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Lesson 1.2 - Solubility

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AICE Marine Science Study Guide: Water Solubility
Grade 11 | Lesson 1.2 | Intermediate Level

🎯 LEARNING OBJECTIVES

By the end of this study session, you will be able to:
1. **Explain** the molecular basis of water's solvent properties
2. **Identify** factors that affect solubility in marine environments
3. **Analyze** how salinity impacts marine organism distribution
4. **Calculate** basic concentration and solubility problems
5. **Evaluate** the role of dissolved substances in ocean chemistry

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📋 CONTENT PRIORITIZATION GUIDE

🔴 **ESSENTIAL** - Will definitely be on exam
🟡 **IMPORTANT** - Likely to be tested
🟢 **SUPPORTING** - Helpful context

I. WATER AS THE UNIVERSAL SOLVENT

A. Molecular Properties of Water 🔴

1. Polarity and Hydrogen Bonding
- **Water molecule structure**: H_2O with bent geometry
- **Polar covalent bonds**: Oxygen more electronegative than hydrogen
- **Dipole formation**: Partial negative (δ-) on oxygen, partial positive (δ+) on hydrogens

KEY TERM BOX:
Polarity: Uneven distribution of electrical charge in a molecule, creating positive and negative regions

2. Hydrogen Bond Network 🔴
- **Definition**: Weak attraction between H^+ of one molecule and lone pair electrons of another
- **Strength**: ~10% of covalent bond strength
- **Marine significance**: Enables dissolution of ionic and polar compounds

Quick Check: Why is water called the "universal solvent"? What molecular property makes this possible?

B. Solubility Principles 🔴

1. "Like Dissolves Like" Rule
- **Polar substances** dissolve in polar solvents (water)
- **Nonpolar substances** dissolve in nonpolar solvents
- **Ionic compounds** dissociate in polar solvents

2. Hydration Process 🟡
- **Ion-dipole interactions**: Water molecules surround dissolved ions
- **Hydration shell formation**: Multiple water layers around each ion
- **Energy considerations**: Lattice energy vs. hydration energy

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II. FACTORS AFFECTING SOLUBILITY IN MARINE SYSTEMS

A. Temperature Effects 🔴

1. Solubility-Temperature Relationships
- **Most solids**: Solubility ↑ as temperature ↑
- **Gases**: Solubility ↓ as temperature ↑ (inverse relationship)
- **Marine application**: Cold water holds more dissolved O_2

CONNECTION POINT: This explains why polar waters are more oxygen-rich than tropical waters!

2. Thermodynamic Principles 🟡
- **Endothermic dissolution**: Heat required, solubility increases with temperature
- **Exothermic dissolution**: Heat released, solubility decreases with temperature

B. Pressure Effects 🟡

1. Henry's Law for Gases
- **Formula**: C = kP (where C = concentration, k = Henry's constant, P = pressure)
- **Marine application**: Deep ocean waters under high pressure dissolve more gases
- **Decompression effects**: Gas bubbles form when pressure decreases

2. Solid Solubility and Pressure 🟢
- **Generally minimal effect** on solid solubility
- **Exception**: Some salts show slight pressure dependence

C. pH and Chemical Environment 🟡

1. Acid-Base Effects
- **pH influences** solubility of many compounds
- **Carbonate system**: $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
- **Ocean acidification**: Affects shell-forming organisms

Quick Check: How does ocean acidification affect the solubility of calcium carbonate in seawater?

III. SEAWATER COMPOSITION AND SALINITY

A. Major Dissolved Components 🔴

1. Principal Ions (by concentration)
1. **Chloride (Cl^-)**: 55.0% of dissolved salts
2. **Sodium (Na^+)**: 30.6% of dissolved salts
3. **Sulfate (SO_4^{2-})**: 7.7% of dissolved salts
4. **Magnesium (Mg^{2+})**: 3.7% of dissolved salts
5. **Calcium (Ca^{2+})**: 1.2% of dissolved salts
6. **Potassium (K^+)**: 1.1% of dissolved salts

KEY TERM BOX:
Salinity: Total amount of dissolved salts in seawater, typically expressed in parts per thousand (‰) or practical salinity units (PSU)

2. Trace Elements and Nutrients 🟡
- **Nitrogen compounds**: NO_3^-, NO_2^-, NH_4^+
- **Phosphorus**: PO_4^{3-}
- **Silicon**: SiO_4^{4-}
- **Dissolved gases**: O_2, CO_2, N_2

B. Salinity Variations 🔴

1. Global Patterns
- **Average ocean salinity**: 35‰ (35 PSU)
- **Range**: 32-37‰ in open ocean
- **Factors affecting salinity**:
- Evaporation (increases salinity)
- Precipitation (decreases salinity)
- River input (decreases salinity)
- Ice formation/melting

2. Measurement Methods 🟡
- **Conductivity**: Most common modern method
- **Refractometry**: Measures light refraction
- **Titration**: Chemical analysis method

IV. BIOLOGICAL IMPLICATIONS OF SOLUBILITY

A. Osmoregulation in Marine Organisms 🔴

1. Osmotic Challenges
- **Hyperosmotic environment**: Seawater has higher solute concentration than body fluids
- **Water loss tendency**: Organisms tend to lose water to environment
- **Salt gain**: Tendency to accumulate excess salts

KEY TERM BOX:
Osmoregulation: Process by which organisms maintain water and salt balance in their bodies

2. Adaptation Strategies 🟡
- **Bony fish**: Active salt excretion through gills, concentrated urine
- **Sharks**: Urea retention to match seawater osmolarity
- **Marine invertebrates**: Often isosmotic with seawater

B. Nutrient Availability and Distribution 🟡

1. Dissolved Nutrients
- **Limiting factors**: N, P, Si often limit primary productivity
- **Solubility controls**: Affect nutrient availability
- **Upwelling importance**: Brings dissolved nutrients to surface

2. Oxygen Distribution 🔴
- **Surface saturation**: High O_2 from atmospheric exchange and photosynthesis
- **Oxygen minimum zones**: Mid-water regions with low dissolved O_2
- **Temperature effects**: Cold water holds more dissolved O_2

CONNECTION POINT: Remember that oxygen solubility decreases with temperature - this creates vertical oxygen gradients in the ocean!

V. CALCULATIONS AND PROBLEM-SOLVING

A. Concentration Units 🔴

1. Common Units in Marine Science
- **Parts per thousand (‰)**: g solute/kg solution × 1000
- **Molarity (M)**: moles solute/L solution
- **Parts per million (ppm)**: mg solute/L solution
- **Percentage by mass**: (g solute/g solution) × 100

2. Conversion Formulas 🔴
- **Salinity to density**: $\rho \approx 1.025$ g/mL for average seawater
- **ppm to molarity**: ppm ÷ (molecular weight × 1000) = M

Quick Check: If seawater has a salinity of 35‰, how many grams of salt are dissolved in 1 kg of seawater?

B. Solubility Calculations 🟡

1. Solubility Product (Ksp)
- **For ionic compounds**: $Ksp = [A^+]^a[B^-]^b$
- **Precipitation prediction**: Q vs Ksp comparison
- **Marine applications**: Carbonate shell formation

2. Henry's Law Applications 🟡
- **Gas solubility**: $C = kH \times P$
- **Temperature corrections**: kH varies with temperature
- **Depth calculations**: Pressure increases ~1 atm per 10m depth

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🔍 EXAM PREPARATION CHECKLIST

Essential Formulas to Memorize:
- [ ] Henry's Law: C = kP
- [ ] Salinity calculation: ‰ = (g salt/kg seawater) × 1000
- [ ] Pressure-depth relationship: P ≈ 1 atm + (depth in m/10)

Key Concepts for Short Answer:
- [ ] Explain water's polarity and hydrogen bonding
- [ ] Describe factors affecting gas vs. solid solubility
- [ ] Compare osmoregulation strategies in different marine organisms
- [ ] Analyze salinity patterns and their causes

Common Exam Question Types:
1. **Calculate concentrations** in different units
2. **Predict solubility changes** with temperature/pressure
3. **Explain biological adaptations** to marine salinity
4. **Interpret graphs** of solubility vs. environmental factors

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📝 STUDY NOTES SECTION
Use this space for additional notes and connections

My Key Insights:

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Questions to Ask:

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Memory Devices:

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FINAL QUICK CHECK: Can you explain how a change in ocean temperature would affect both oxygen availability for marine life and the solubility of calcium carbonate for shell-forming organisms? This type of multi-concept question is common on AICE exams!