SEAWATER 101

Seawater's Amazing Physical and Chemical Properties

Introductory Oceanography

Ray Rector - Instructor

The Nature of Seawater

Topics To Be Covered

- Elements of Water
- Chemical Bonding
- The Water Molecule
- Hydrogen Bonding
- Thermal Properties
- Water's Affect on Climate
- Light and Sound in Water
- Seawater Temperature, Salinity, and Density Profile
- Seawater Salinity
- Seawater pH

Physical Properties of Water's

Key Concepts

1) Water is a strongly polar compound made up of 2 hydrogen atoms covalently bonded to 1 oxygen atom

2) Water exists in all three physical states on Earth

3) Water's amazing physical and chemical properties are mainly attributed to it's relatively strong inter-molecule hydrogen bonds

4) The Earth's blanket of liquid water and ice act as a great global climate moderator – thanks to its unique thermal properties

   a) High heat capacity b) High latent heats

5) Seawater density is controlled by 1) temperature and 2) salinity

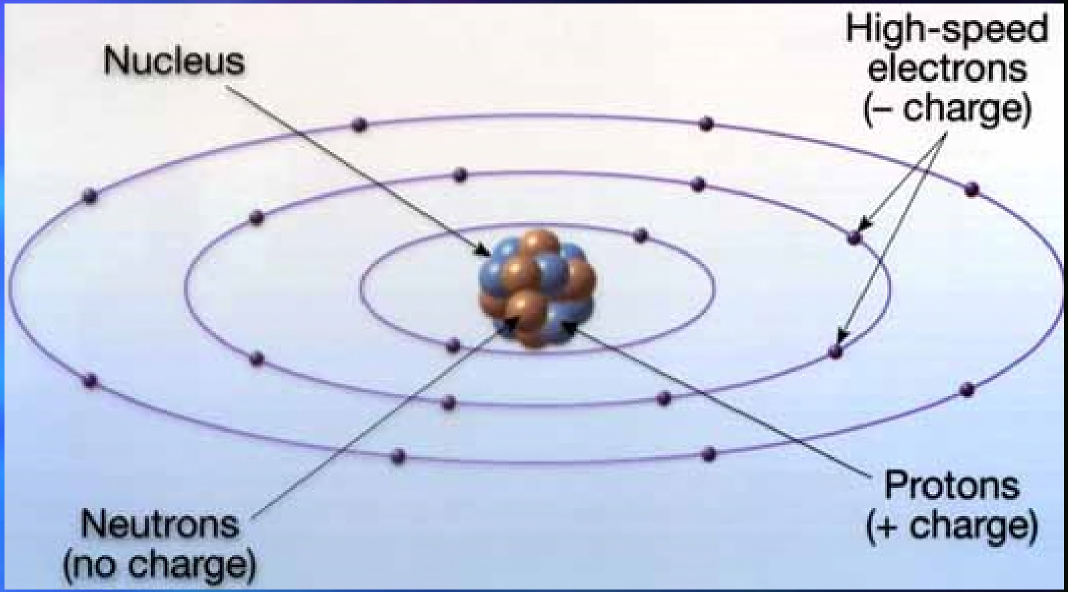
6) The ocean's water column is density stratified into 3 horizontal layers: surface zone, pycnocline, and deep zone

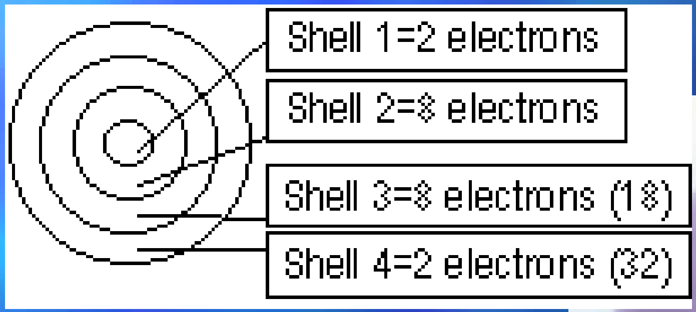
Structure of Atoms

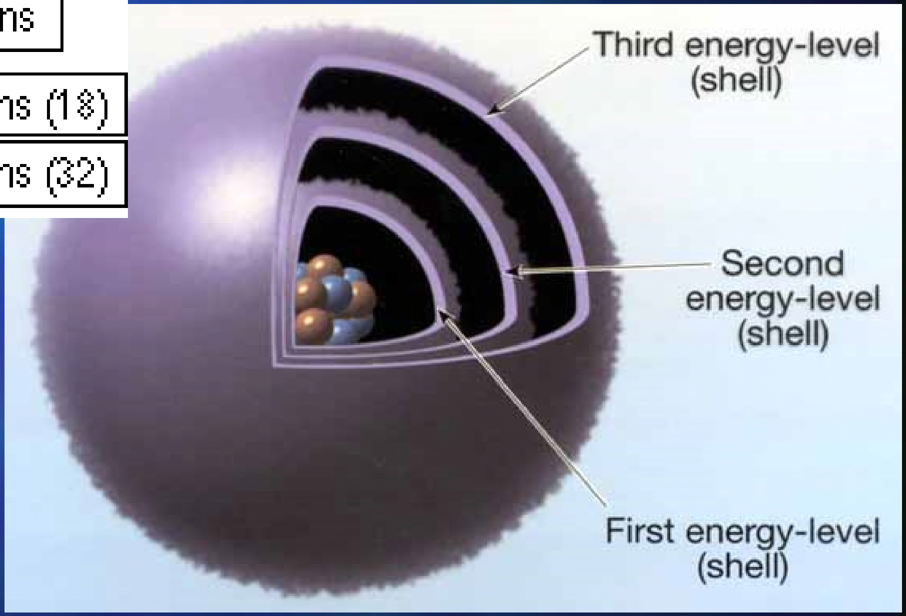
Three Major Components

- ✓ Protons
- ✓ Neutrons
- ✓ Electrons

Nucleus







Electron Energy Shells

✓Elemental atoms have an equal numbers of (+) charged protons and (–) charged electrons

✓Electrons are grouped into energy shells

✓Atoms are 99.9% empty space

Periodic Table of Elements

Group number

s-block elements | p-block elements | d-block elements | f-block elements

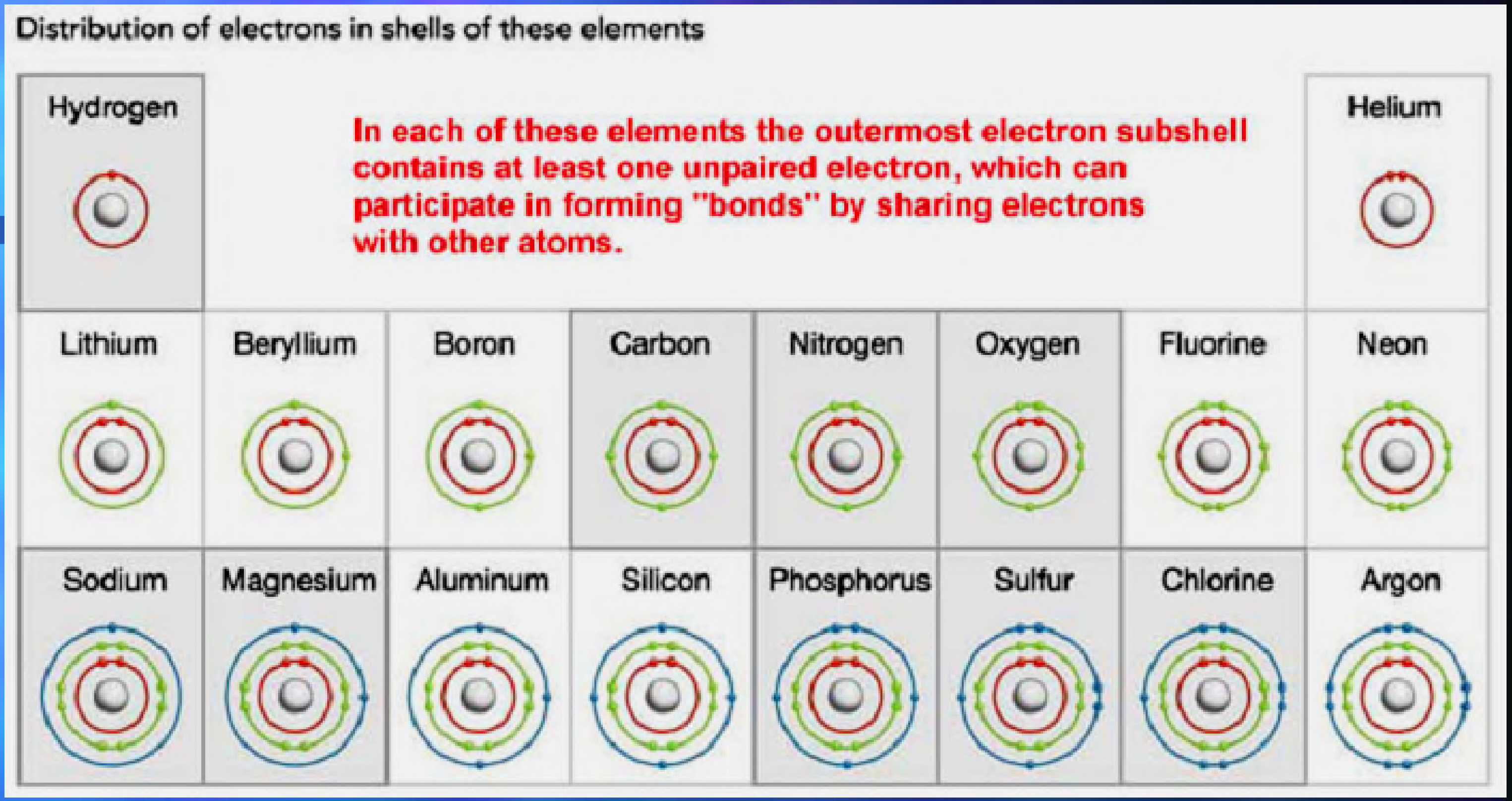
Periods	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 **H** $1s^1$																	2 **He** $1s^2$
2	3 **Li** $2s^1$	4 **Be** $2s^2$											5 **B** $2s^22p^1$	6 **C** $2s^22p^2$	7 **N** $2s^22p^3$	8 **O** $2s^22p^4$	9 **F** $2s^22p^5$	10 **Ne** $2s^22p^6$
3	11 **Na** $3s^1$	12 **Mg** $3s^2$											13 **Al** $3s^23p^1$	14 **Si** $3s^23p^2$	15 **P** $3s^23p^3$	16 **S** $3s^23p^4$	17 **Cl** $3s^23p^5$	18 **Ar** $3s^23p^6$
4	19 **K** $4s^1$	20 **Ca** $4s^2$	21 **Sc** $3d^14s^2$	22 **Ti** $3d^24s^2$	23 **V** $3d^34s^2$	24 **Cr** $3d^54s^1$	25 **Mn** $3d^54s^2$	26 **Fe** $3d^64s^2$	27 **Co** $3d^74s^2$	28 **Ni** $3d^84s^2$	29 **Cu** $3d^{10}4s^1$	30 **Zn** $3d^{10}4s^2$	31 **Ga** $4s^24p^1$	32 **Ge** $4s^24p^2$	33 **As** $4s^24p^3$	34 **Se** $4s^24p^4$	35 **Br** $4s^24p^5$	36 **Kr** $4s^24p^6$
5	37 **Rb** $5s^1$	38 **Sr** $5s^2$	39 **Y** $4d^15s^2$	40 **Zr** $4d^25s^2$	41 **Nb** $4d^45s^1$	42 **Mo** $4d^55s^1$	43 **Tc** $4d^55s^2$	44 **Ru** $4d^75s^1$	45 **Rh** $4d^85s^1$	46 **Pd** $4d^{10}$	47 **Ag** $4d^{10}5s^1$	48 **Cd** $4d^{10}5s^2$	49 **In** $5s^25p^1$	50 **Sn** $5s^25p^2$	51 **Sb** $5s^25p^3$	52 **Te** $5s^25p^4$	53 **I** $5s^25p^5$	54 **Xe** $5s^25p^6$
6	55 **Cs** $6s^1$	56 **Ba** $6s^2$	57 ***La** $5d^16s^2$	72 **Hf** $5d^26s^2$	73 **Ta** $5d^36s^2$	74 **W** $5d^46s^2$	75 **Re** $5d^56s^2$	76 **Os** $5d^66s^2$	77 **Ir** $5d^76s^2$	78 **Pt** $5d^96s^1$	79 **Au** $5d^{10}6s^1$	80 **Hg** $5d^{10}6s^2$	81 **Tl** $6s^26p^1$	82 **Pb** $6s^26p^2$	83 **Bi** $6s^26p^3$	84 **Po** $6s^26p^4$	85 **At** $6s^26p^5$	86 **Rn** $6s^26p^6$
7	87 **Fr** $7s^1$	88 **Ra** $7s^2$	89 **†Ac** $6d^17s^2$	104 **Rf** $6d^27s^2$	105 **Db** $6d^37s^2$	106 **Sg** $6d^47s^2$	107 **Bh**	108 **Hs**	109 **Mt**	110 (271.15)	111 (272.15)	112 (277)		114 (285)		116 (289)		

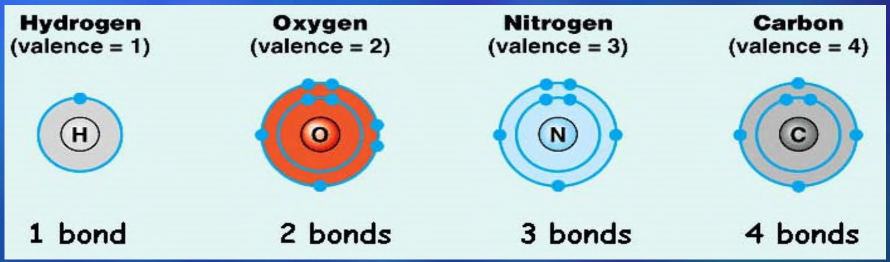
Lanthanides	58 **Ce** $4f^26s^2$	59 **Pr** $4f^36s^2$	60 **Nd** $4f^46s^2$	61 **Pm** $4f^56s^2$	62 **Sm** $4f^66s^2$	63 **Eu** $4f^76s^2$	64 **Gd** $4f^75d^16s^2$	65 **Tb** $4f^96s^2$	66 **Dy** $4f^{10}6s^2$	67 **Ho** $4f^{11}6s^2$	68 **Er** $4f^{12}6s^2$	69 **Tm** $4f^{13}6s^2$	70 **Yb** $4f^{14}6s^2$	71 **Lu** $4f^{14}5d^16s^2$
Actinides	90 **Th** $6d^27s^2$	91 **Pa** $5f^26d^17s^2$	92 **U** $5f^36d^17s^2$	93 **Np** $5f^46d^17s^2$	94 **Pu** $5f^67s^2$	95 **Am** $5f^77s^2$	96 **Cm** $5f^76d^17s^2$	97 **Bk** $5f^97s^2$	98 **Cf** $5f^{10}7s^2$	99 **Es** $5f^{11}7s^2$	100 **Fm** $5f^{12}7s^2$	101 **Md** $5f^{13}7s^2$	102 **No** $5f^{14}7s^2$	103 **Lr** $5f^{14}6d^17s^2$

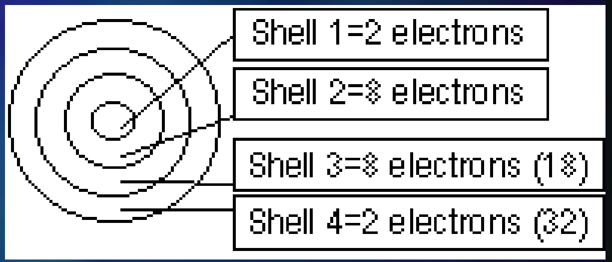
- ✓Elements are arranged in columns according to the number of valence electrons in the atom’s outer shell
- ✓Elements are arranged in rows according to the number of electron energy levels (shells) and their mass

Electrons in Outermost Shell

✓All elements - except for the far right column of noble gasses – have unpaired elements in their outer shell, which makes them chemically reactive with other atoms and elements that also have unpaired electrons.







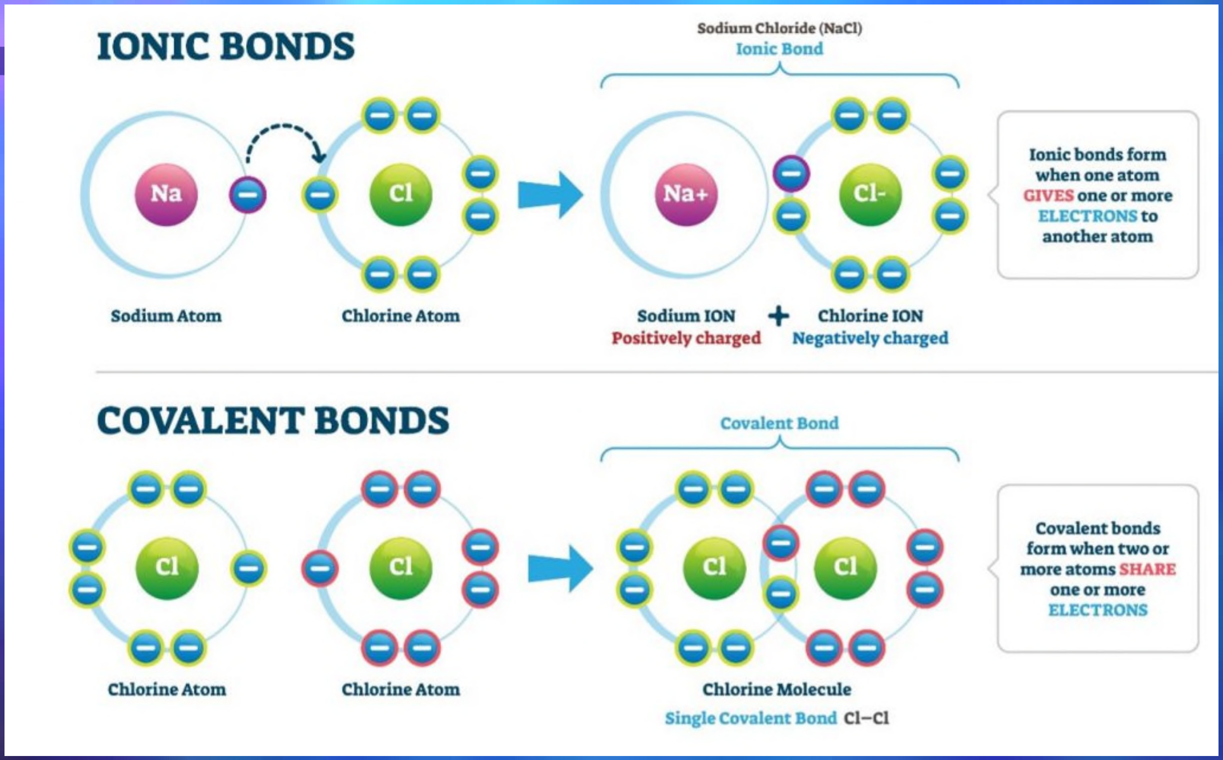
✓Elements on the left side of the periodic table have only one or two electrons in their outer shell (nearly empty)

✓ Elements on the right side of the table (not counting the noble gasses) have six or seven electrons in their outer shell (nearly full)

Types of Chemical Bonding

Bonding Between Atoms and Molecules

https://www.youtube.com/watch?v=eVdL-ipUa1Y

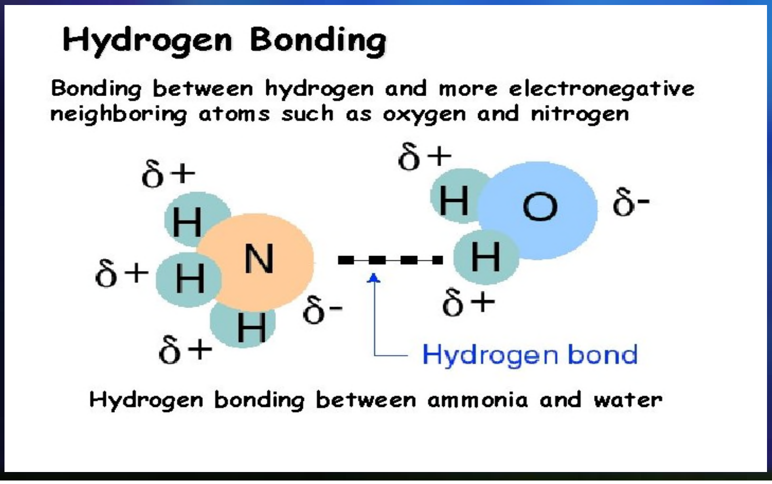


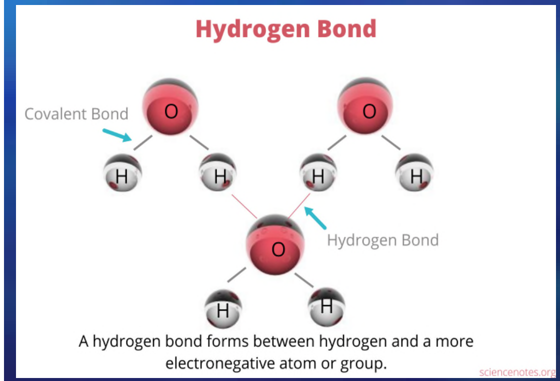
Ionic Bonding

- ✓ Electrostatic bonding
- ✓ Relatively moderate bond
- ✓ Bond within molecule

Covalent Bonding

- ✓ Electron sharing bonding
- ✓ Relatively strong bond
- ✓ Bond within molecule





Hydrogen Bonding

- ✓ Electrostatic bonding
- ✓ Relatively weak bond
- ✓ Bond between molecules

Water – Chemical Bonds in H_2O

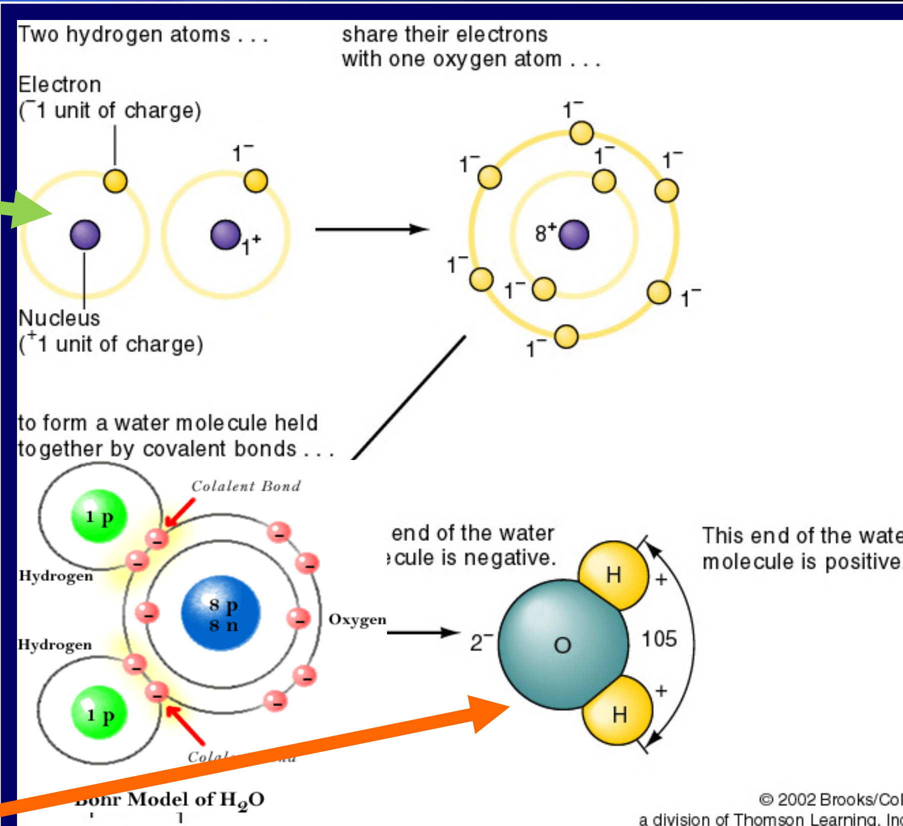
1) Two hydrogen atoms each share an electron with the same single oxygen atom with two covalent bonds

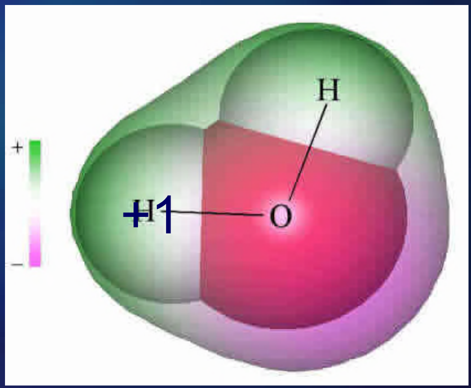
2) Mutual sharing of electrons completes the electron shell of all three atoms

3) Resultant covalent bonds are very strong within a water molecule

4) Water molecule has 105 degree bend

5) H2O charged at ends: 1+ at H's and 2- at O





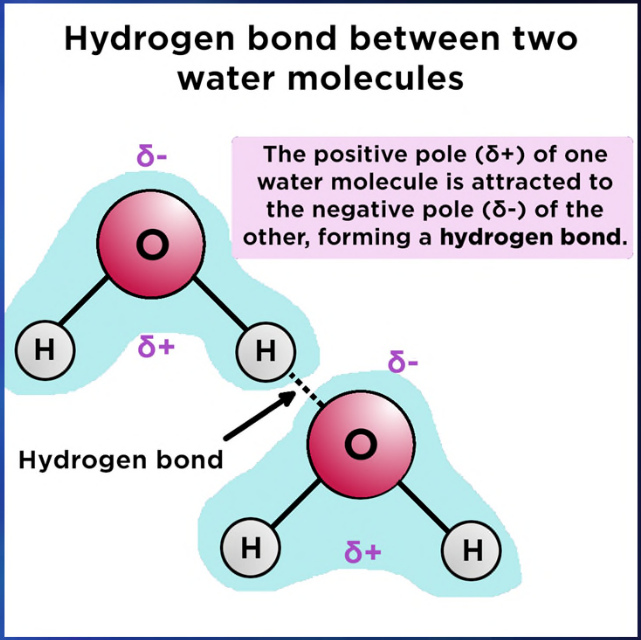
+1

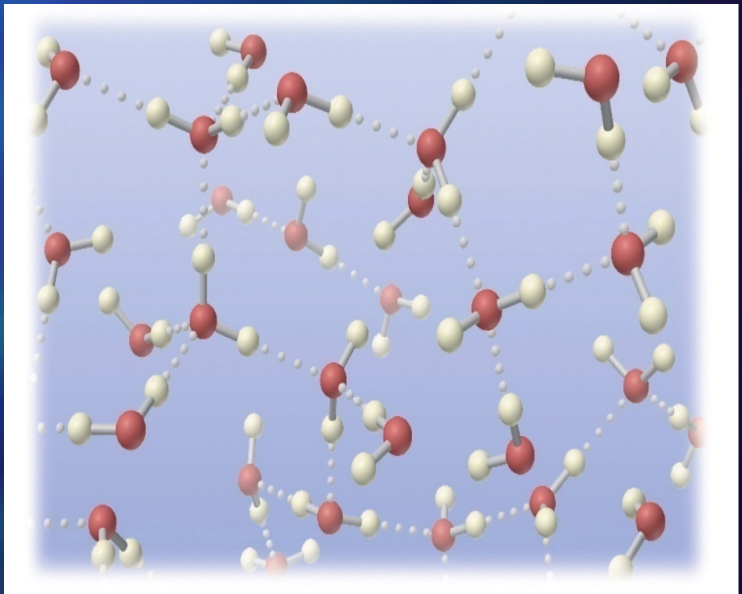
-2

Water's Hydrogen Bonds

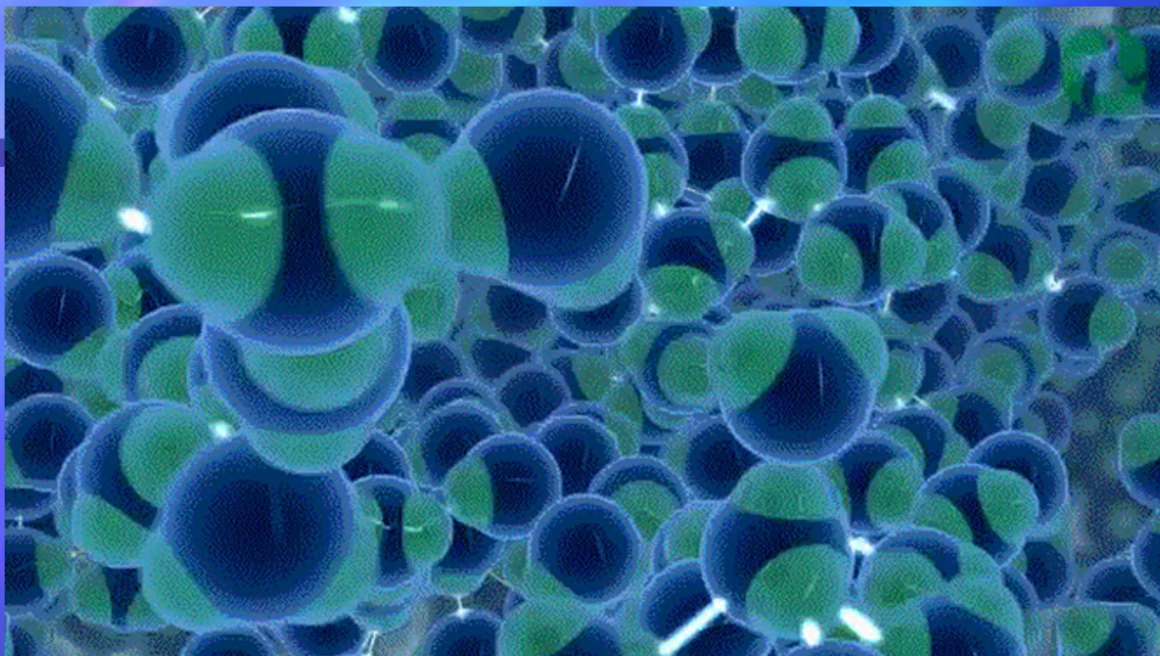
Key Concepts

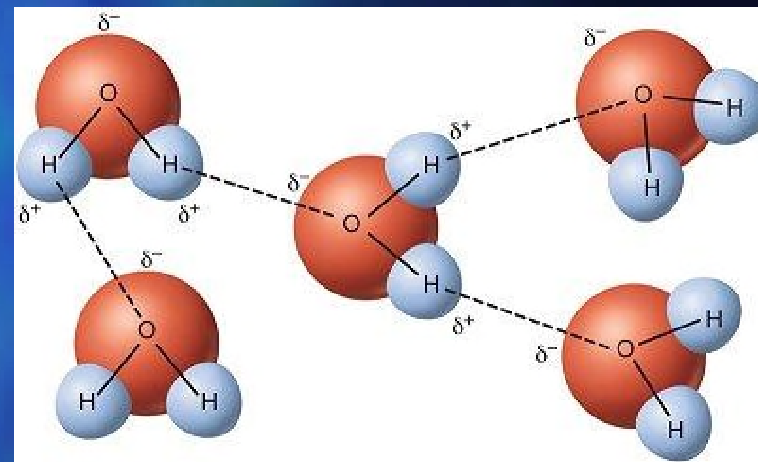
- Water is an electro-statically *polar* molecule made up of 2 hydrogen atoms – each covalently bonded to the central oxygen atom
- The region around the hydrogen ends of the water molecule are positively-charged; the region around the oxygen atom is negatively charged
- Positively charged hydrogen sides of one water molecule attracted to negatively-charged oxygen side of another water molecule and vice versa. This happens between all water molecules within a quantity of water – either in liquid or solid form
- Many of water's amazing properties are attributed to the polar electro-static bonding ***between*** water molecules - termed "Hydrogen bonds"





Hydrogen Bonding – Water's "Magic"





Hydrogen Bonding has a Strong Influence on Water's Nature

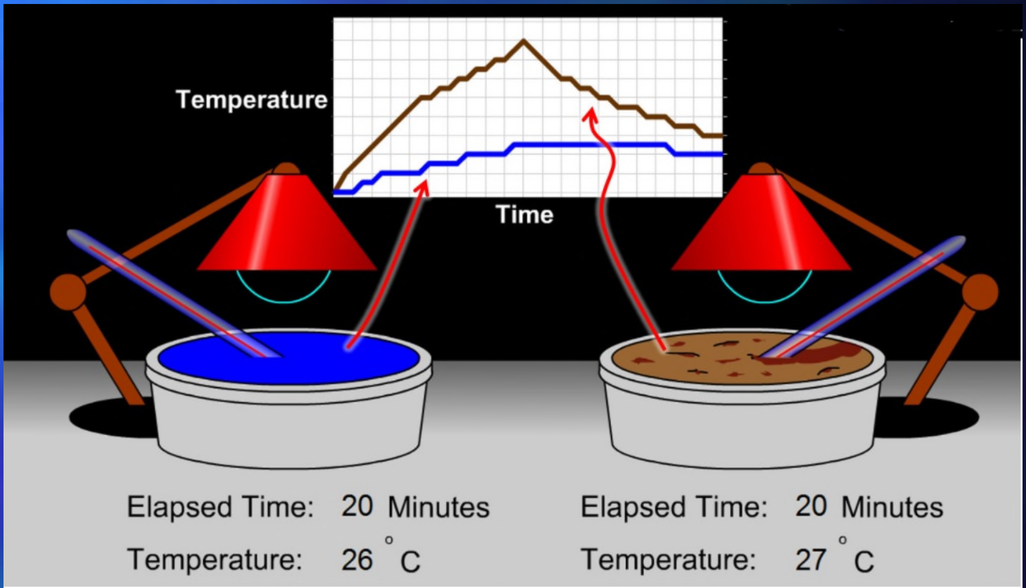
- ✓ Higher Heat Capacity
- ✓ Higher Viscosity
- ✓ Higher Boiling and Freezing Points
- ✓ Larger Latent Heats of Fusion and Vaporization
- ✓ Strong dissolving power = good solvent

Heat Capacity - Important Thermal Property of Water

- Heat Capacity – Defined: Measure of heat required to raise the temperature of 1 gram of a substance by 1 degree Celsius
- Water has a very high heat capacity – it can absorb (or release) large amounts of heat without changing much in temperature

Table 6.1 Heat Capacity of Common Substances

Substance	Heat Capacity[a] in calories/gram/ C
Silver	0.06
Granite	0.20
Aluminum	0.22
Alcohol (ethyl)	0.30
Gasoline	0.50
Acetone	0.51
Pure water	**1.00**
Ammonia (liquid)	1.13



Temperature Experiment - Heating and Cooling of Water and Sand

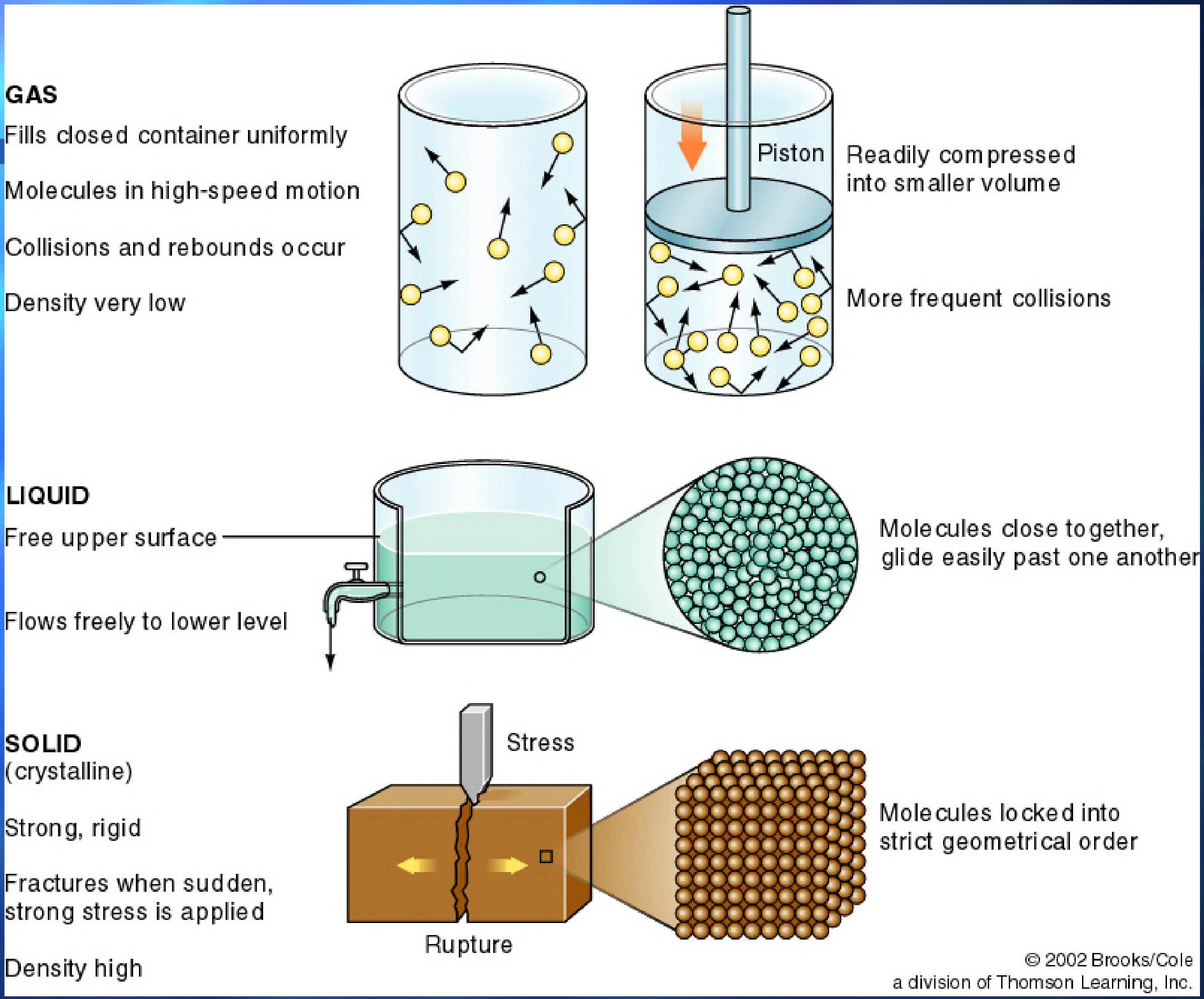
- Water has very higher than most other common substances, like rock and sediment
- Why does beach sand get so hot and the ocean stays cool on a hot day?

Three Physical States or Phases of Water

Gas

Liquid

Solid



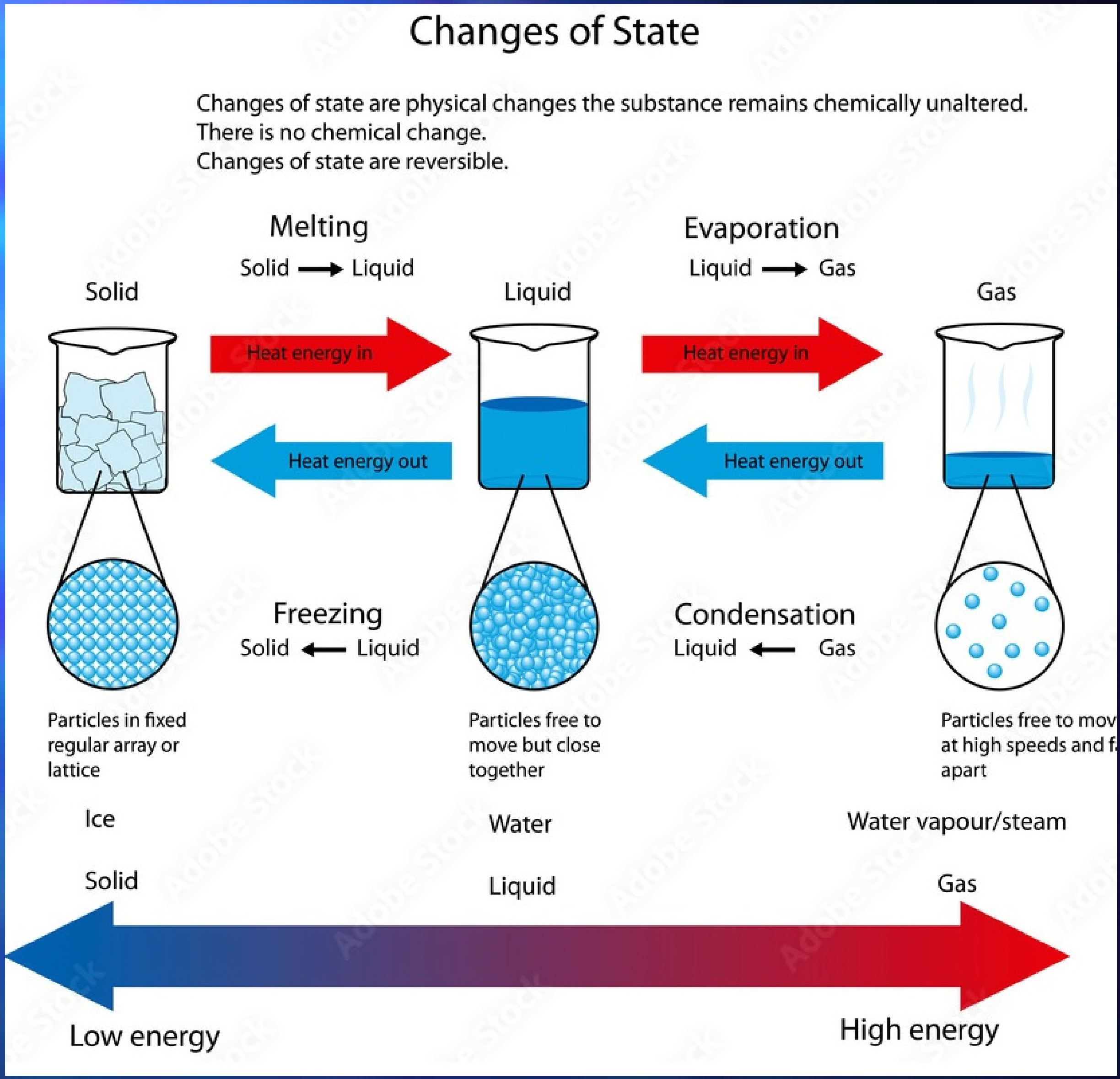
Phase Changes of Water

✓ A change in state or *phase* of water involves no chemical change – only a change in energy

✓ Solid is lowest energy phase; liquid moderate energy; and gas is highest energy phase

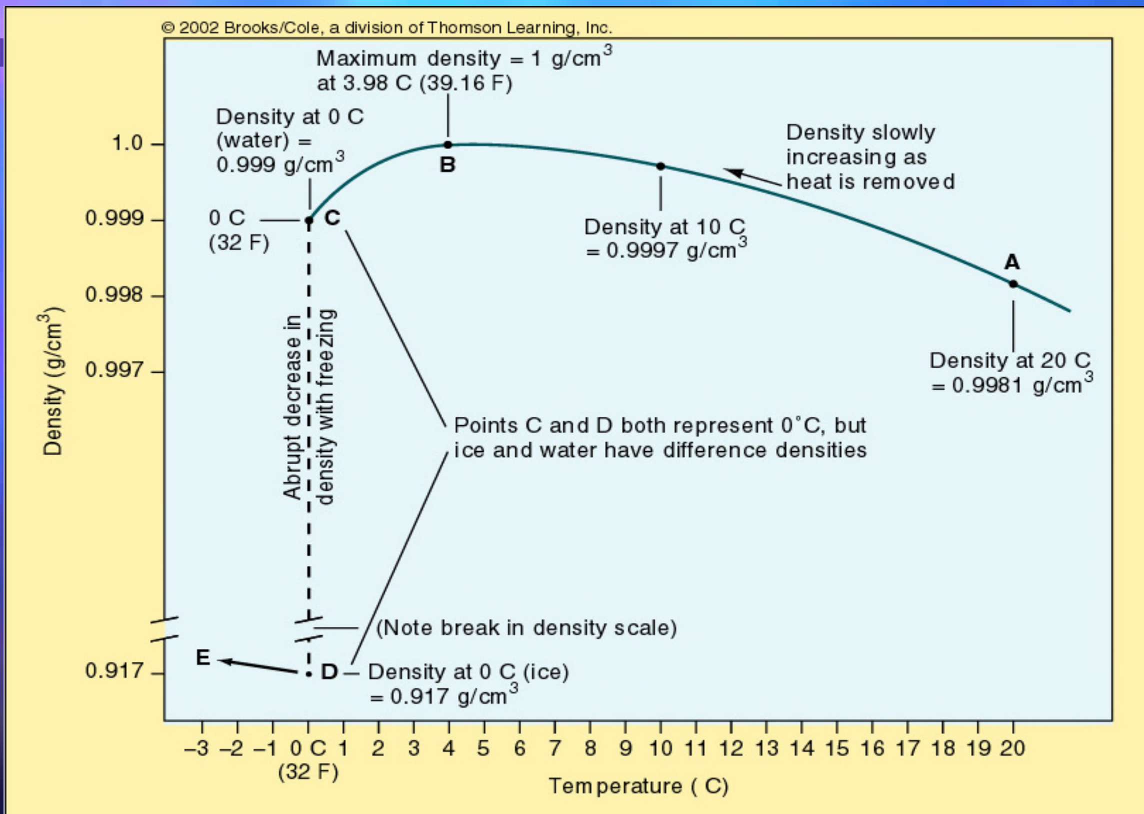
✓ A change in state requires an addition or subtraction of energy from the water mass, depending on which direction of phase change

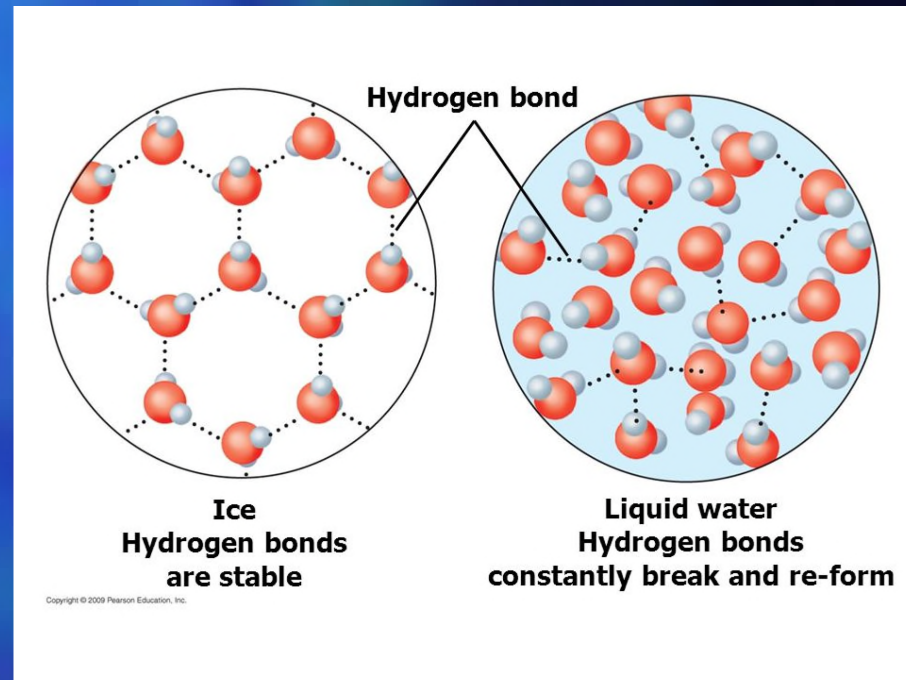
✓ Change in density occurs when matter changes phase; typically solid is densest; gas least dense, but water is unique: liquid is densest



Unique Density Properties of Water

Water Density-Temperature Graph

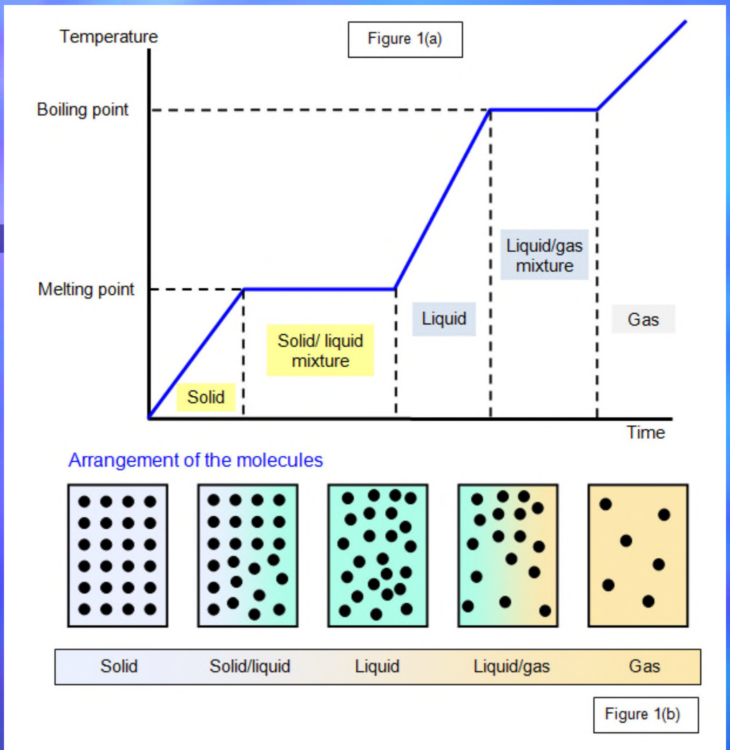


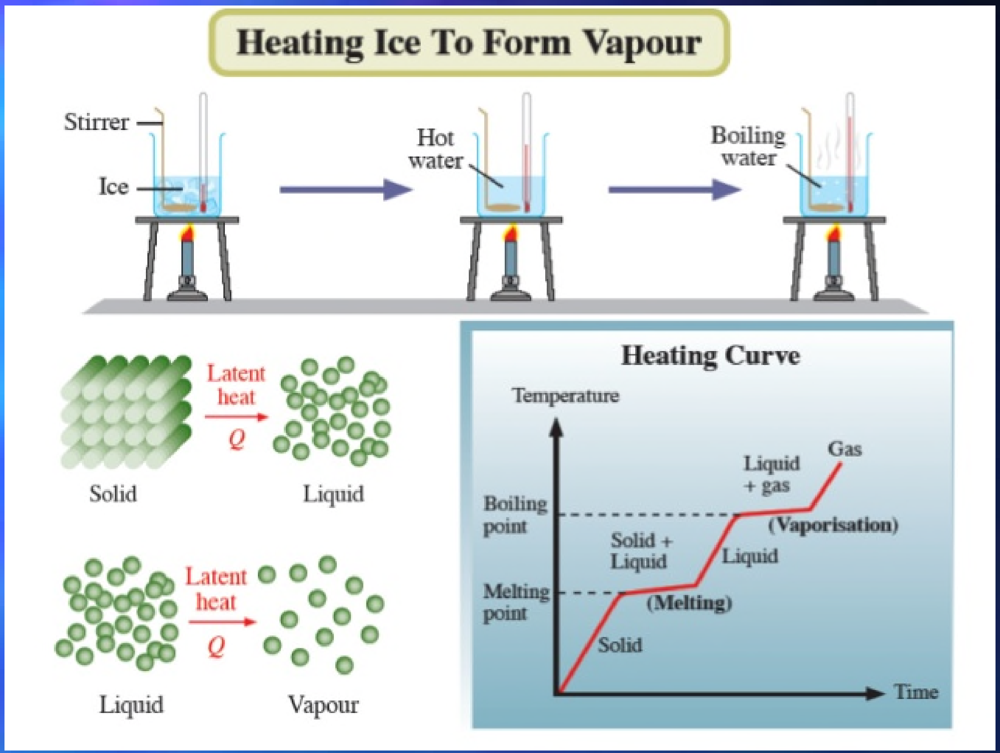


H2O Ice Crystal Lattice

- ✓ Water’s liquid phase is the denser than its solid phase
- ✓ Ice floats on liquid water due to the hydrogen bonds in the crystal lattice structure of water ice that are spread the molcules further apart than its liquid phase

Heat Transfer During Water Phase Changes





Temperature - Phase Change Graphs

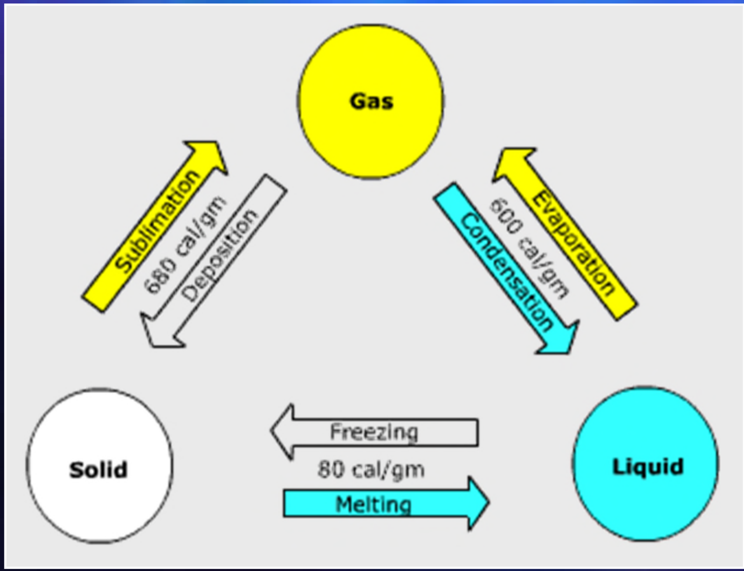
✓ Heat needs to be added to system to change water's solid (ice) phase to liquid phase and liquid phase to gas (vapor) phase

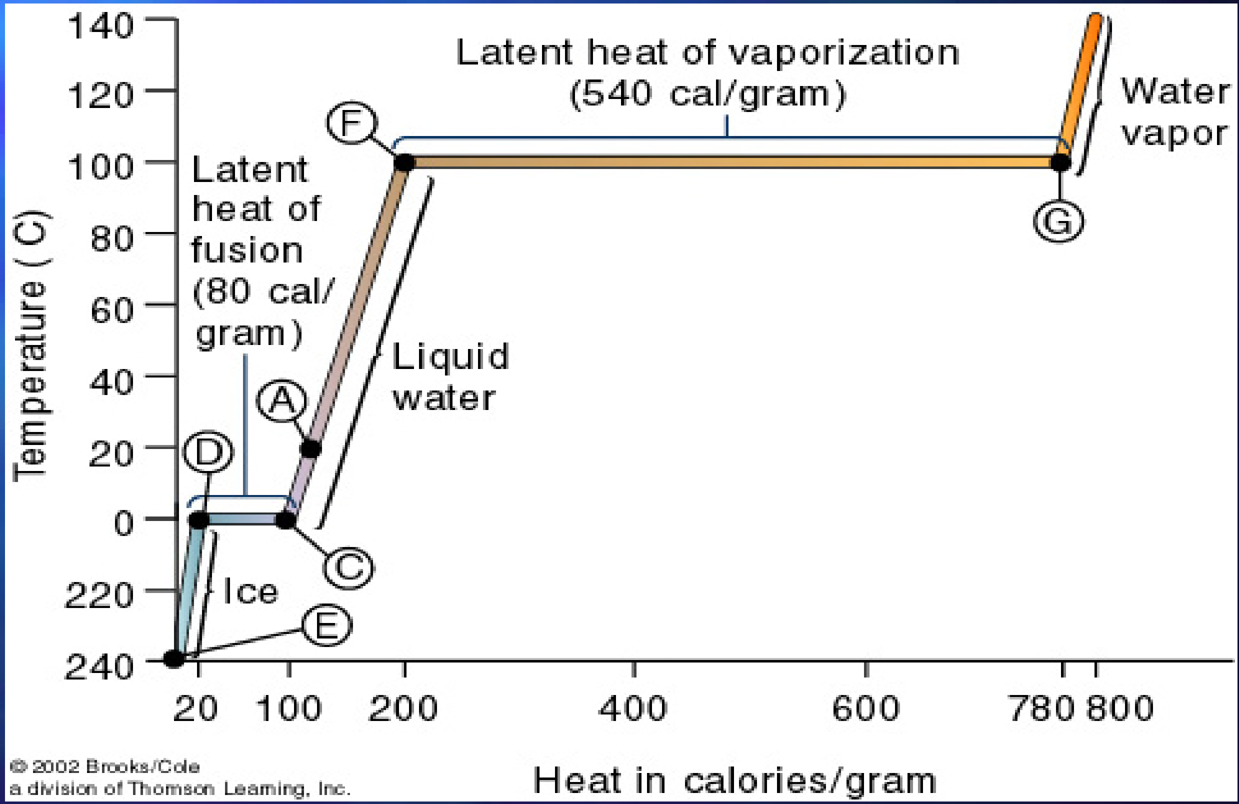
✓ Heat needs to be removed from system to change water's gas (vapor) phase to liquid phase and liquid phase to solid (ice) phase

✓As heat is added to system, temperature changes in the current phase until the phase change begins. Once the phase change begins, temperature no longer changes, but remains constant until the phase change is complete

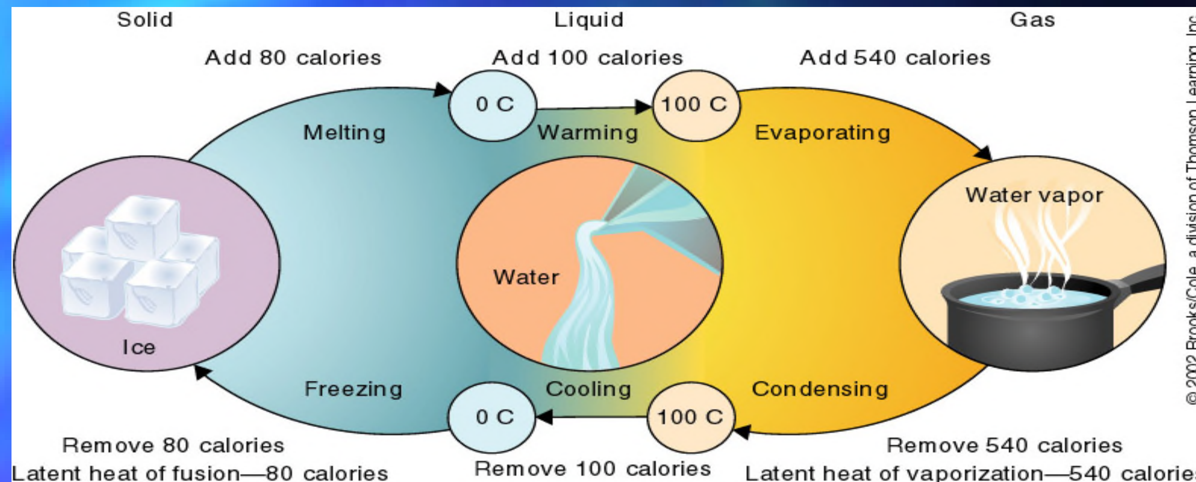
Thermal Properties of Water

- **Latent Heat of Fusion** – Amount of heat gained (or loss) to change a water's state from a solid to a liquid (or liquid to a solid) without raising (or lowering) the substance's temperature (80 calories/gram)
- **Latent Heat of Vaporization** – Amount of heat gained (or loss) to change a water's state from a liquid to a gas (or gas to a liquid) without raising (or lowering) the substance's temperature (540 calories/gram)
- **Water** has **very high latent heats**



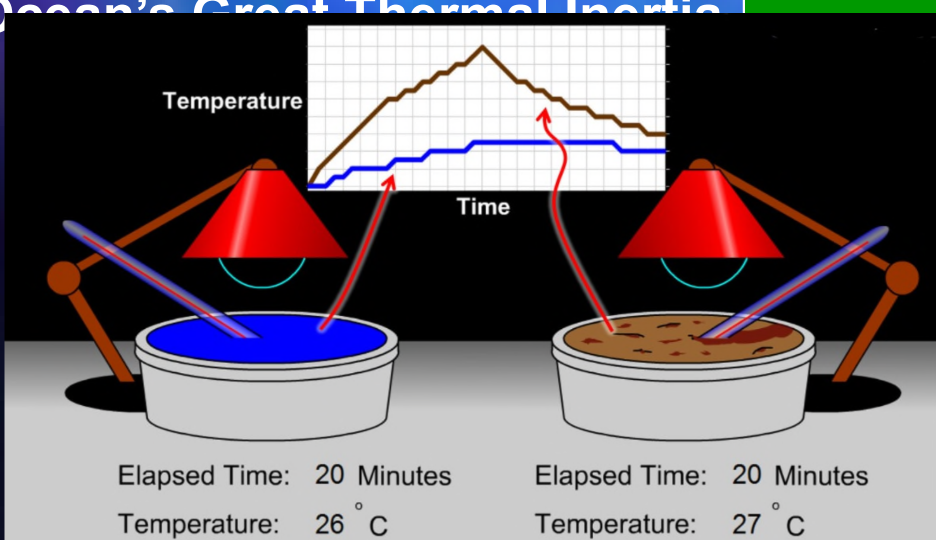


Global Thermostatic Effects of Water



Moderating Thermostatic Properties of Water

Ocean's Great Thermal Inertia

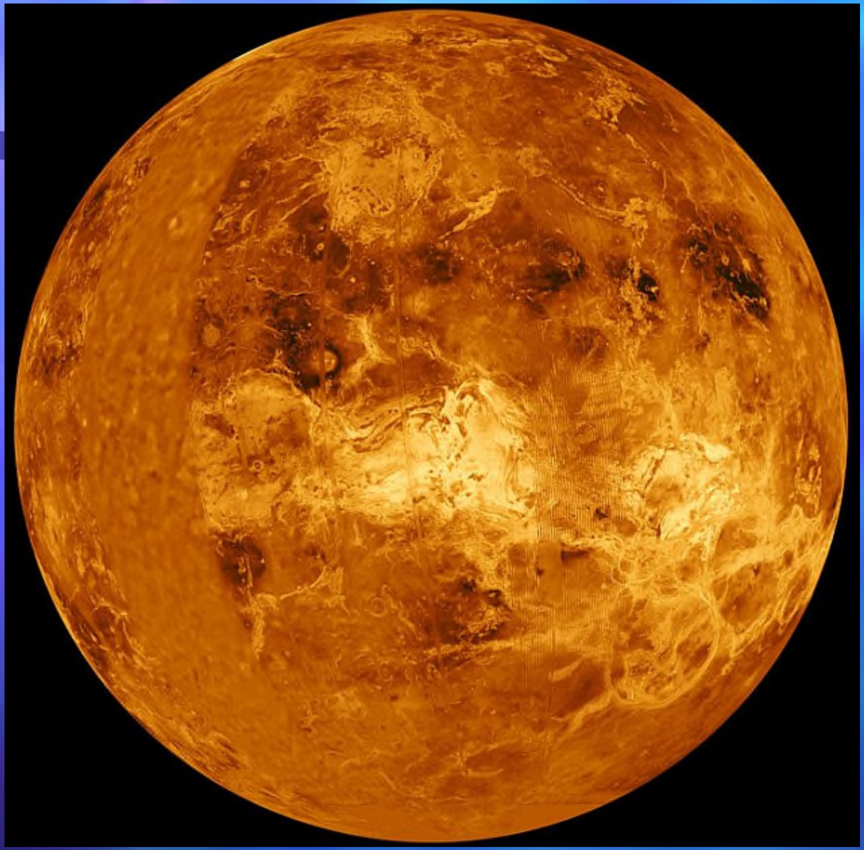


- Water absorbs the Sun's energy without great temperature changes
- …ing, freezing, evaporation, condensation of …e waters stores and releases vast quanities …r energy
- …an and atmosphere moderates Earth's big …e temperature swings of its land masses
- …rmal moderation takes place on many … – from local to global

Global Thermostatic Effects of Water

- Ocean's great thermal inertia makes planet Earth a relatively very comfortable place for life and humans
- If we had little to no ocean, these people would not be smiling!

Global Thermostatic Effects Without Water

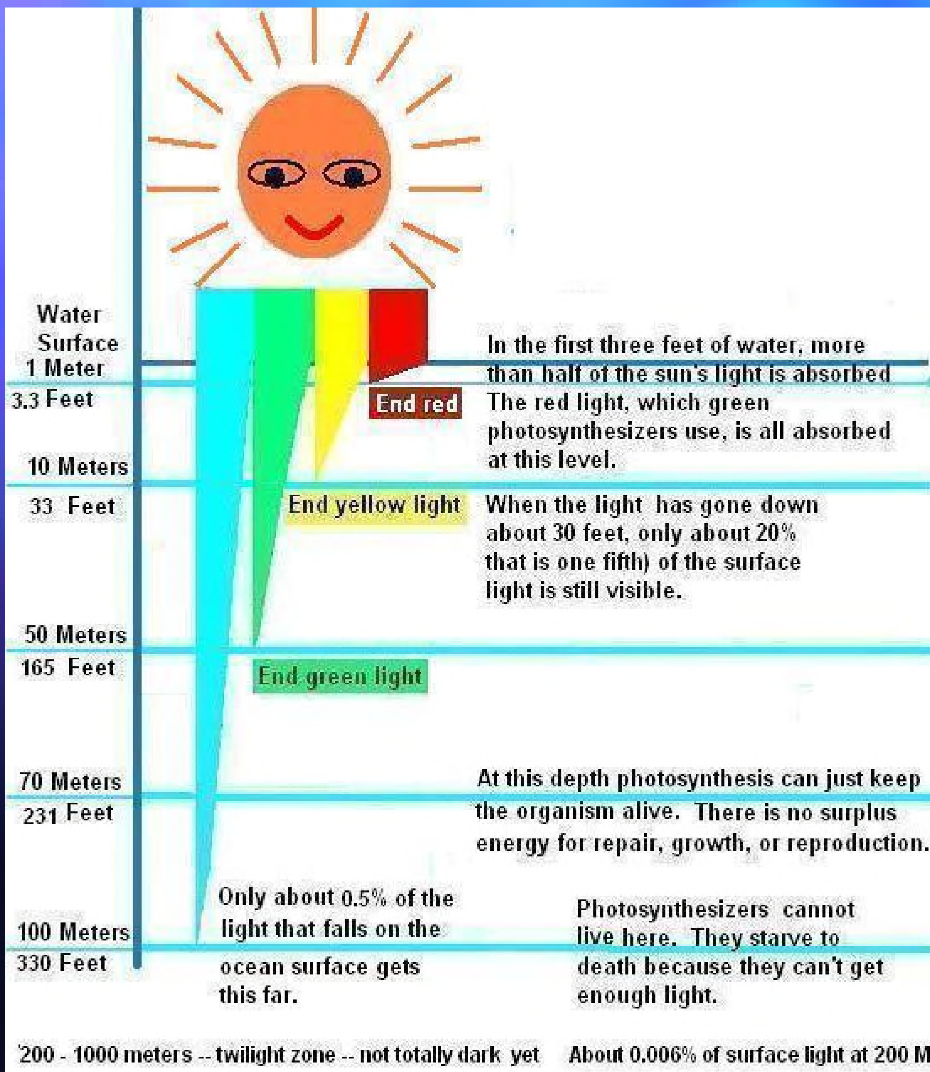


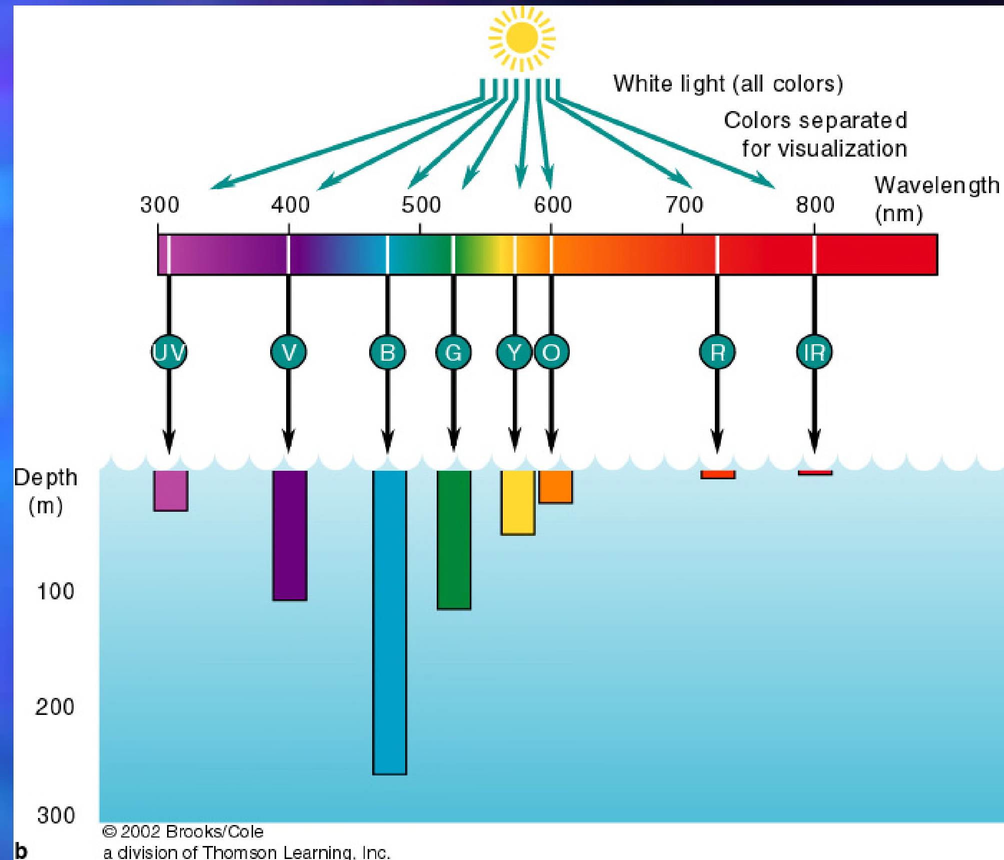
- Planet Venus does not have an ocean that can absorb and hold huge quantities of heat and carbon dioxide (greenhouse gas)
- Venus has a surface that is so hot that a car battery would instantly melt.   Lack of large amounts of surface water is mainly the cause

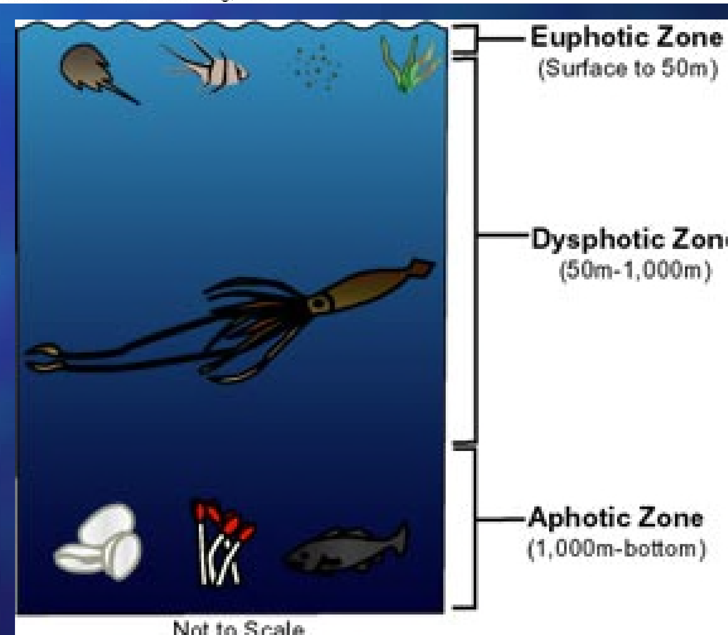
Other Physical Properties of the Ocean

1) **Light**
2) **Sound**
3) **Density**
4) **Salinity**
5) **Temperature**

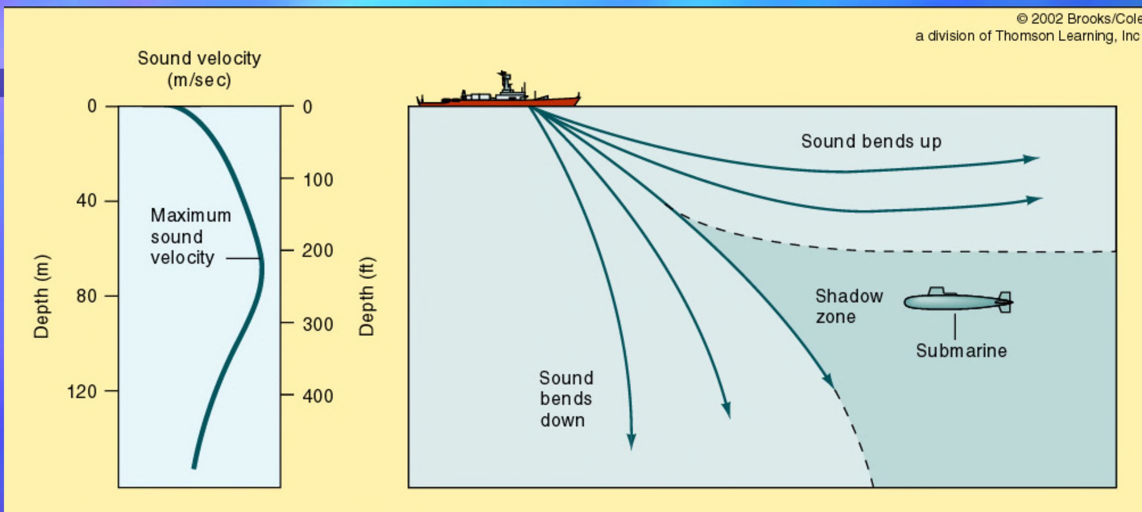
Light in the Ocean

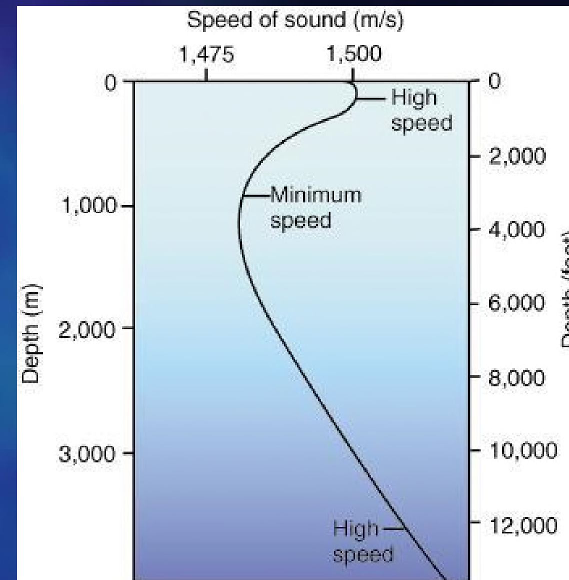




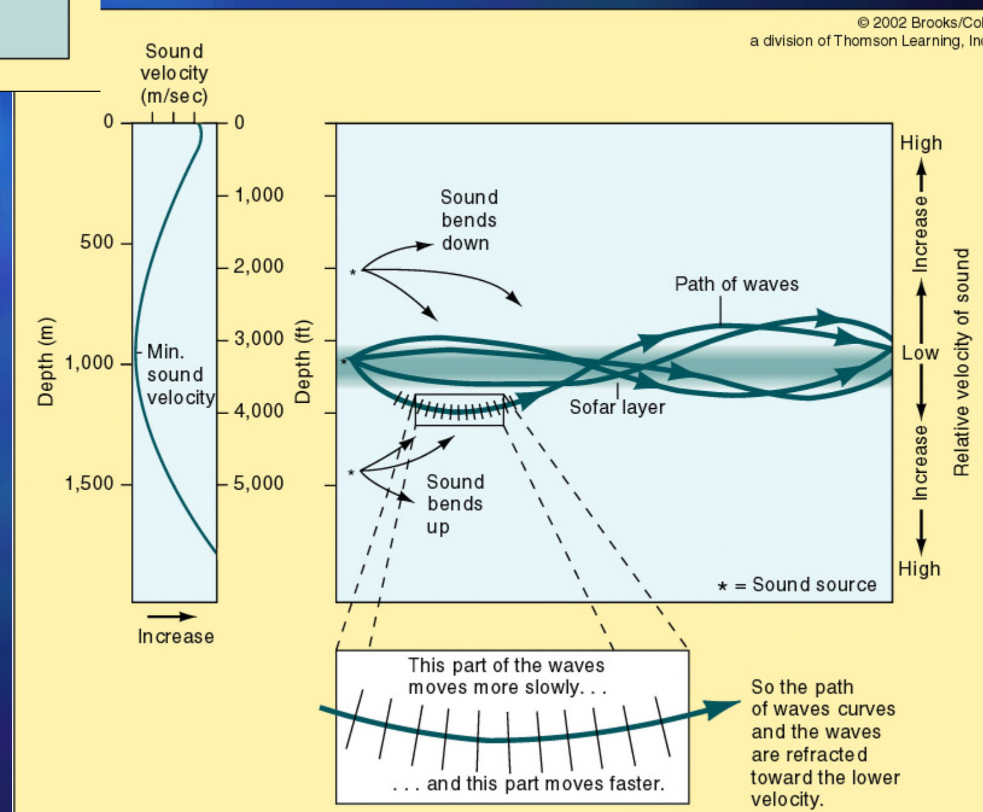


Sound in the Ocean





- Water travels five times faster in water than air – 1500 m/s
- Speed of sound in ocean varies according to depth
- Minimum sound speed occurs at around 1200 meters; termed the Sofar Layer
- Measuring speed of sound along sofar layer used to accurately calculate the ocean's water temperature



Ocean Surface Temperature

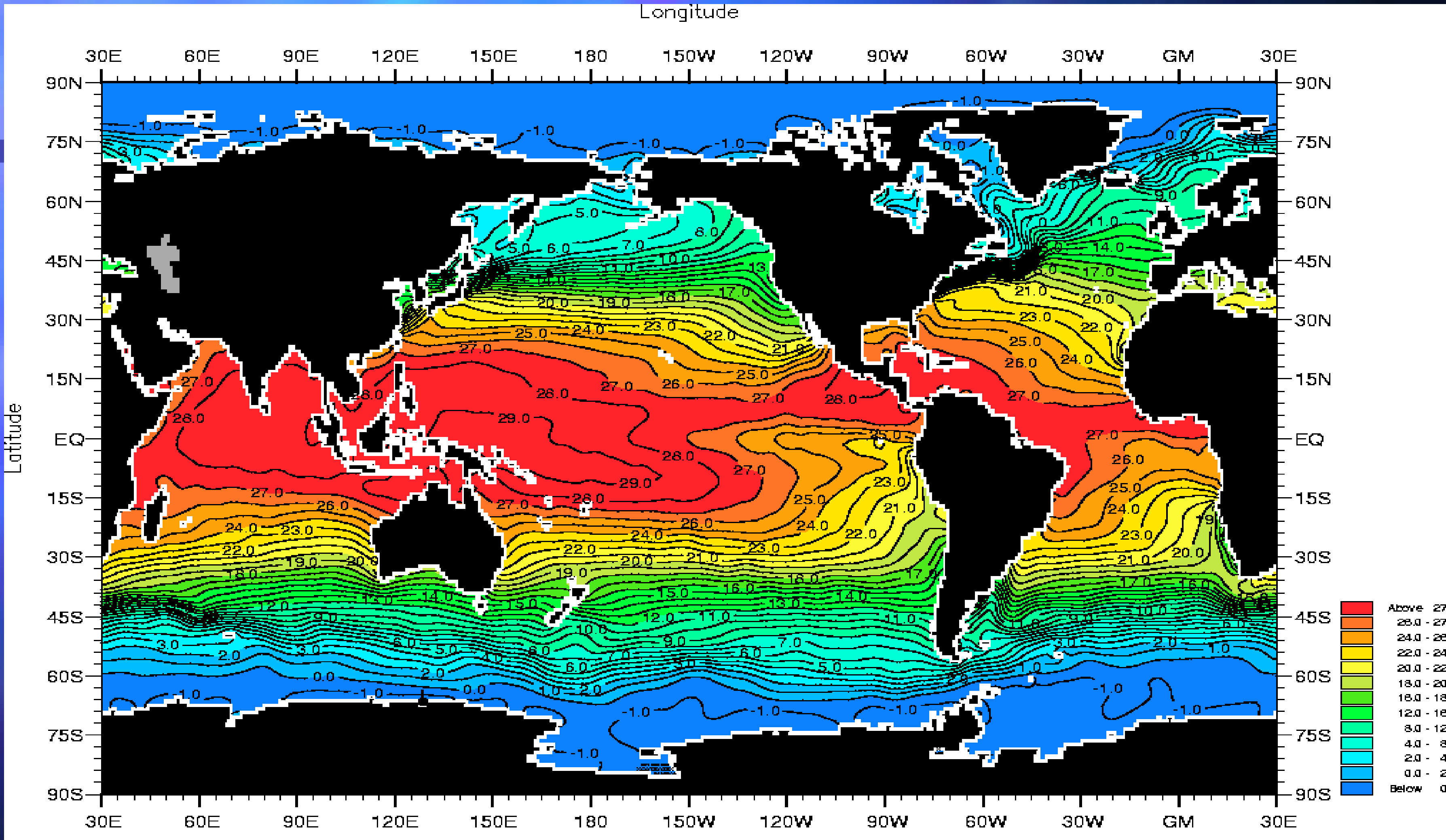


Fig. A2-1. Annual mean temperature (℃) at the surface .

Sea Surface Temperature (Annual mean temperature (^{o}C) at the surface)

- Warmest in low-latitudes
- Coldest in high latitudes

Ocean Surface Salinity

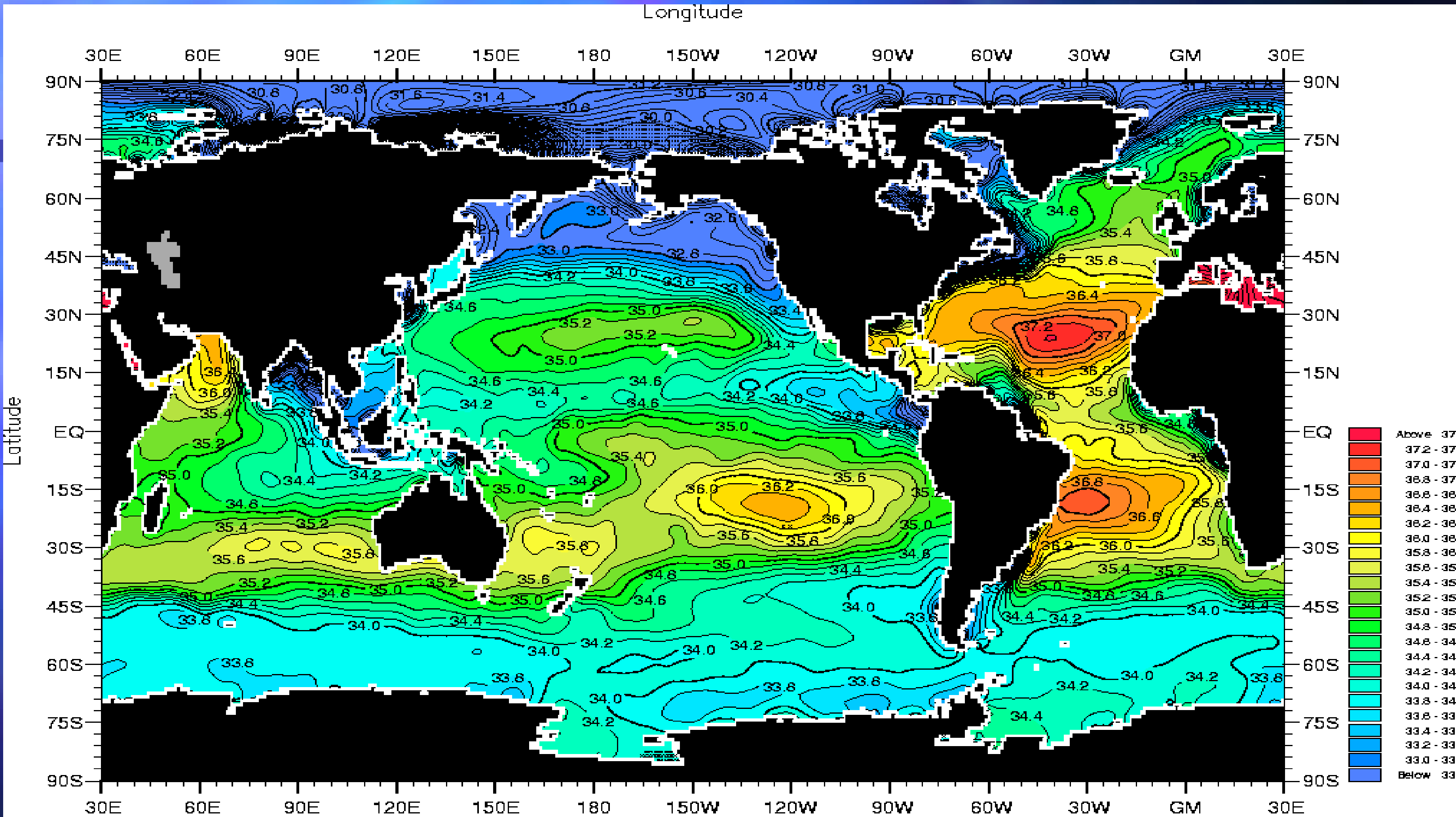


Fig. A2-1. Annual mean salinity (PSS) at the surface .

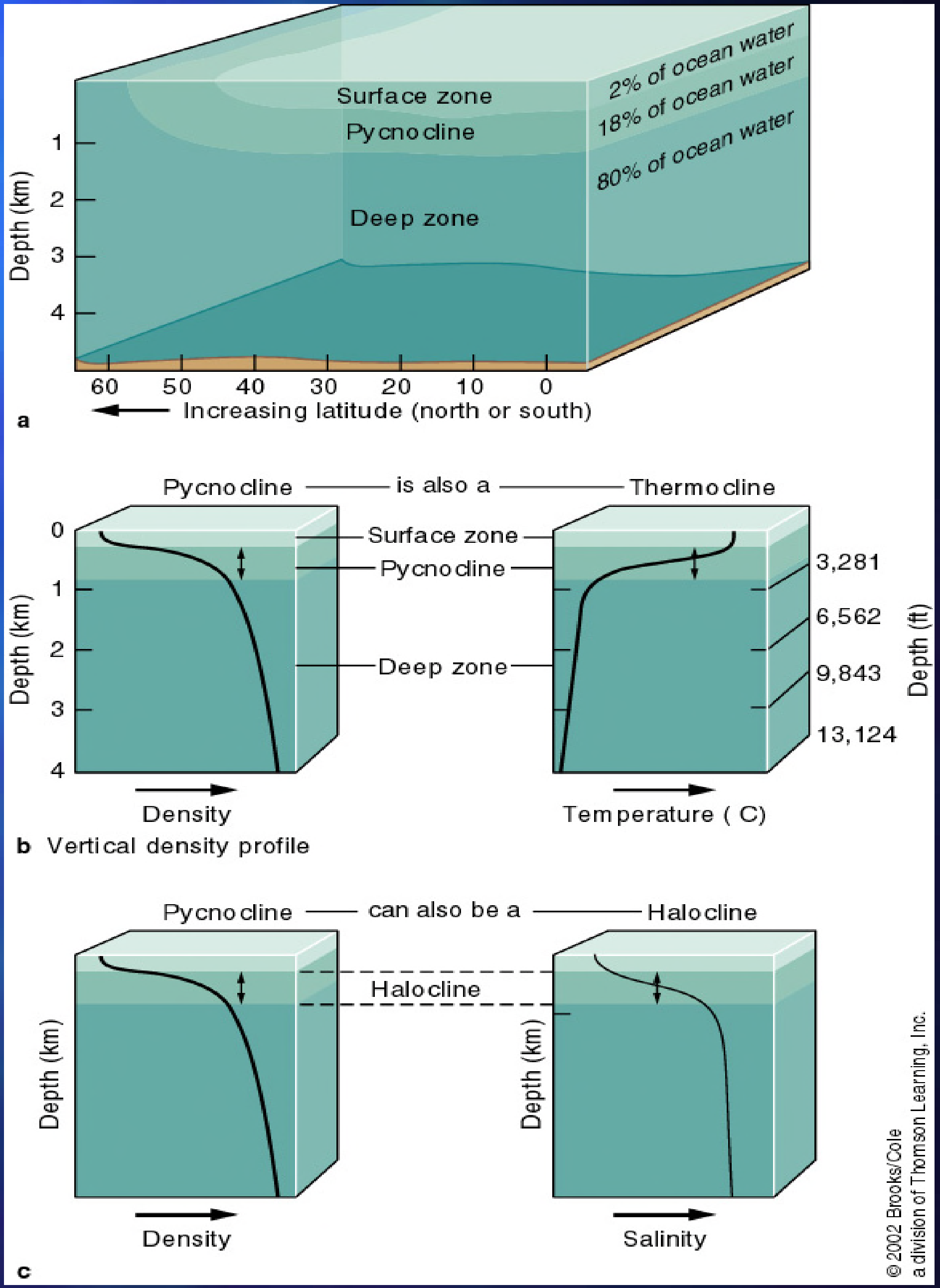
Minimum Value= 3.57 Maximum Value= 40.02 Contour Interval: 0.20

Sea Surface Salinity (Annual mean salinity (PSS) at the surface)

- Saltiest in mid-latitude Atlantic, Pacific and Mediterranean
- Freshest in high latitudes

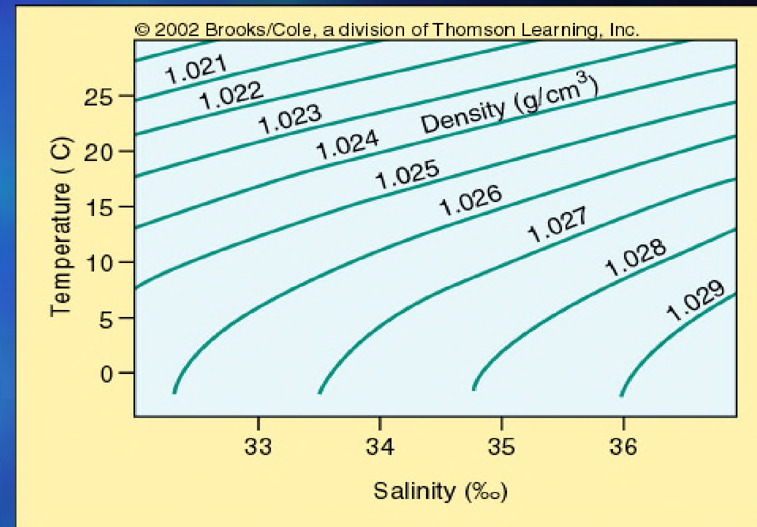
Density Structure of the Ocean

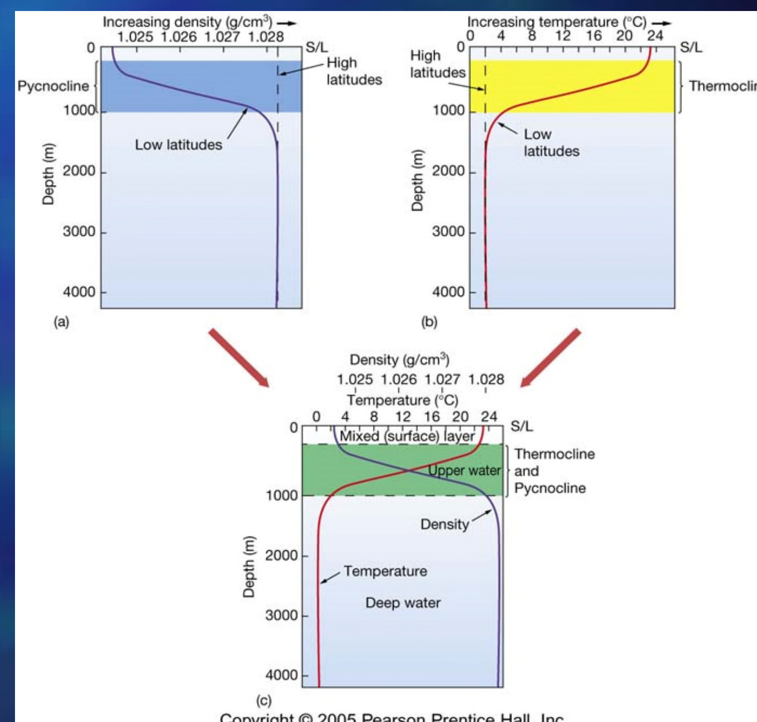
- Ocean divided into three horizontal density layers or zones
  - Surface Zone
  - Pycnocline
  - Deep Zone
- Surface Zone
  - Warmest, least dense
  - Typically extends down to 150 meters
  - Makes up only 2% of ocean
- Pycnocline
  - Density increases with increasing depth
  - Isolates the surface zone from the deep zone
  - Makes up about 18% of ocean
- Deep Zone
  - Top is at about 1000 meters down
  - Coldest, densest
  - Contains about 80% of ocean



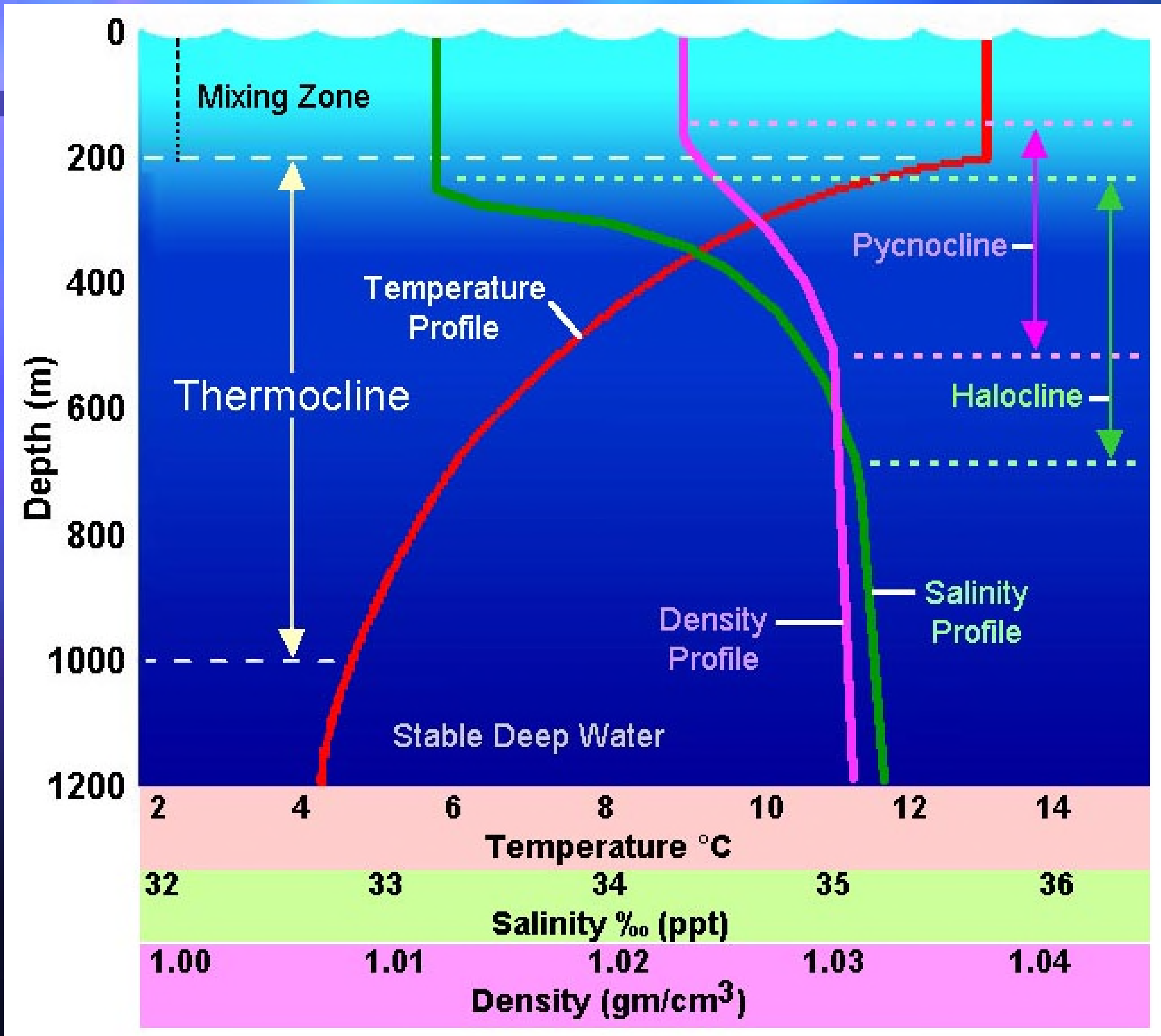
The Ocean's Temperature-Salinity Relationship to Seawater Density

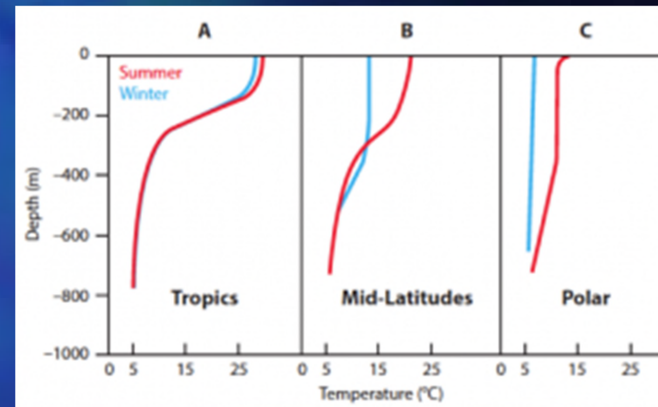
- Density of seawater is function of temperature and salinity
- Two samples of seawater can have same density at different combinations of temperature and salinity
- Seawater tends to form stable density layers
  - Coldest saltiest at the bottom
  - Warmest, least saltiest at the surface
- Changes in ocean temperature and salinity are primarily controlled by surface processes





The Ocean's Temperature-Salinity Relationship to Seawater Density





Ocean Temperature Variation According to Season and Latitude

Review of Seawater's Physical and Thermal Properties

Review and Discussion

- Elements of Water
- Chemical Bonding
- The Water Molecule
- Hydrogen Bonding
- Thermal Properties of Water
- Water's Affect on Climate
- Light and Sound in Water
- Salinity
- Temperature
- Density

Seawater Chemistry

Seawater's Chemical Properties

Topics of Study

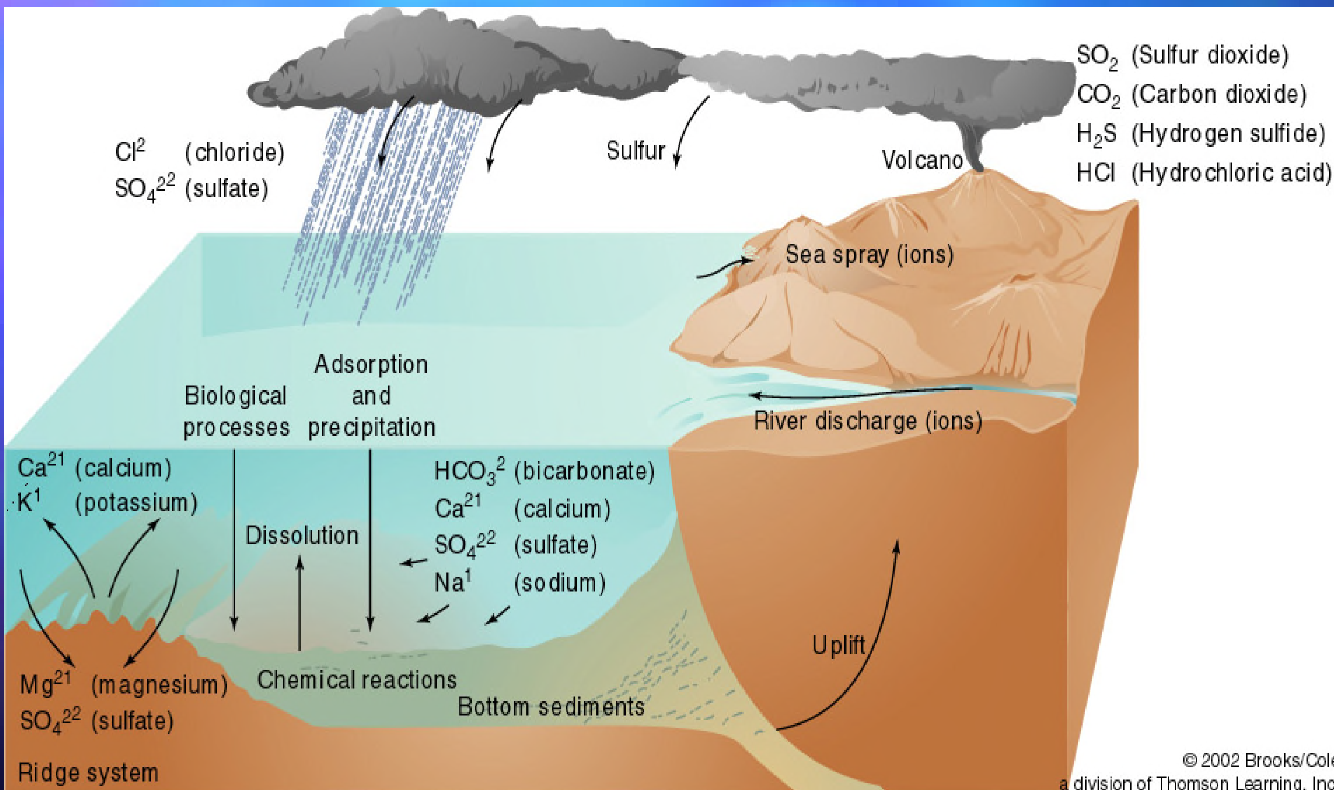
- ✓ Water's Dissolving Power
- ✓ Chemical Make-up of Seawater
- ✓ Salinity
- ✓ Measuring Salinity
- ✓ Sources and Sinks of Ocean Salts
- ✓ Dissolved Gasses in Seawater
- ✓ Residence Times of Ocean Salts
- ✓ Seawater Acid-Base Balance - pH
- ✓ Seawater Chemistry and Life
- ✓ Ocean's Temperature & Salinity Profile
- ✓ Temperature & Salinity Chart
- ✓ Ocean's Density Profile
- ✓ Ocean Water Masses

Seawater's Chemical Properties

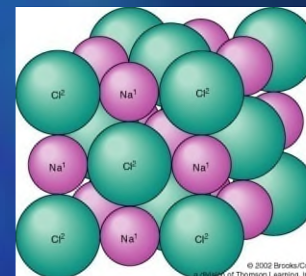
The Major Points

1) Water's is a powerful solvent – due to its polar nature and its hydrogen bonds.
2) Seawater is a solution: a mix of water, dissolved ions and gases.
3) Salinity = amount of dissolved ions and gases in water – in parts per 1000
4) Salinity has 7 major, 14 minor, and numerous trace element constituents.
5) Dissolved salts recycle in the ocean via numerous sources and sinks at different rates (different residence times).
6) The ocean is in chemical equilibrium (salinity input = output) – both in total salinity and the proportion of the major constituents (constant proportionality)
7) Seawater has 3 major dissolved gases: nitrogen, oxygen, carbon dioxide.
8) Sources of dissolved gases are from atmosphere, ocean, and sea bottom
9) Dissolved oxygen is derived from photosynthesis processes
10) Seawater pH is slightly alkali (8) but is becoming increasingly acidic
11) Seawater pH is chemically buffered by a carbonate system
11) The ocean is stratified in terms of temperature, salinity and density
12) Temperature and salinity control the ocean's density.

Water – The Universal Solvent

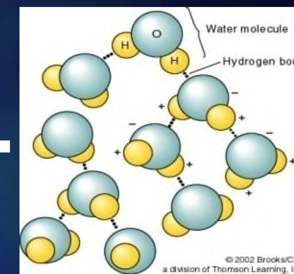


Mineral Salts and Gasses from Several Sources Dissolve Readily in Seawater

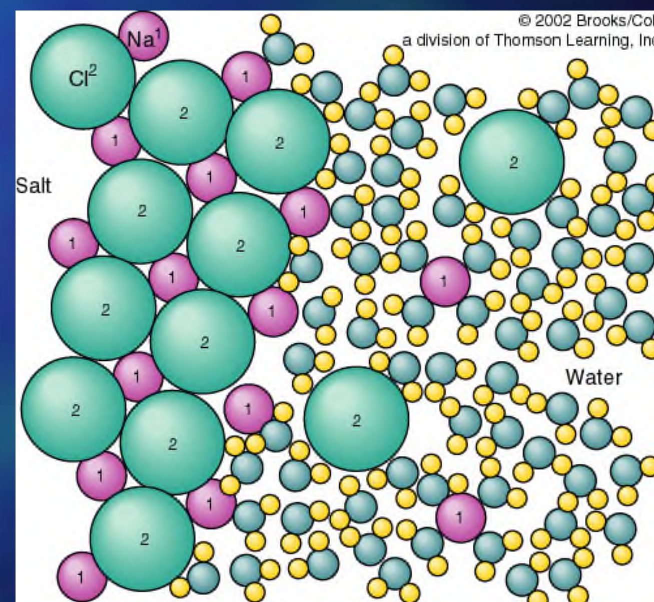


Salt

+

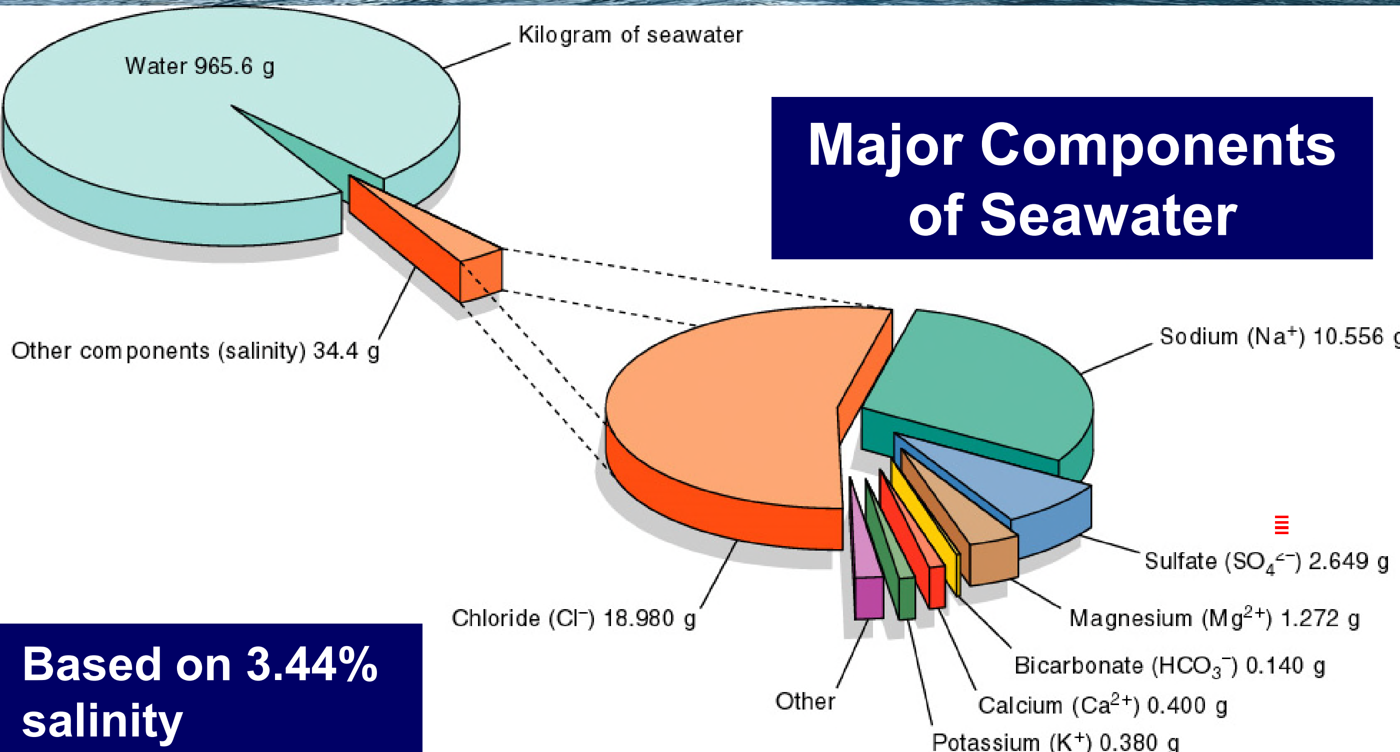


Water



Dissolving Power of H2O = Salty Ocean Water

Seawater "Earth Soup"



Major Components of Seawater

Based on 3.44% salinity

Some Interesting Facts

Chloride (55.04 %) plus Sodium (30.61 %) make up 85.65 % of all the dissolved constituents.

Major Constituents (ppt)

- Chloride
- Sodium
- Sulfate
- Magnesium
- Calcium
- Potassium
- Bicarbonate

Minor Constituents (ppm)

- Bromide
- Strontium
- Borate
- Fluorine
- Iron
- Silica
- Carbon

Trace Elements (ppb)

Lithium, Aluminum, Zinc, Iodide, Manganese, Phosphorus, Heavy metals, REE's, Precious metals

Seawater Salinity - Defined

Definition of Salinity

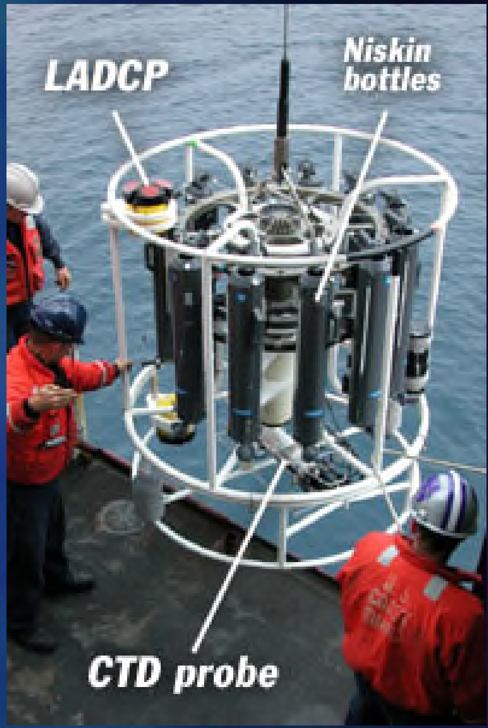
Total amount of dissolved solids (ions) and gasses in one kilogram of sea water.

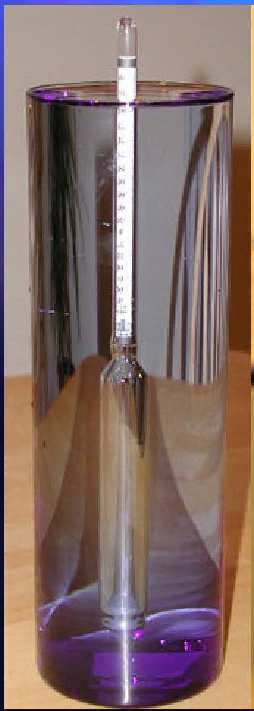
Routinely measured in parts per thousand (‰)

Methods Used to Measure Salinity

1) Derive from Seawater Density and Temperature
2) Refractometry
3) Chlorinity
4) Conductivity

Measuring Ocean Salinity



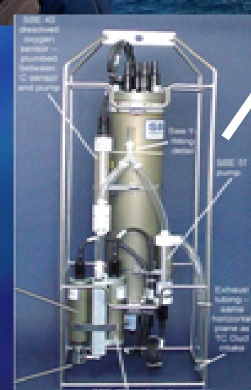


Various Means Available

Measuring Seawater Salinity

Methods Used to Measure Salinity

1) Seawater Density and Temperature
2) **Conductivity**
3) **Refractometry**
4) Chlorinity
5) Distillation



Conductivity-
Temperature-
Depth Probe

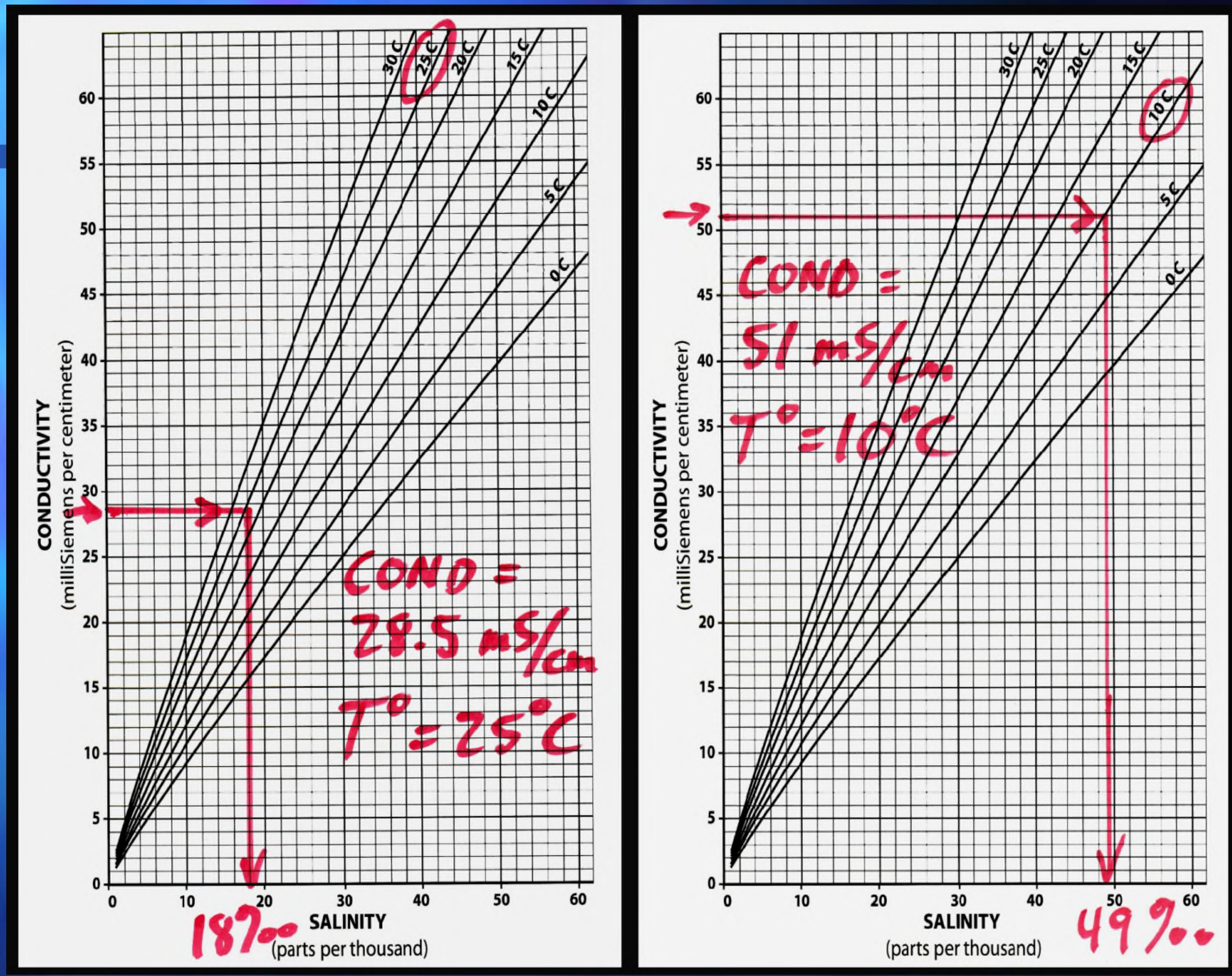
Measuring Salinity with a Conductivity Meter

Using a Conductivity Meter

1) Conductivity of a seawater sample is a function of the samples temperature and salinity
2) Measure conductivity and temperature using a hand-held conductivity meter.
3) Graduated units are in milli- and micro-seimens.
4) Use the C-T-S graph to estimate the corrected salinity of the sample

Conductivity – Temperature - Salinity

1) Measure sample's conductivity
2) Determine sample's temperature
3) Find the associated salinity for specific pair of conductivity & temperature along the bottom of graph



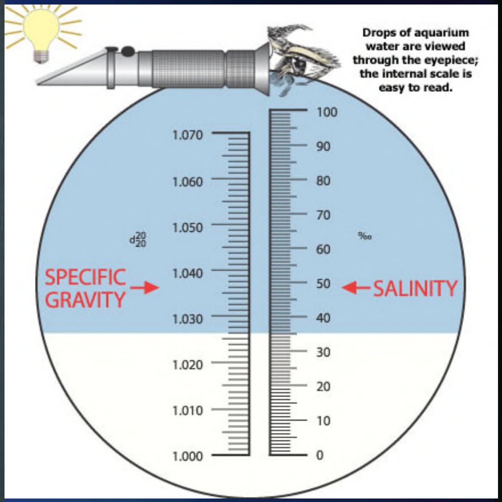
Two Examples of Determining Salinity

Measuring Salinity with a Refractometer

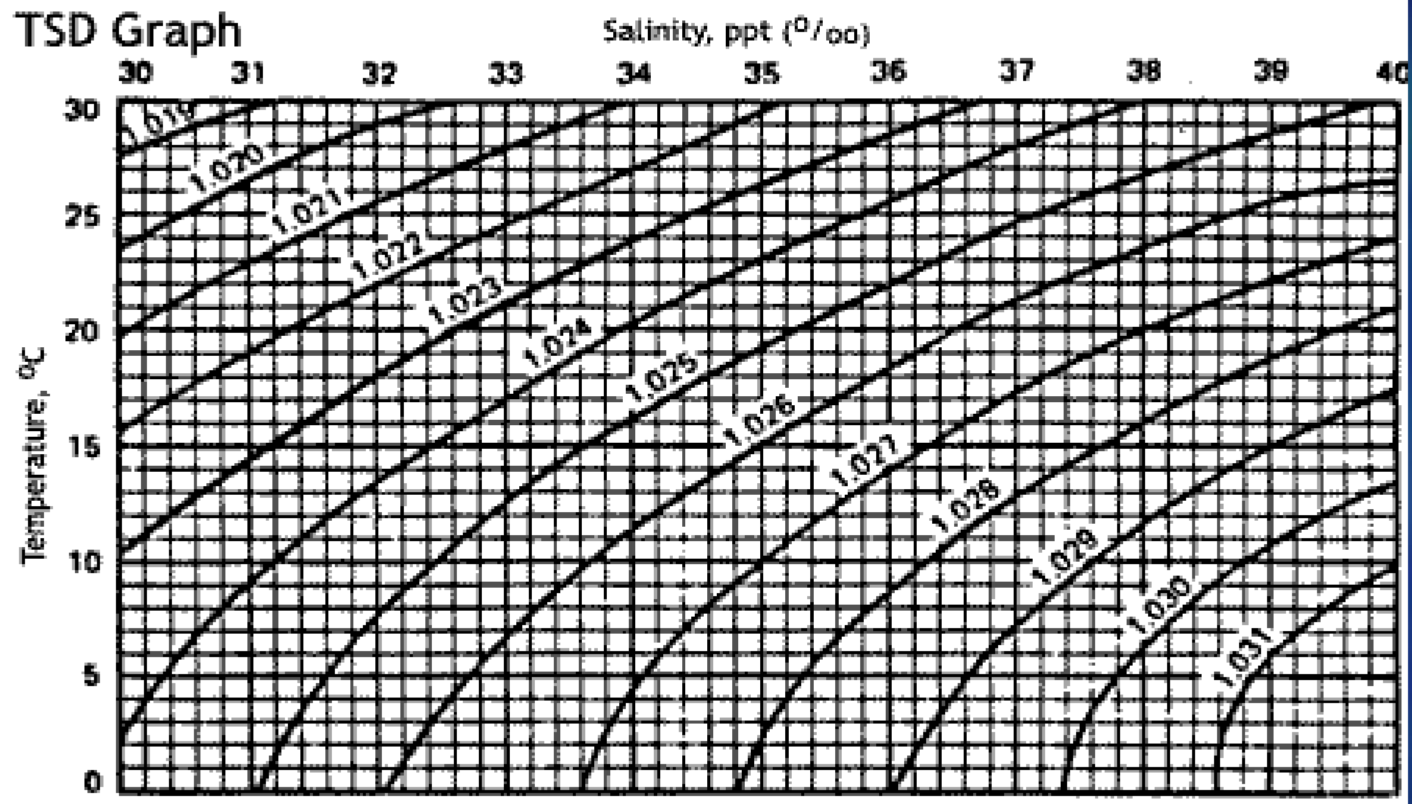
1) Refractometer needs a a bright light source
2) Add a few drops of sample onto the test surface of meter

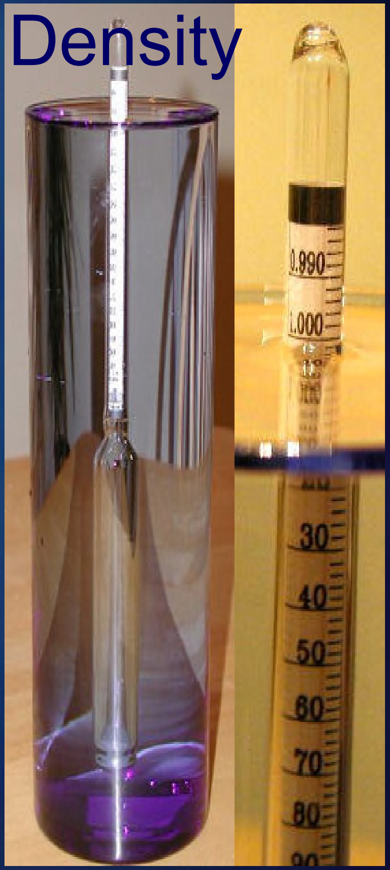
3) Measure salinity at the line separating the blue from the white field

1) Graduated units are in either grams per milliliter or parts per thousand



Find Temperature and Density to Determine Salinity



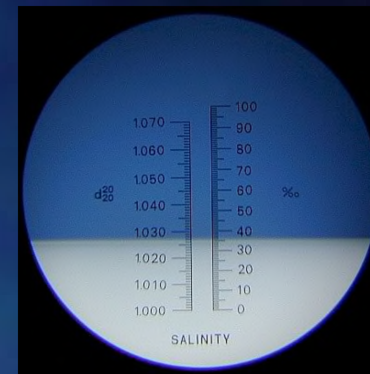


Hydrometer

- ✓ Measure seawater temperature
- ✓ Measure seawater density
- ✓ Use TSD graph to determine salinity

Measuring Salinity with a Refractometer

- ✓ Hand-like device
- ✓ Measures bending of light from air into seawater to indicate density and salinity
- ✓ Place seawater sample on plate
- ✓ Close clear gate and view gauge panel
- ✓ Density on the left
- ✓ Salinity on the right
- ✓ Value where blue & white fields meet



Seawater Salinity - Quantifying

Salinity Based on Chlorinity and Conductivity

1. *Salinity* = $0.03 + 1.805Cl$

where ***chlorinity*** *Cl* is defined as "the mass of silver required to precipitate completely the halogens in 0.328 523 4kg of the sea-water sample.

2. *Salinity*= $0.0080 - 0.1692\, R^{1/2}{}_{15} + 25.3851\, R_T + 14.0941\, R^{3/2}{}_T - 7.0261\, R^2{}_T + 2.7081\, R^{5/2}{}_T + \Delta S R_T = C(S,T,0) / C(KCl,T,0)(6.4b) \Delta S = [(T - 15) / (1 + 0.0162(T - 15))] + 0.005 - 0.0056\, R^{1/2}{}_T - 0.0066\, R_T - 0.0375\, R^{3/2}{}_T + 0.636\, R^2{}_T - 0.0144\, R^{5/2}{}_T 2 \leq S \leq 42$

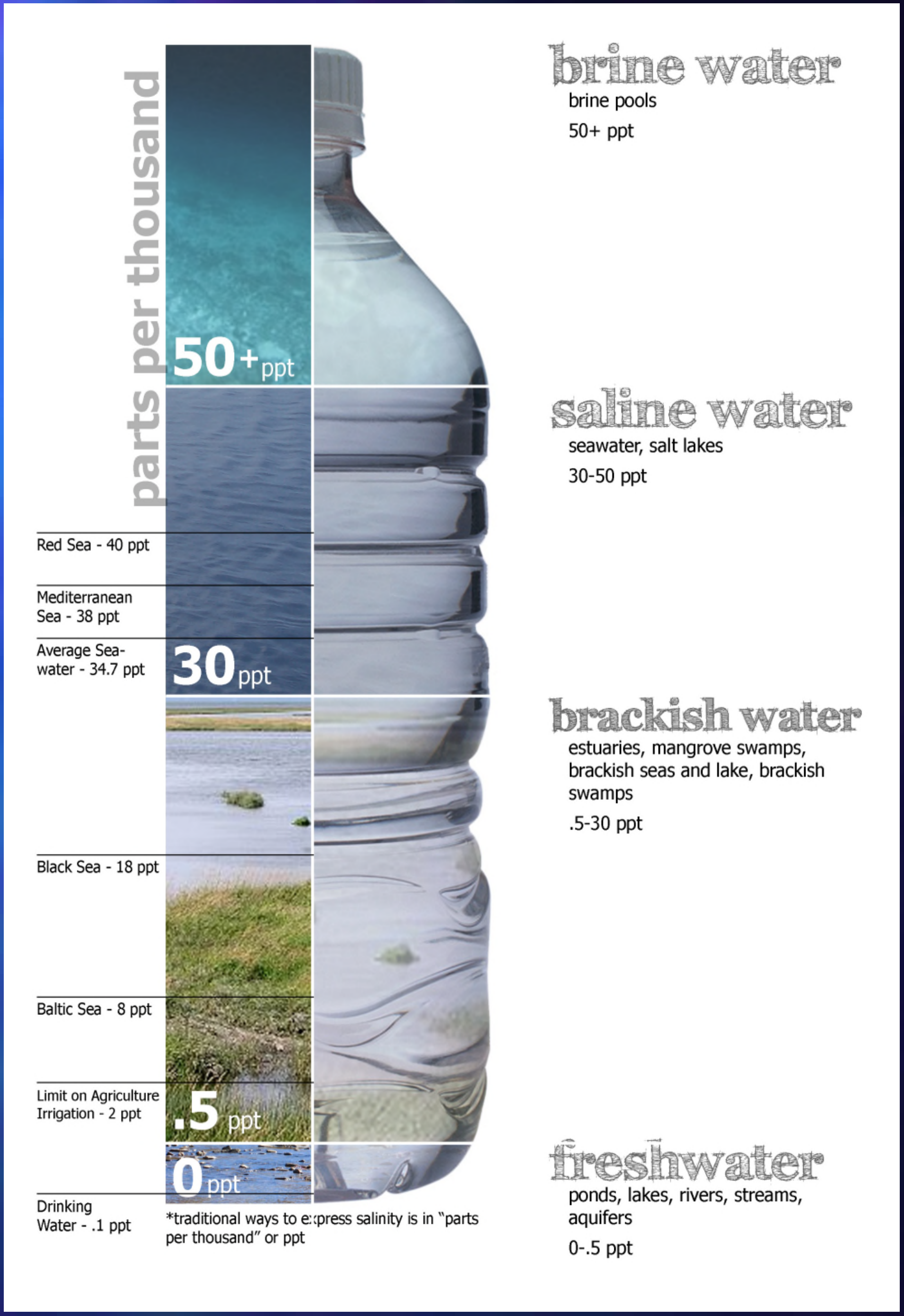
where $C(S, T, 0)$ is the ***conductivity*** of the sea-water sample at temperature *T* and standard atmospheric pressure, and $C(KCl, T, 0)$ is the conductivity of the standard potassium chloride (*KCl*) solution at temperature *T* and standard atmospheric pressure.

Measure Seawater Conductivity to Determine Salinity

‰\ °C	15	16	17	18	19	20	21	22	23	24	25
30.0	1022,1	1021,9	1021,7	1021,4	1021,2	1020,9	1020,7	1020,4	1020,1	1019,9	1019,6
30.5	1022,5	1022,3	1022,1	1021,8	1021,6	1021,3	1021,1	1020,8	1020,5	1020,2	1019,9
31.0	1022,9	1022,7	1022,4	1022,2	1021,9	1021,7	1021,4	1021,2	1020,9	1020,6	1020,3
31.5	1023,3	1023,0	1022,8	1022,6	1022,3	1022,1	1021,8	1021,6	1021,3	1021,0	1020,7
32.0	1023,7	1023,4	1023,2	1023,0	1022,7	1022,5	1022,2	1021,9	1021,7	1021,4	1021,1
32.5	1024,0	1023,8	1023,6	1023,4	1023,1	1022,9	1022,6	1022,3	1022,0	1021,7	1021,4
33.0	1024,4	1024,2	1024,0	1023,7	1023,5	1023,2	1023,0	1022,7	1022,4	1022,1	1021,8
33.5	1024,8	1024,6	1024,4	1024,1	1023,9	1023,6	1023,3	1023,1	1022,8	1022,5	1022,2
34.0	1025,2	1025,0	1024,8	1024,5	1024,3	1024,0	1023,7	1023,5	1023,2	1022,9	1022,6
34.5	1025,6	1025,4	1025,1	1024,9	1024,6	1024,4	1024,1	1023,8	1023,6	1023,3	1023,0
35.0	1026,0	1025,7	1025,5	1025,3	1025,0	1024,8	1024,5	1024,2	1023,9	1023,6	1023,3
35.5	1026,4	1026,1	1025,9	1025,7	1025,4	1025,1	1024,9	1024,6	1024,3	1024,0	1023,7
36.0	1026,7	1026,5	1026,3	1026,0	1025,8	1025,5	1025,3	1025,0	1024,7	1024,4	1024,1
36.5	1027,1	1026,9	1026,7	1026,4	1026,2	1025,9	1025,6	1025,4	1025,1	1024,8	1024,5
37.0	1027,5	1027,3	1027,0	1026,8	1026,5	1026,3	1026,0	1025,7	1025,4	1025,2	1024,9
37.5	1027,9	1027,7	1027,4	1027,2	1026,9	1026,7	1026,4	1026,1	1025,8	1025,5	1025,2
38.0	1028,3	1028,0	1027,8	1027,6	1027,3	1027,0	1026,8	1026,5	1026,2	1025,9	1025,6

- ✓ Most widely used method for measuring seawater salinity
- ✓ Conductivity (CTD) meter used to measure seawater conductivity
- ✓ CTD measure conductivity, temperature, and depth
- ✓ CTD’s can measure continuously in real time in water column
- ✓ Typically installed on a water sampling rosette instrument rack
- ✓ Need a conductivity-temperature chart to calculate to salinity

Levels of Salinity of Various Waters



Seawater "Chemical Equilibrium"

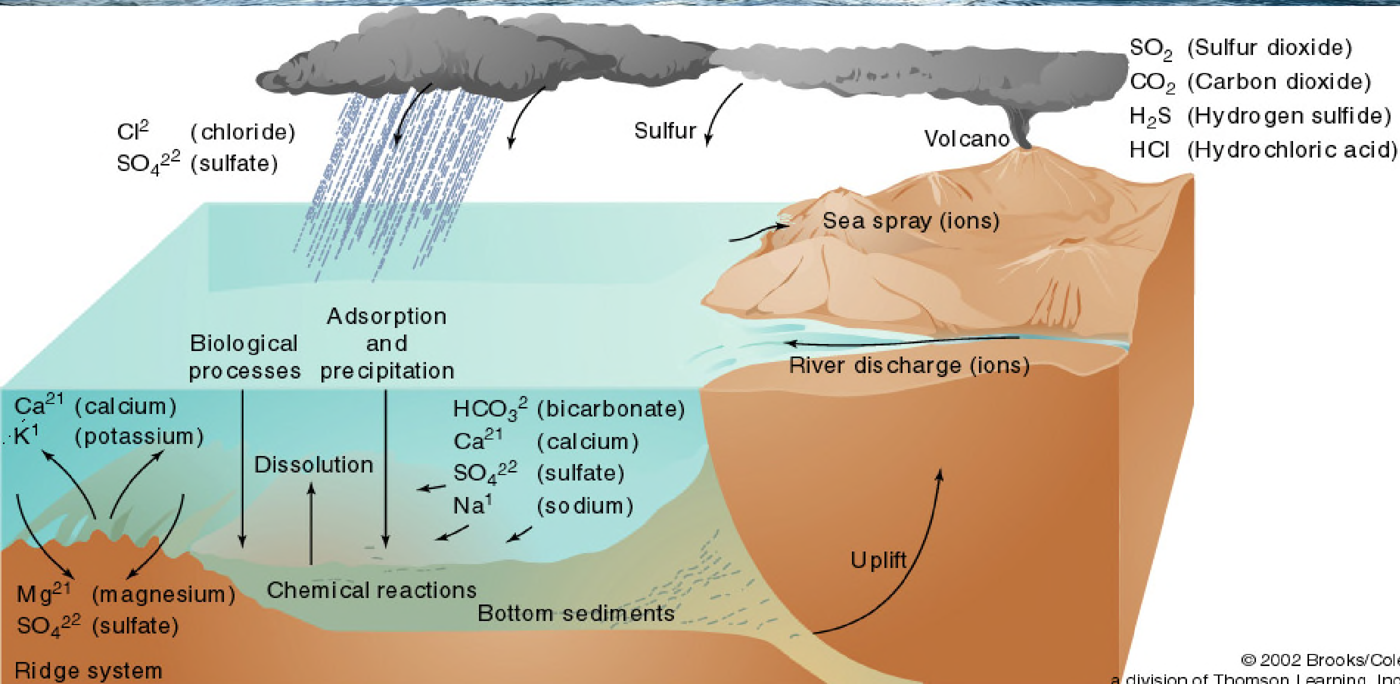
The Ocean is in Chemical Equilibrium

1) Ocean salinity nearly constant (billions of years)
   - Amount of each constituent going into ocean (from sources) appears to equal the amount going out (to sinks)

2) Major constituents in constant ratio with each other
   - *Principle of Constant Proportionality*
   - *Examples: Chloride and Sodium*

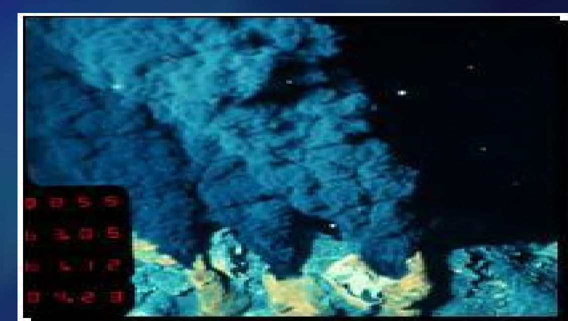
3) Acid-base (pH) balance of ocean is very stable

Sources for Dissolved Solids in Seawater



CO_2, H_2O, H_2S, HCl, and SO_2

$Fe^{++} + Mg^{++} + SiO_4 + K^{+} + Na^{+} + Ca^{+} + HCO_3^{-} + SO_4^{2-} + PO_4^{2-}$

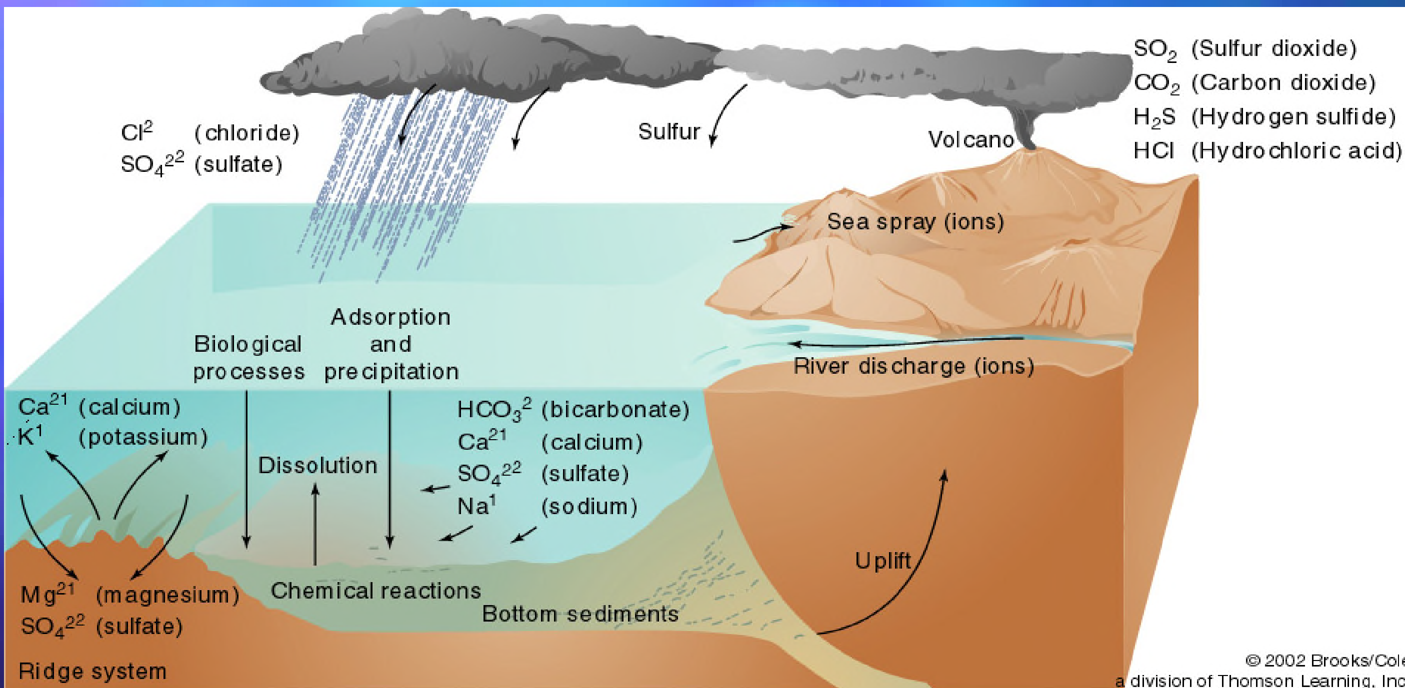


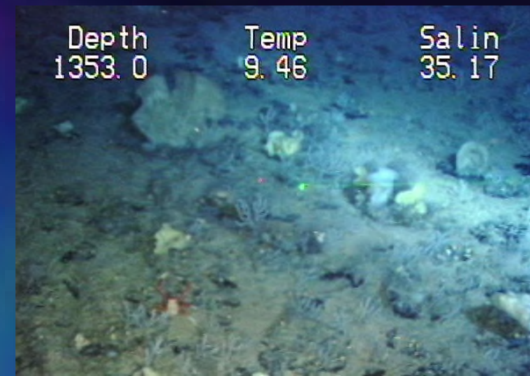
$Ca^{++} + SO_4^{=} \text{-->} CaSO_4$
Mg^{++} + Basalt + H_2O --> $Mg(OH)SiO_3 + H^{+}$

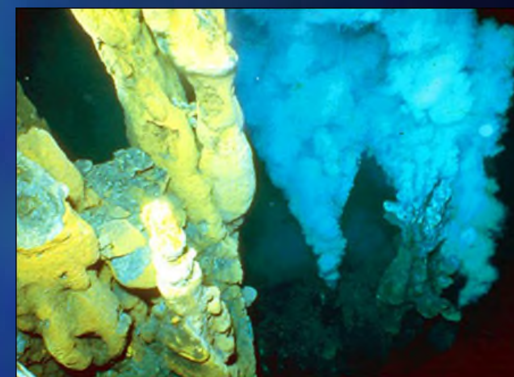
Salt Sources

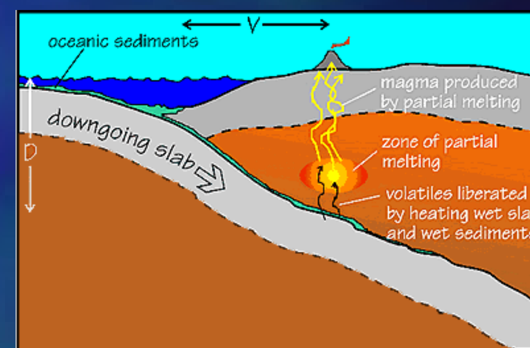
- Land Erosion (via rivers, wind glaciers and groundwater)
- Volcanic eruptions
- Hydrothermal Seafloor Venting
- Bottom Sediment Dissolution

Sinks for Dissolved Solids in Seawater



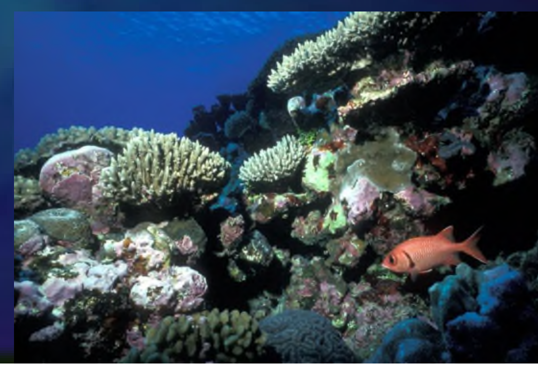






Salt Sinks

- Ocean Bottom Sediments
- Deep Sea Hydrothermal Systems
- Biological Processes
- Subduction of Ocean crust



Seawater – "Residence Time"

- Residence Time - defined

$$\frac{\text{Amount of element/ion in the ocean}}{\text{Rate at which the element/ion is added (or removed from) the ocean}}$$

- Mixing Time of Ocean
  - Calculated to be 1,600 years
  - Based on steady state conditions and effective mixing processes
- Conservative Constituents
  - Occur in constant proportions
  - Have very long residence times
  - Examples: Chloride and Sodium
- Nonconservative Constituents
  - Tied to seasonal or biological cycles
  - Have short residence times
  - Examples: Iron and Aluminum

Table 7.3 Approximate Residence Times for Constituents of Seawater

Constituent	Residence Time (years)
Chloride (Cl^{2})	100,000,000
Sodium (Na^{1})	68,000,000
Magnesium (Mg^{21})	13,000,000
Potassium (K^{1})	12,000,000
Sulfate (SO_4^{22})	11,000,000
Calcium (Ca^{21})	1,000,000
Carbonate (CO_3^{22})	110,000
Silicon (Si)	20,000
Water (H_2O)	4,100
Manganese (Mn)	1,300
Aluminum (Al)	600
Iron (Fe)	200

Residence time of Chloride in the Ocean

R (amount) = $[Cl]_{sw}$ x Ocean Volume

$[Cl]_{sw}$ = 19 g/kg

F (river influx) = $[Cl]_{rw}$ x Global River Discharge

$[Cl]_{rw} \approx$ 6 mg/kg

$$t = \frac{R}{F}$$

$$= \frac{[Cl]_{sw}}{[Cl]_{rw}} \times \frac{\text{Ocean Volume}}{\text{Global River Discharge}}$$

$$= \frac{19}{6 \times 10^{-3}} \times 4 \times 10^{4}$$

$$= 3 \times 10^{3} \times 4 \times 10^{4}$$

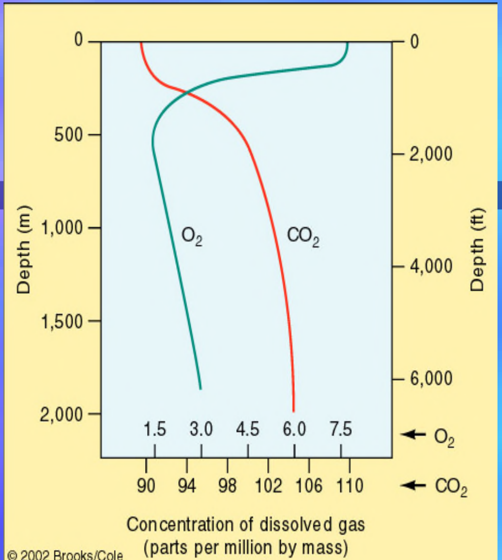
$$= \boxed{1.2 \times 10^{8} = \text{120 million years}}$$

Seawater's Dissolved Oxygen

Major Concepts

- Seawater has 3 major dissolved gases: nitrogen, oxygen, and carbon dioxide.
- Dissolved Gases measured in milliliters per liter (ml/l)
- **Origin** of Dissolved Oxygen in Seawater
  - Byproduct of *Photosynthesis by Phytoplankton*
- **Amount** of Dissolved Oxygen in Seawater Varies
  - **Biological factors:** *Photosynthesis (+) and Respiration (-)*
  - **Physical factors:** *Water Temperature and Pressure*
- Dissolved Oxygen can be measured chemically
- Use modified *Winkler Method* to quantify the amount of dissolved oxygen in unknown seawater samples

Seawater – Dissolved Oxygen



Major Gases in Seawater and Air

Gas	Percent of Gas in Atmosphere, by Volume	Percent of Dissolved Gas in Seawater, by Volume	Concentration in Seawater in Parts per Million, by Mass
Nitrogen (N_2)	78.08%	48%	10–18 ppm
Oxygen (O_2)	20.95%	36%	0–13 ppm
Carbon dioxide (CO_2)[a]	0.035%	15%	64–107 ppm

Enrichment of Oxygen in Seawater

1. Marine Plants (Photosynthesis)
2. Surface mixing with atmosphere
3. Temperature (Decrease)

Depletion of Oxygen in Seawater

1. Marine Animals (Respiration)
2. Temperature (Increase)

3) Pollution

Factors Controlling Dissolved Oxygen Content

1. Biological Factors
   - ✓ Photosynthesis = increase
   - ✓ Respiration = decrease
2. Physical Factors
   - ✓ Water Temperature
   - ✓ Water Agitation (Mixing)
   - ✓ Water Pressure

Seawater Titration – Dissolved Oxygen

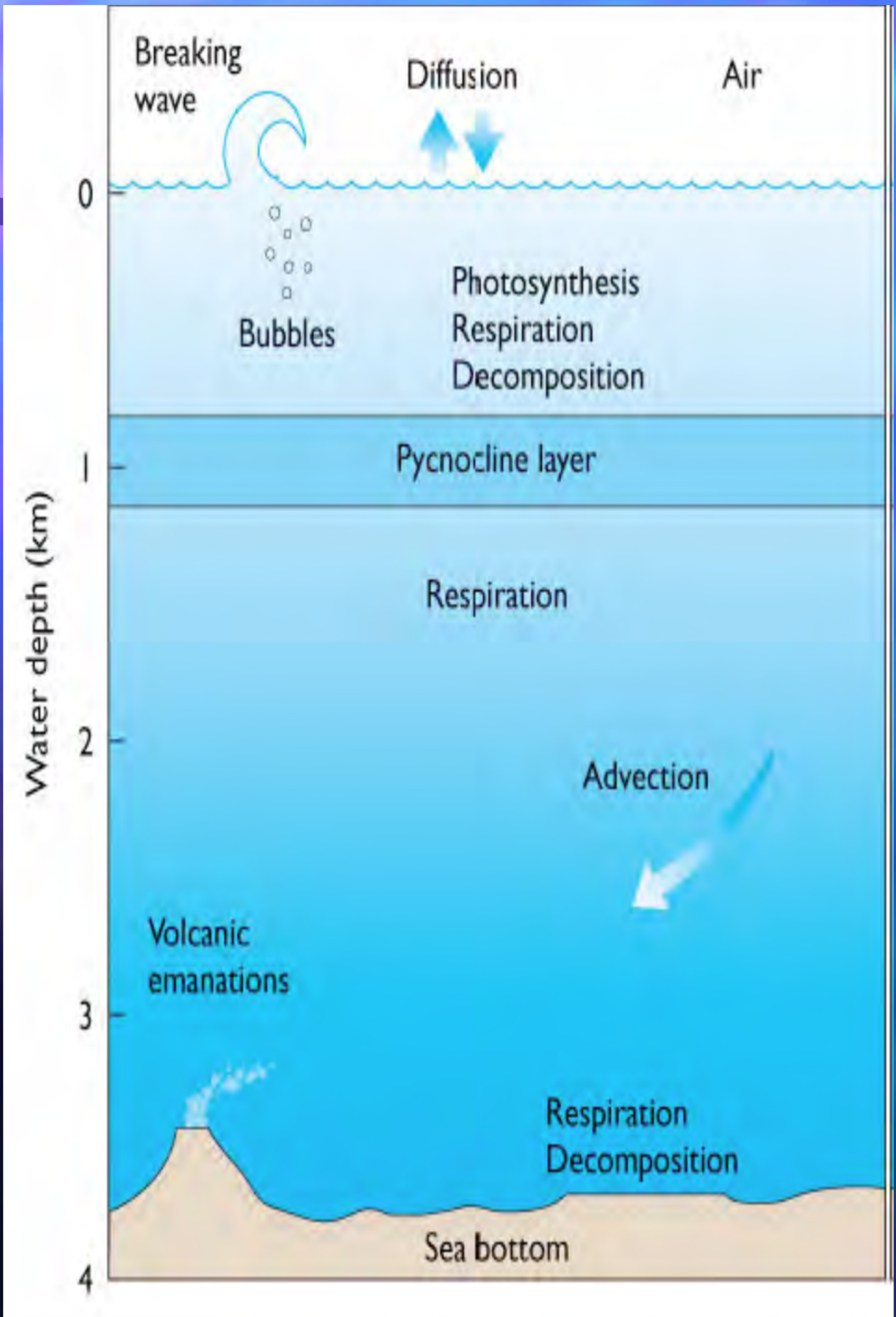
Modified Winkler Method

1. "Fix" Seawater Samples
2. Prepare and Titrate a "Standard" Sample
3. Titrate "Standard" sample

4) Titrate "Unknown" samples

5) Use Titration formula to determine dissolved gas content for Unknown samples

Seawater – Dissolved Gasses



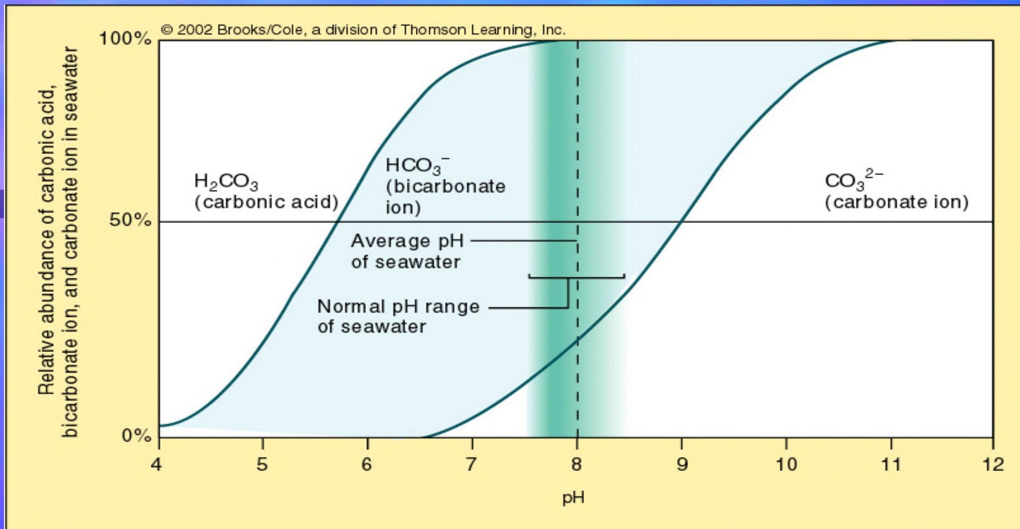
Sources of Gases Entering Ocean

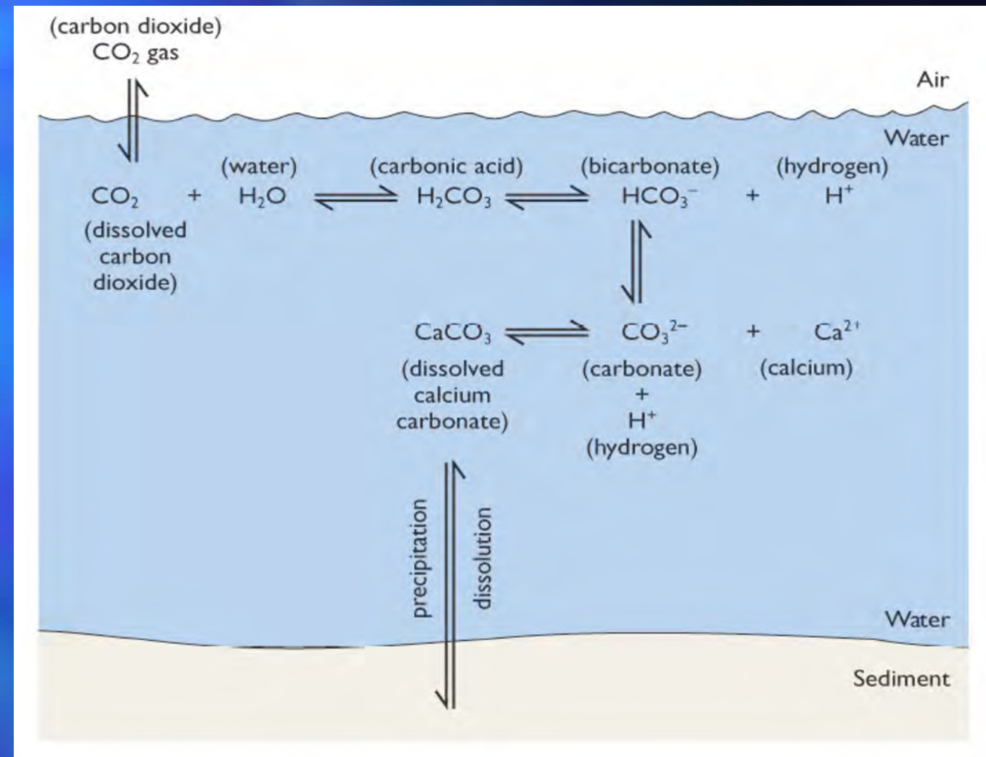
1. Atmosphere (N_2, O_2)
2. Volcanic Activity (H_2S)
3. Chemical Processes (CO_2)
    - Fossil Fuel Burning
4. Biological Processes (O_2, CO_2)

Sinks for Gases Leaving Ocean

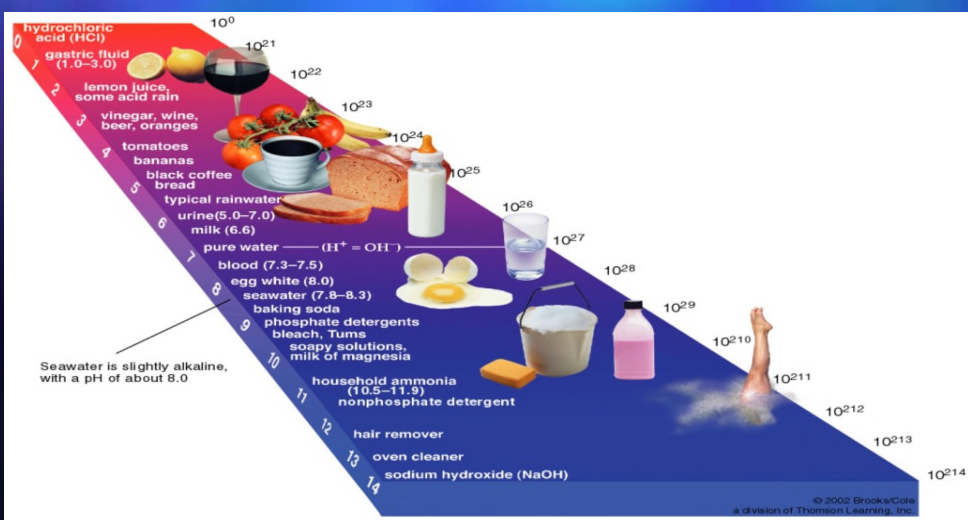
1. Atmosphere (N_2, O_2, CO_2)
2. Chemical Processes (CO_2)
    - Dissolved Carbonate Ions
    - Calcium Carbonate Precipitates
    - Dissolved Sulfate Ions
3. Biological Processes (O_2, CO_2)
    - Photosynthesis
    - Respiration

Seawater Acid-Base Balance





- ✓ Ocean pH average is 8
- ✓ Ocean gets more acidic with depth



The pH Acid-Base Scale

Ocean's Carbonate Buffer System

- Helps maintain a steady pH balance
- Three step acid-base buffer system

Step One: $CO_2 + H_2O \longleftrightarrow H_2CO_3$

Step Two: $H_2CO_3 \longleftrightarrow HCO_3^- + H^+$

Step Three: $HCO_3^- + H^+ \longleftrightarrow CO_32^- + 2H^+$

Ocean Surface Temperature

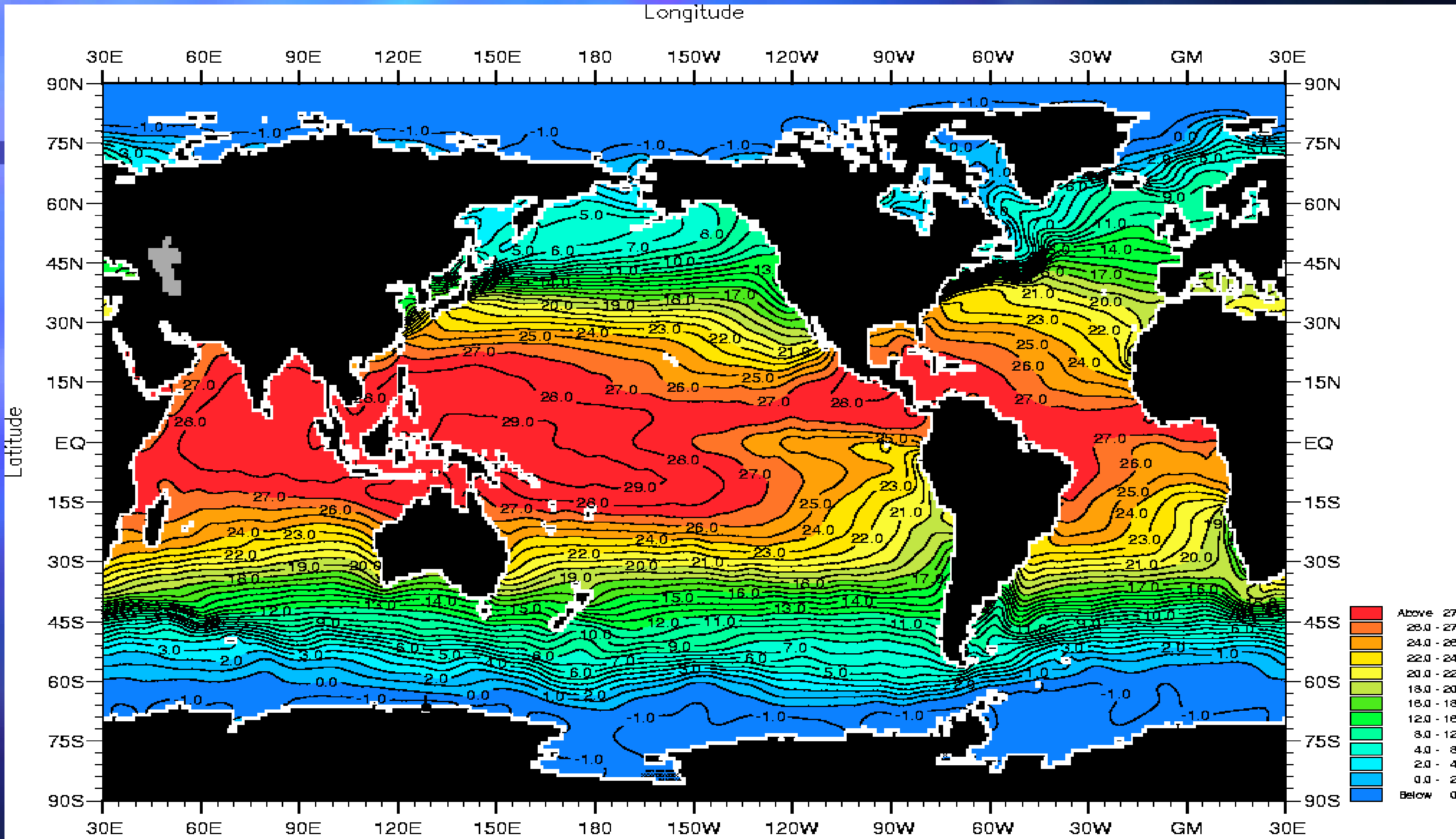


Fig. A2-1. Annual mean temperature (°C) at the surface .

Minimum Value= -1.93 Maximum Value= 29.90 Contour Interval: 1.00

Sea Surface Temperature (Annual mean temperature (°C) at the surface)

- Warmest in low-latitudes
- Coldest in high latitudes

Ocean Surface Salinity

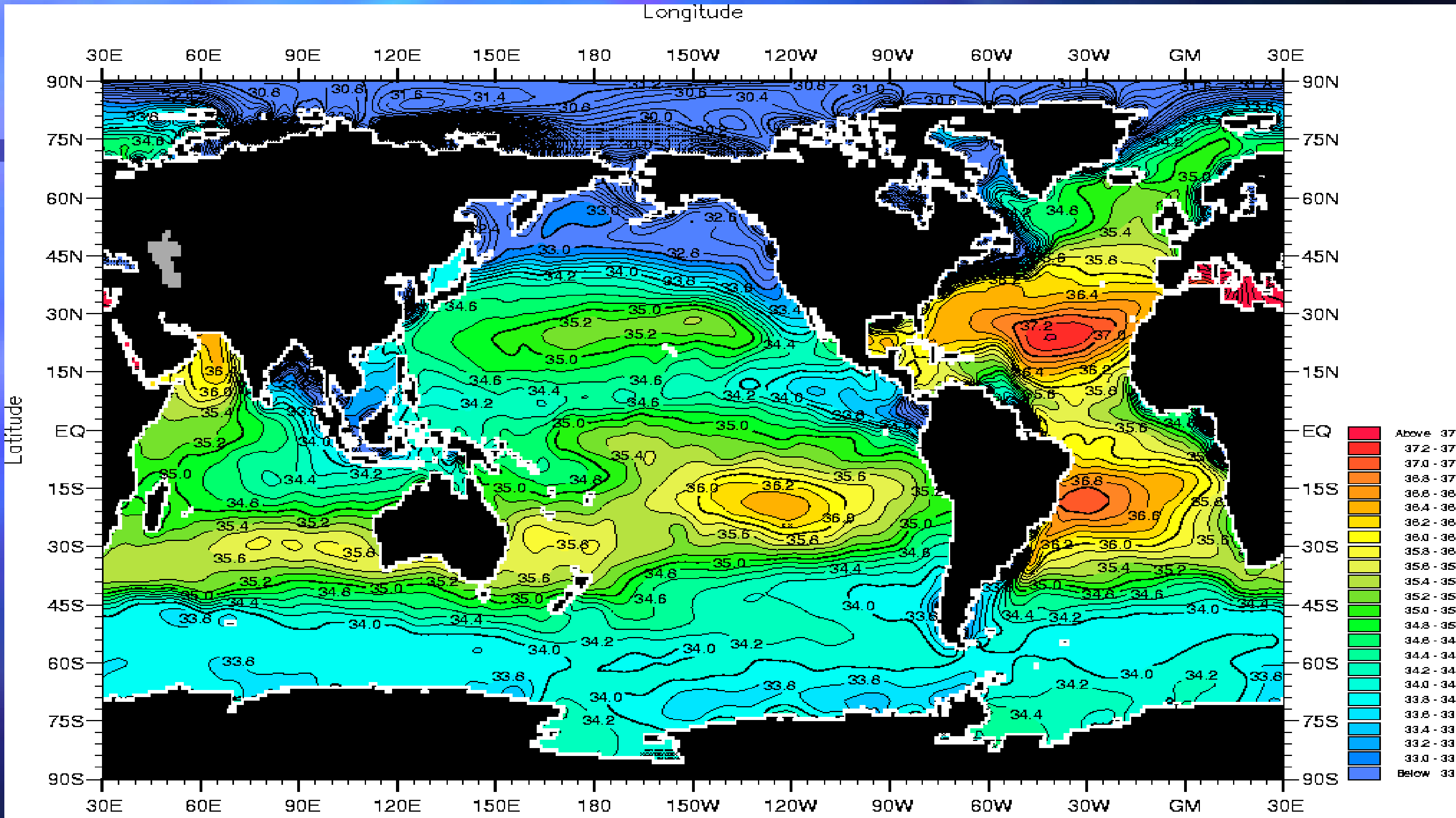


Fig. A2-1. Annual mean salinity (PSS) at the surface .

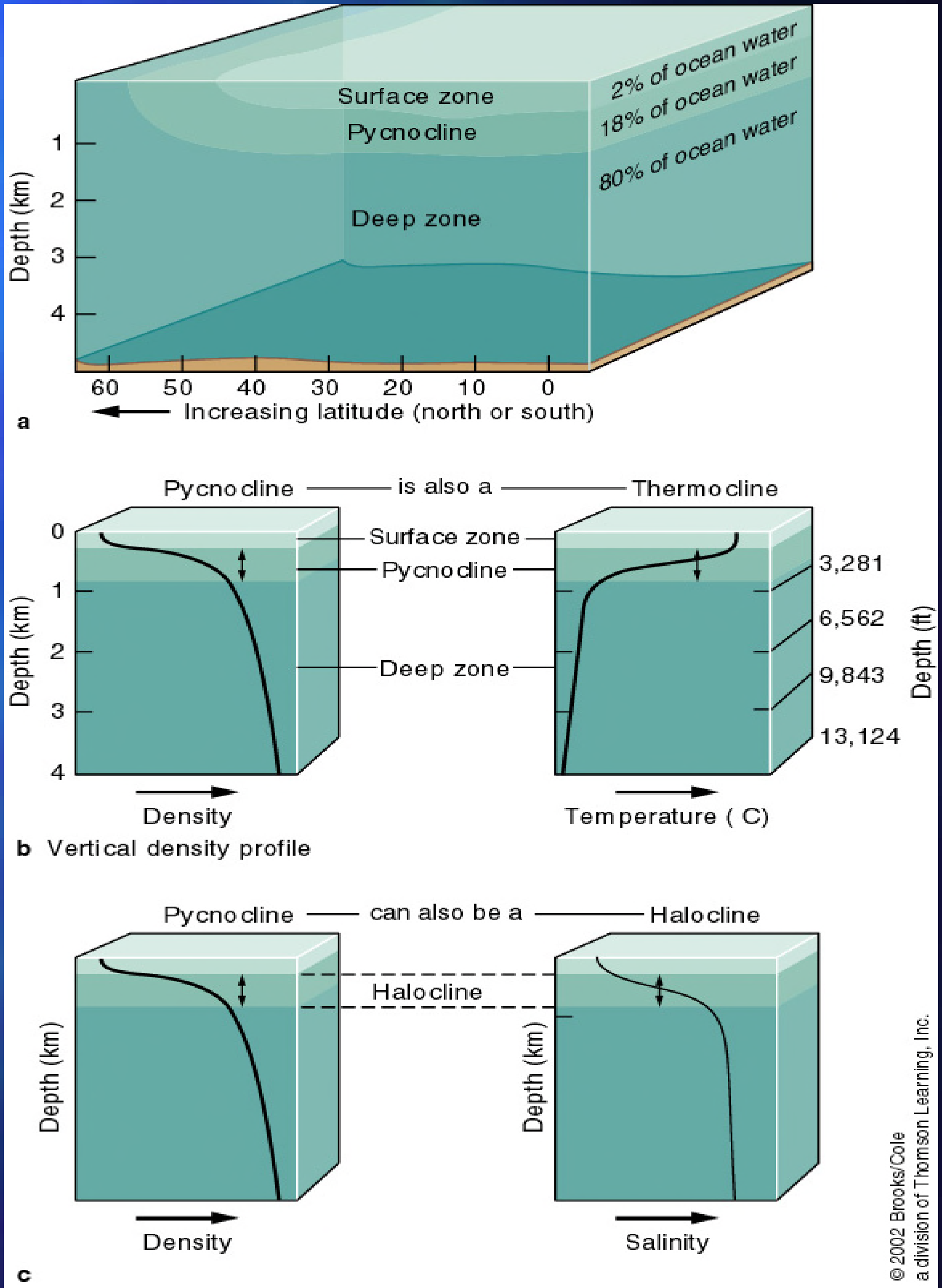
Minimum Value= 3.57 Maximum Value= 40.02 Contour Interval: 0.20

Sea Surface Salinity (Annual mean salinity (PSS) at the surface)

- Saltiest in mid-latitude Atlantic, Pacific and Mediterranean
- Freshest in high latitudes

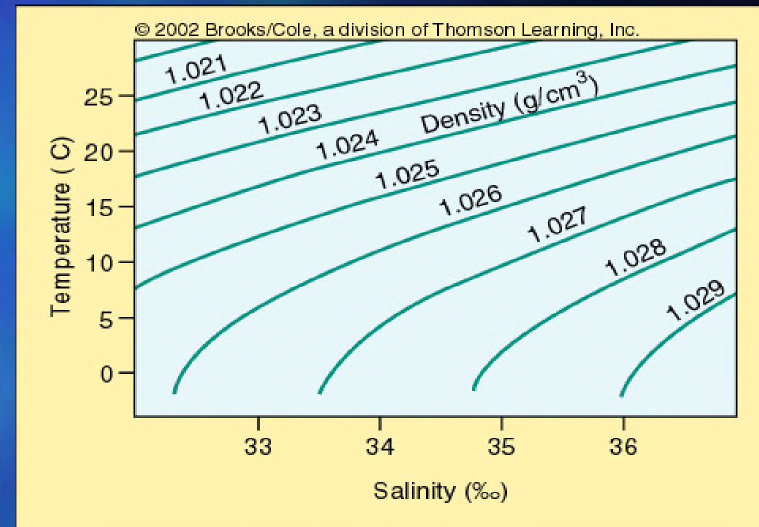
Density Structure of the Ocean

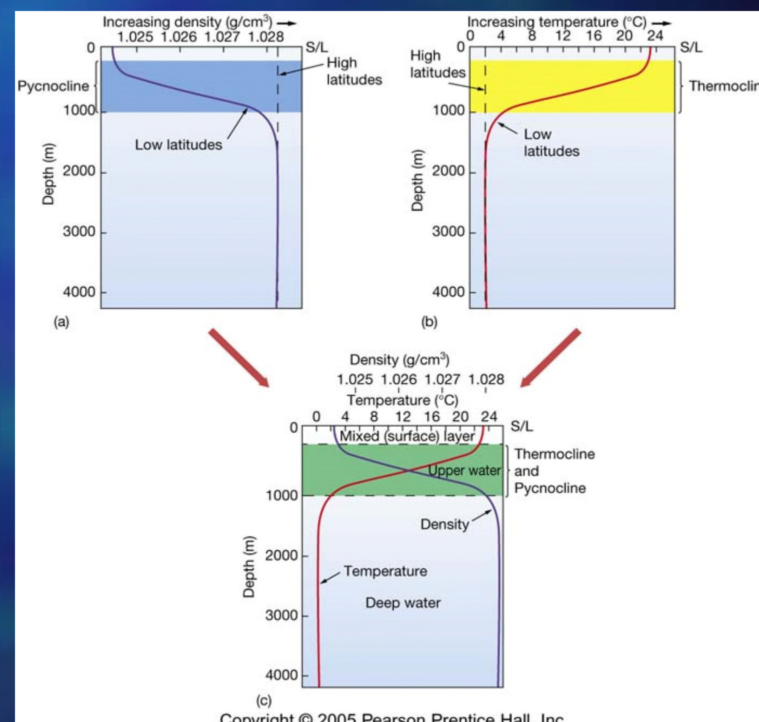
- Ocean divided into three horizontal density layers or zones
  - Surface Zone
  - Pycnocline
  - Deep Zone
- Surface Zone
  - Warmest, least dense
  - Typically extends down to 150 meters
  - Makes up only 2% of ocean
- Pycnocline
  - Density increases with increasing depth
  - Isolates the surface zone from the deep zone
  - Makes up about 18% of ocean
- Deep Zone
  - Top is at about 1000 meters down
  - Coldest, densest
  - Contains about 80% of ocean



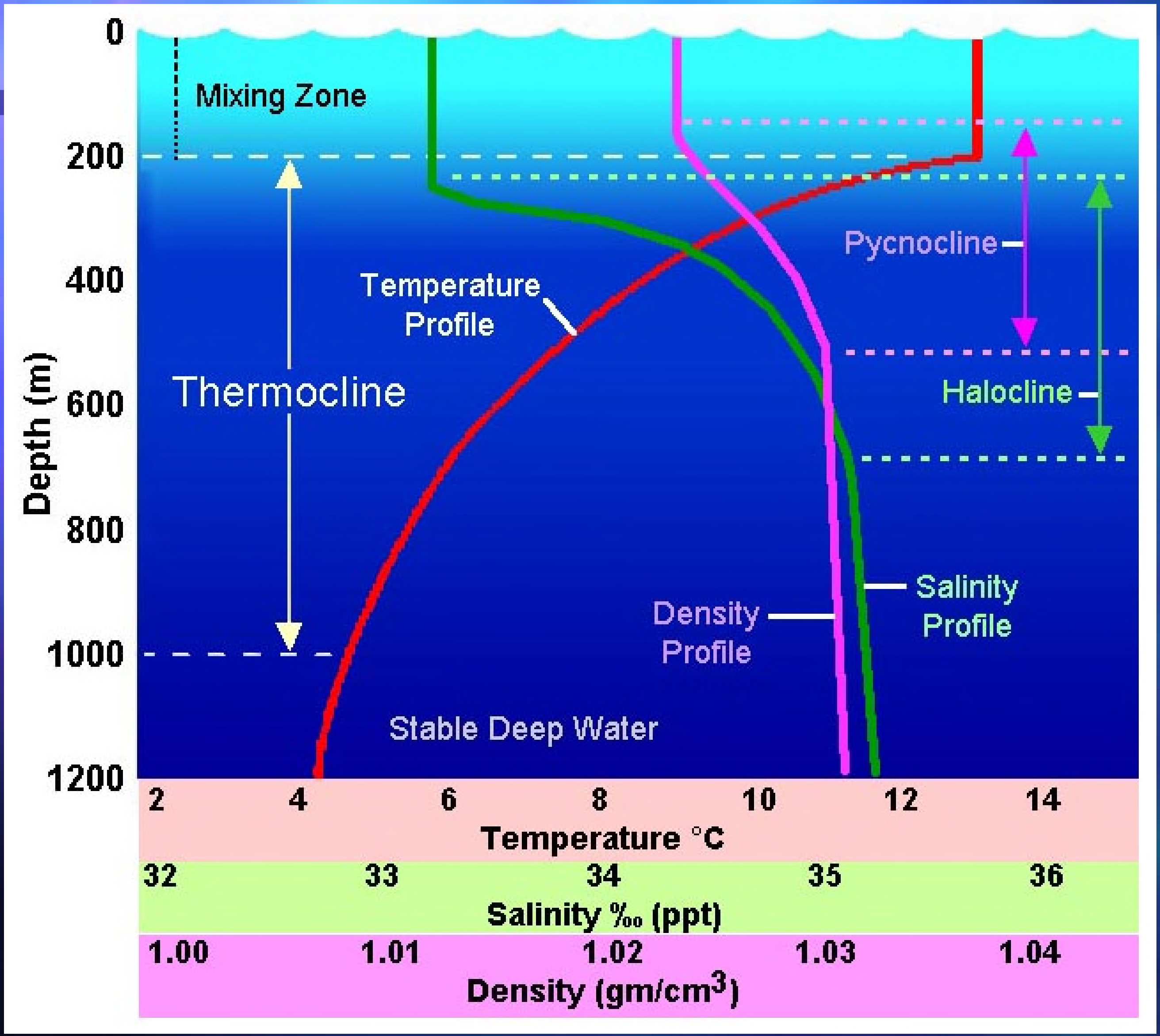
The Ocean's Temperature-Salinity Relationship to Seawater Density

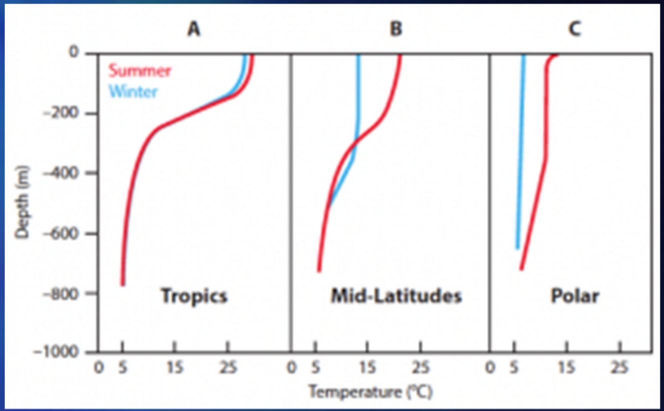
- Density of seawater is function of temperature and salinity
- Two samples of seawater can have same density at different combinations of temperature and salinity
- Seawater tends to form stable density layers
  - Coldest saltiest at the bottom
  - Warmest, least saltiest at the surface
- Changes in ocean temperature and salinity are primarily controlled by surface processes





The Ocean's Temperature-Salinity Relationship to Seawater Density



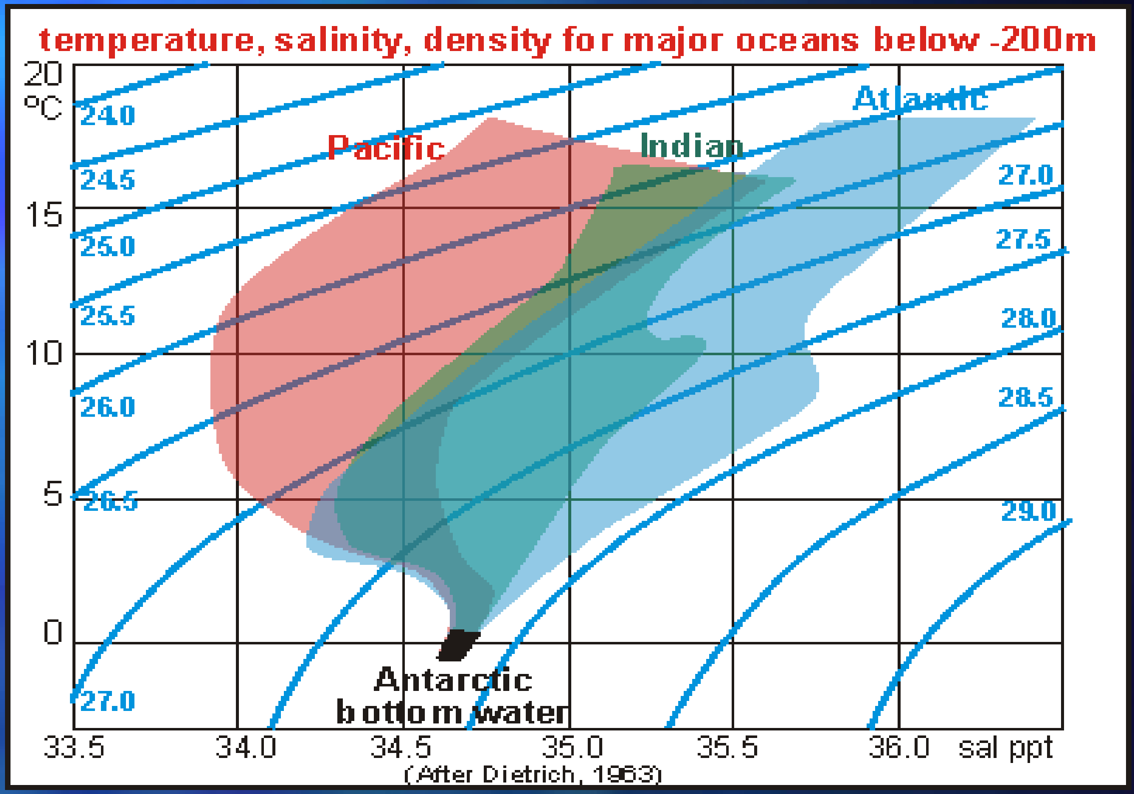


Ocean Temperature Variation According to Season and Latitude

Temp – Salinity - Density Profiles of the Major Oceans

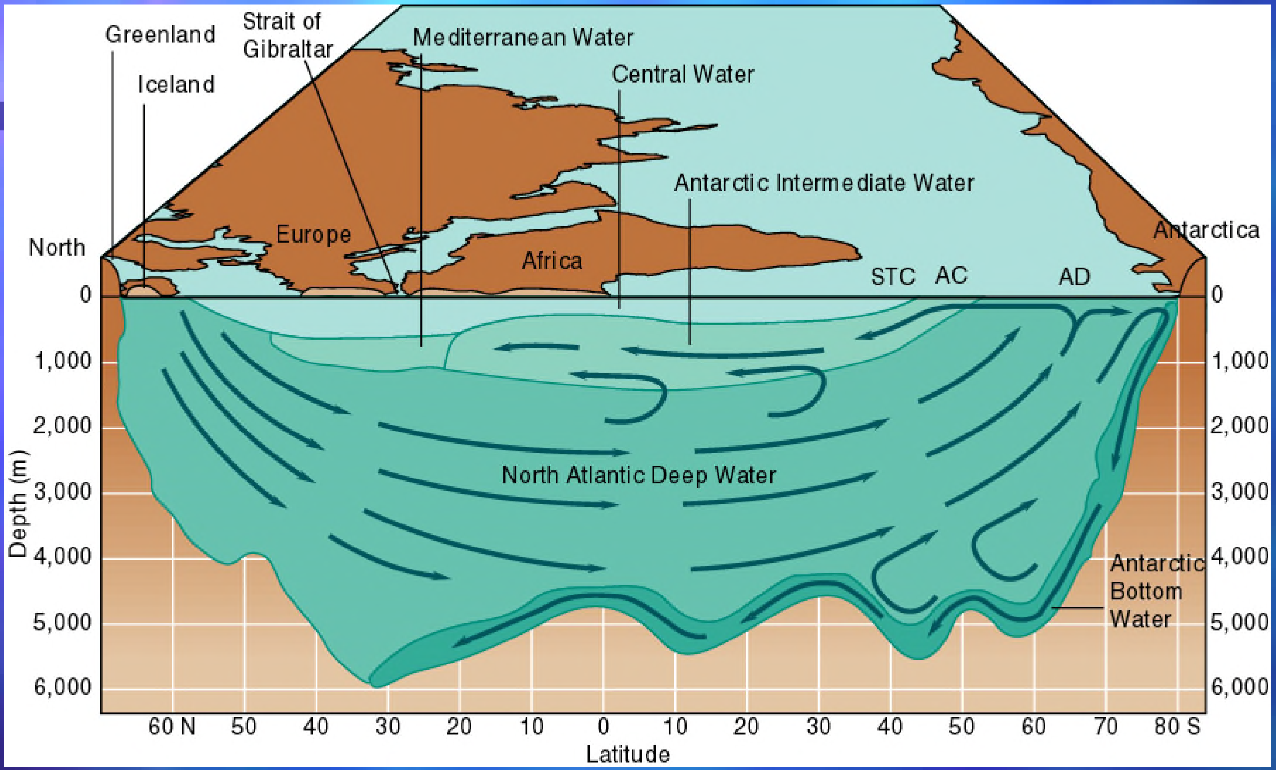
Comparing the Major Oceans

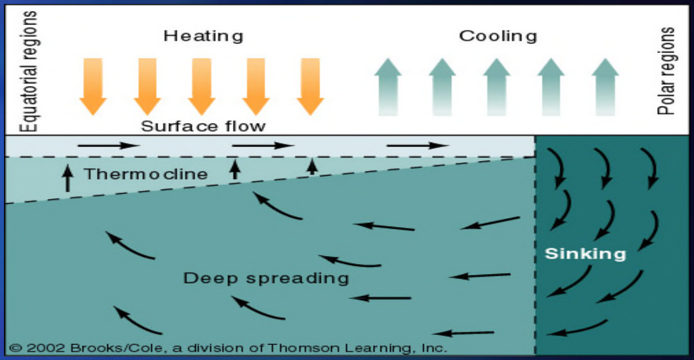
- Pacific Ocean Water
  - Lowest Avg Salinity
  - Intermediate temp variation
  - Least dense
- Atlantic Ocean Water
  - Highest Avg Salinity
  - Greatest temp variation
  - Most dense
- Indian Ocean Water
  - Intermediate Avg Salinity
  - Least temp variation
  - Intermediate density



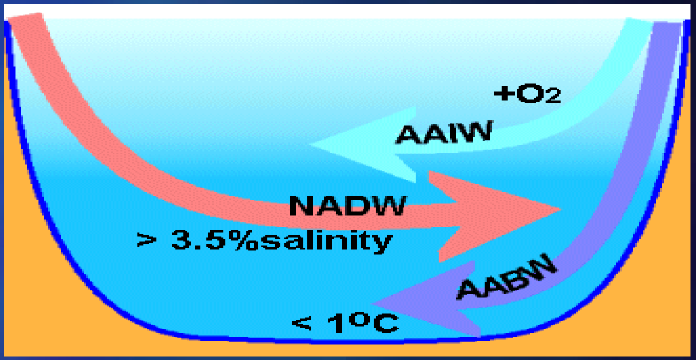
Deep Ocean Water Masses

Deep Circulation in the Atlantic Ocean





Density Circulation Model



Deep Ocean Water Masses

- ✓ Formation and sinking of polar Antarctic Bottom Water (AABW) and North Atlantic Deep Water (NADW) due to super-cooling of surface waters
- ✓ Formation and sinking of Antarctic (due to current convergence) and Mediterranean (due to hyper-evaporation) Intermediate Waters (AAIW and MIW)
- ✓ Very slow lateral deep water current flow and overlapping of water masses

Seawater Chemistry Summary

- **Important Chemical Properties**
  - **Nature's Strongest Solvent**
  - **Saline Solution**
  - **Major, Minor, and Trace Constituents**
  - **Methods of Measuring Salinity**
  - **Sources and Sinks of Sea Salts**
- **Ocean in Chemical Equilibrium**
  - **Stable Salinity**
  - **Constant Proportionality**
  - **Density Stratified Ocean controlled by Seawater Temperature and Salinity**
  - **Buffered pH-balance**
- **Ocean Stratification**
  - **Temperature profile**
  - **Salinity profile**
  - **Density profile**
  - **Ocean Water Masses**