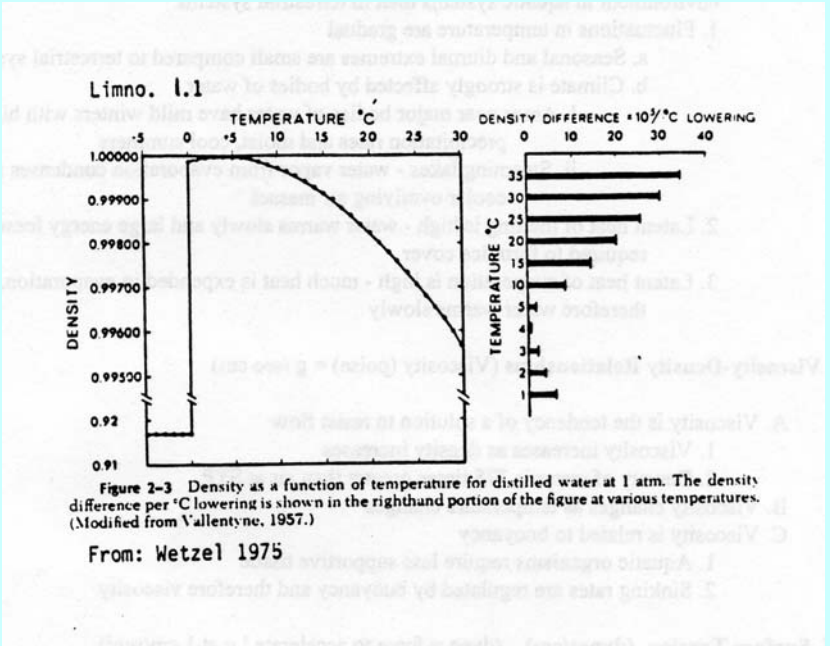


Figure 2-3 Density as a function of temperature for distilled water at 1 atm. The density difference per °C lowering is shown in the righthand portion of the figure at various temperatures. (Modified from Vallentyne, 1957.)

III. Density Relationships
(Continued)

- C. Effect of salinity on density
  - 1. Density increases as concentration of dissolved salts (salinity) increases
    - a. Increase is approximately linear
    - b. Salinity of lakes is generally in the range of 0.01 - 1.0 g/l
      - i. Range is most commonly 0.01 - 0.5 g/l
      - ii. Saline lakes can exceed 60 g/l
      - iii. Salinity of seawater is ~35 g/l
  - 2. Temperature of maximum density decreases as salinity increases
    - a. Rate of 0.2°C decrease for each g/l
    - b. Maximum density of seawater is at -3.52°C
- D. Effect of Pressure
  - 1. Pressure can compress water and lower temperature of maximum density
  - 2. Pressure increases by 1 atmosphere per 10 m of depth
  - 3. Temperature of maximum density decreases 0.1°C/100 m of depth

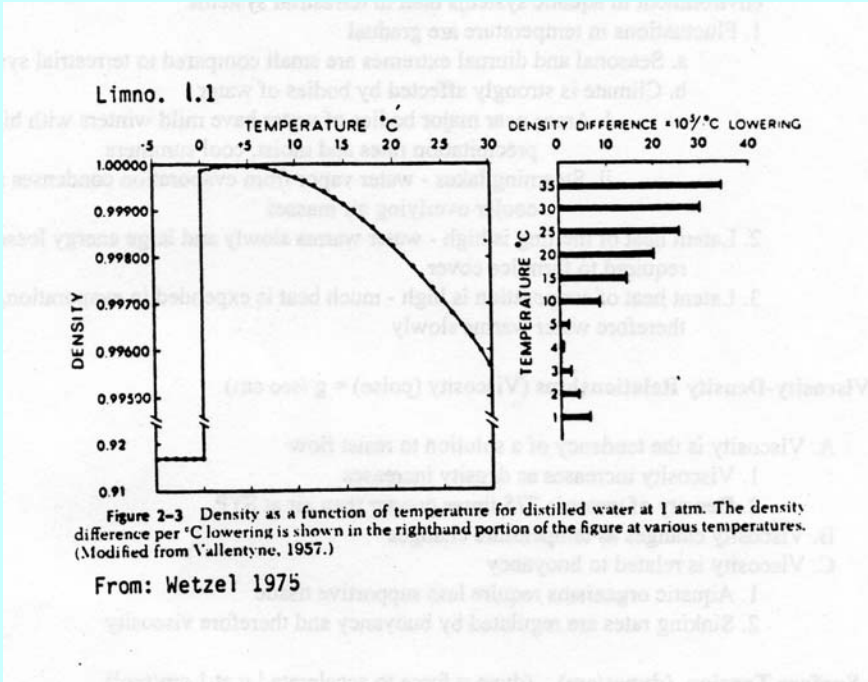


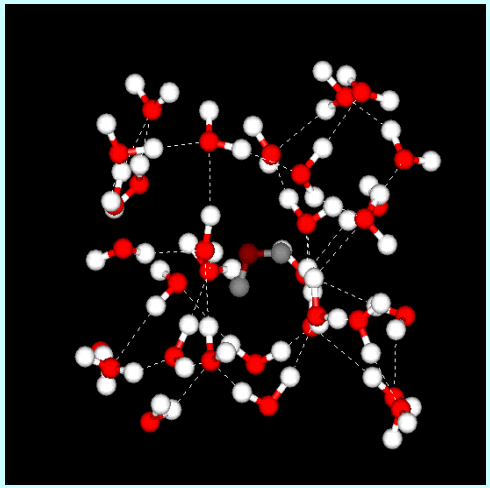
Figure 2-3 Density as a function of temperature for distilled water at 1 atm. The density difference per °C lowering is shown in the righthand portion of the figure at various temperatures. (Modified from Vallentyne, 1957.)

From: Wetzel 1975

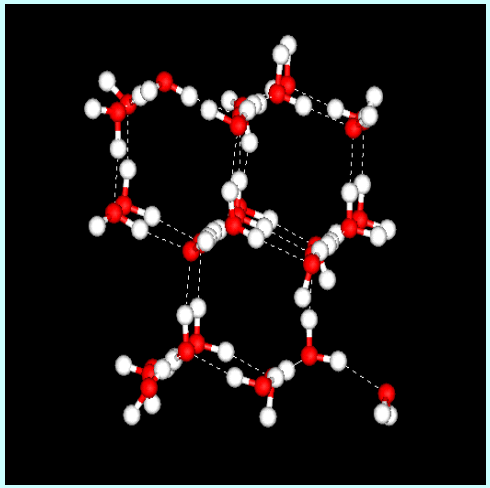
IV. Structure of Ice

(See Figure 1.2)

- A. Each molecule is H-bonded to nearest four neighbors
  - 1. Every oxygen atom is the center of a tetrahedron formed by four oxygen atoms
  - 2. O-H bonds are directed toward electrons of adjacent oxygen molecule
  - 3. Its lone pairs of electrons are directed toward O-H bonds of adjacent molecules
  - 4. Results in open lattice with both perpendicular and parallel voids
  - 5. Voids allow ice to float on water (lower density)
- B. Vibrational Energy
  - 1. Ice molecules vibrate (translational and reorientation movement) at a rate of ~106 movements/sec at 0°C
  - 2. Water at 0°C vibrates at ~1012 movements/sec
  - 3. Rate of vibration increases as temperature increases and results in decreasing viscosity
  - 4. As water melts, H-bonds are disrupted and water fills the voids and density increases up to 3.98oC
  - 5. Above 3.98°C, vibrations continue to increase and the distance between bonds increases and density decreases



Structure of Water



Structure of Ice

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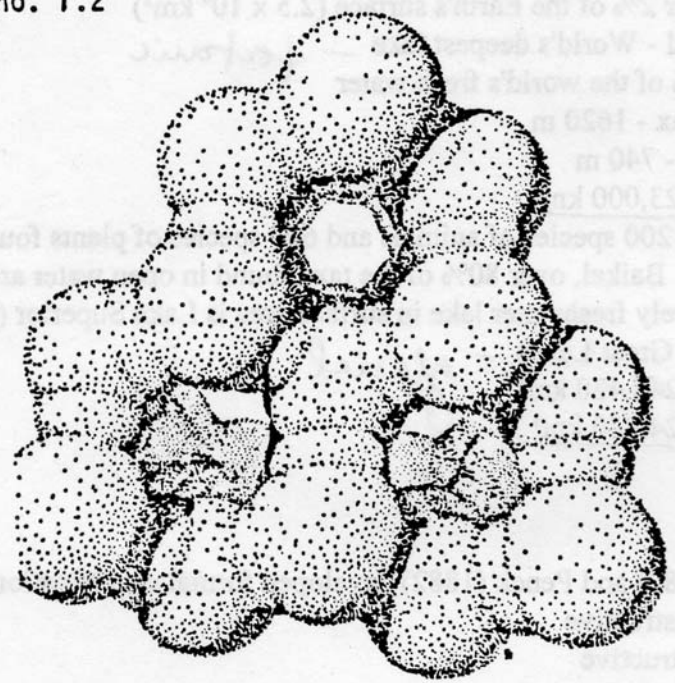

Figure 2–2 A diagrammatic representation of an ice crystal showing the van der Waals radii of the atoms and open voids between the aggregated molecules. (From Pimental, G. C., and McClellan, A. L.: The Hydrogen Bond. San Francisco, W. H. Freeman and Co., copyright © 1960.)

From: Wetzel 1975

V. Specific Heat (cal/gram)

- A. Specific heat is the amount of heat in calories that is required to raise the temperature 1°C of a unit mass (usually 1 gram) of a substance
  - 1. Specific heat of water is 1.0 cal/g - very high
  - 2. Few substances have a higher specific heat
    - a. Liquid ammonia - 1.23 cal/g
    - b. Liquid hydrogen - 3.4 cal/g
  - 3. Most substances have much lower specific heats
    - a. Rocks or Al (e.g. engine block) = 0.2 cal/g
    - b. Tungsten = 0.03 cal/g
- B. Water also has a high latent heat of evaporation - (also called heat of vaporization) heat energy required to evaporate a unit mass of liquid at a constant temperature
  - 1. Latent heat of evaporation of water - 540 cal/g
  - 2. Latent heat of melting - 79.72 cal/g
  - 3. Latent heat of sublimation - 679 cal/g

V. Specific Heat (cal/gram) (Continued)

- C. These heat characteristics are a function of the heat energy required to disrupt hydrogen bonding
- D. Heat-requiring and heat-retaining properties of water provide a much more stable environment in aquatic systems than in terrestrial systems
  - 1. Fluctuations in temperature are gradual
    - a. Seasonal and diurnal extremes are small compared to terrestrial systems
    - b. Climate is strongly affected by bodies of water
      - i. Areas near major bodies of water have mild winters with higher precipitation rates and moist, cool summers
      - ii. Steaming lakes - water vapor from evaporation condenses in cooler overlying air masses
  - 2. Latent heat of melting is high - water warms slowly and large energy losses are required to form ice cover
  - 3. Latent heat of evaporation is high - much heat is expended in evaporation, therefore, water warms slowly

VI. Viscosity-Density Relationships

(Viscosity (poise) = g /sec cm)

- A. Viscosity is the tendency of a solution to resist flow
  - 1. Viscosity increases as density increases
  - 2. Density of water is 775 times greater than air at STP
- B. Viscosity changes as temperature changes
- C. Viscosity is related to buoyancy
  - 1. Aquatic organisms require less supportive tissue
  - 2. Sinking rates are regulated by buoyancy and therefore viscosity

VII. Surface Tension (dynes/cm)

(dyne = force to accelerate 1 g at 1 cm/sec2)

- A. Bonding properties are disrupted at the air-water interface
  - 1. Molecular attractions are directed inward toward liquid phase
  - 2. Surface tension of water is higher than that for any other liquid except mercury
- B. Surface tension decreases with increasing temperature
- C. Surface tension increases slightly with dissolved salts
- D. Surface tension is greatly reduced by the addition of organic compounds