**Chapter 2 Active Reading Guide**

**The Chemical Context of Life**

This chapter covers the basics that you may have learned in your chemistry class. Whether your teacher goes over this chapter, or assigns it for you to review on your own, the questions that follow should help you focus on the most important points.

### Section 1

1. Define and give an example of the following terms:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter</td>
<td>everything that takes up space and has a shape</td>
</tr>
<tr>
<td>Element</td>
<td>a substance that cannot be broken down to other substances by chemical reaction</td>
</tr>
<tr>
<td>Compound</td>
<td>a substance consisting of two or more different elements combined in a fixed ratio.</td>
</tr>
</tbody>
</table>

2. What four elements make up 96% of all living matter?
   - The four elements that make up 96% of all living matter are oxygen, carbon, hydrogen and nitrogen.

3. What is the difference between an *essential element* and a *trace element*?
   - An essential element is an element that an organism needs to live a healthy life and reproduce.
   - A trace element is required by an organism in only minute quantities.

### Section 2

4. Sketch a model of an atom of helium, showing the electrons, protons, neutrons, and atomic nucleus.

5. What is the atomic number of helium? **2**
   Its atomic mass? **4**
6. Here are some more terms that you should firmly grasp. Define each term.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron:</td>
<td>Part of the atom that has no charge</td>
</tr>
<tr>
<td>proton:</td>
<td>Particle positively charged</td>
</tr>
<tr>
<td>electron:</td>
<td>Particle negatively charged</td>
</tr>
<tr>
<td>atomic mass:</td>
<td>An approximation of the total mass of an atom, measured in Daltons</td>
</tr>
<tr>
<td>atomic number:</td>
<td>Indicates the number of protons and electrons in the atom</td>
</tr>
<tr>
<td>isotope:</td>
<td>Elements that have the same atomic # but different atomic mass</td>
</tr>
<tr>
<td>electron shells:</td>
<td>Represented as concentric circles in diagrams; represent the average distance from the nucleus and energy level of e circling the nucleus of an atom.</td>
</tr>
<tr>
<td>energy:</td>
<td>The capacity to cause change, by doing work.</td>
</tr>
</tbody>
</table>

7. Consider the entry in the periodic table for carbon.

What is the atomic mass? 12 _____  What is the atomic number? _6_____  

How many electrons does carbon have? _6__  How many neutrons? _6___

8. What are isotopes? Use carbon as an example.
   - Isotopes are different atomic formations of the same element having more neutrons than other atoms of the same element, and therefore having greater mass. In nature, an element occurs as a mixture of its isotopes. For example carbon C has 3 isotopes.
   - Carbon with mass number 12-99% in nature
   - Carbon with mass number 13- with 7 neutrons
   - Carbon with mass number 14-8 neutrons. All have 6 protons; otherwise they would not be carbon

9. Explain radioactive isotopes and one medical application that use them.
   - A radioactive isotope is one in which the nucleus decays spontaneously giving off particles and energy. When the decay leads to a change in the number of protons, it transforms the atom to an atom of a different element. For example when a radioactive carbon atom decays, it becomes nitrogen. In medicine radioactive tracers are used as a diagnostic tool by injection into the blood and radioactive tracers, and with imaging equipment such as PET scanners to monitor cancer growth.

10. Which is the only subatomic particle that is directly involved in the chemical reactions between atoms?
    - The only subatomic particle that is directly involved in the chemical reactions between atoms is electron.
11. What is potential energy?
   - Potential energy is the energy that matter possesses because of its location or structure.

12. Explain which has more potential energy in each pair:
   a. boy at the top of a slide/boy at the bottom
      - The boy at the top of the slide has more potential energy because of its location.
   b. electron in the first energy shell/electron in the third energy shell
      - The electron in the third energy shell has more potential energy because of its relative distance from the nucleus.
   c. water/glucose
      - Glucose has more potential energy, because of its structure. Energy is stored in chemical bonds and there are more chemical bonds in glucose \( \text{C}_6\text{H}_{12}\text{O}_6 \) than in water \( \text{H}_2\text{O} \).

13. What determines the chemical behavior of an atom?
   - The chemical behavior of an atom is determined by the distribution of electrons in the atomic electron shells.

14. Sketch an electron distribution diagram for sodium:

   ![Electron Distribution Diagram](image)

   a. How many valence electrons does it have? __1__
      Circle the valence electron(s).
   b. How many protons does it have? __11__

**Section 3**

15. Define molecule.
   - Two or more atoms held together by a covalent bond form a molecule.
16. Now, refer back to your definition of a compound and fill in the following chart:

<table>
<thead>
<tr>
<th></th>
<th>Molecule? (y/n)</th>
<th>Compound? (y/n)</th>
<th>Molecular Formula</th>
<th>Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Yes</td>
<td>Yes</td>
<td>H₂O</td>
<td>H-O-H</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>Yes</td>
<td>Yes</td>
<td>CO₂</td>
<td>O=C=O</td>
</tr>
<tr>
<td>Methane</td>
<td>Yes</td>
<td>Yes</td>
<td>CH₄</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>Yes</td>
<td>No</td>
<td>O₂</td>
<td>O=O</td>
</tr>
</tbody>
</table>

17. What type of bond is seen in O₂? Explain what this means.
   - In O₂ there is double covalent bond. Two oxygen atoms form a molecule by sharing two pairs of valence electrons.

18. What is meant by electronegativity?
   - Electronegativity is the attraction of a particular atom for the electrons of a covalent bond,

19. Explain the difference between a nonpolar covalent bond and a polar covalent bond.
   - A nonpolar covalent bond occurs between atoms of the same element, the electrons are shared equally, and their polarity is neutral. A polar covalent bond occurs when one atom is bonded to a more electronegative atom and the electrons are not shared equally.
   - H₂O-polar covalent bond
   - H₂-nonpolar covalent bond

20. Make an electron distribution diagram of water. Which element is most electronegative? Why water is considered a polar molecule? Label the regions that are more positive or more negative. (This is a very important concept. Spend some time with this one!)

   Oxygen is the most electronegative element.
   Water is considered a polar molecule because oxygen is more electronegative than hydrogen, and therefore the shared electrons are pulled toward oxygen.
21. Another bond type is the ionic bond. Explain what is happening in Figure 2.10.
   - The attraction between oppositely charged atoms or ions is an ionic bond. Figure 2.10 represents electron transfer and ionic bonding. The lone valence electron of a sodium atom is transferred to join the 7 valence electrons of chlorine atom. Each resulting ion has a completed valence shell with 8 electrons.

22. What two elements are involved above?
   - The two elements involved are sodium Na and chlorine Cl.

23. Define anion and cation. In the preceding example, which is the anion?
   - An anion is a negatively charged ion. A cation is a positively charged ion. In the preceding example chloride ions are the anion.

24. What is a hydrogen bond? Indicate where the hydrogen bond occurs in Figure 2.12.
   - A hydrogen bond is the noncovalent attraction between a hydrogen and an electronegative atom. In figure 2.12 the hydrogen bond occurs between H₂O and NH₃.

25. Explain van der Waals interactions. Though they represent very weak attractions, when these interactions are numerous they can stick a gecko to the ceiling!
   - Molecules with nonpolar covalent bonds may have positively and negatively charged ions. Electrons are not always symmetrically distributed in such a molecule and may accumulate by chance in one part of the molecule, resulting in regions of positive and negative charges. These ever-changing regions of positive and negative charge enable all atoms and molecules to stick to one another. These Van Der Waals interactions are individually weak, and occur only when atoms and molecules are very close together, but can be powerful when many such interactions occur simultaneously.

26. Here is a list of the types of bonds and interactions discussed in this section. Place them in order from the strongest to the weakest: hydrogen bonds, covalent bonds, ionic bonds, van der Waals interactions.

   **STRONG**
   - Covalent Bonds
   - Ionic Bonds
   - Hydrogen Bonds
   - Van der Waals interactions.

   **WEAK**

27. Use morphine and endorphins as examples to explain why molecular shape is crucial in biology.
   - The precise shape of a molecule is usually very important to its function in the living cell and crucial in biology because it determines how biological molecules recognize and respond to one another with specificity. Morphine and other opiates have similar shape to endorphins, and can therefore mimic the pain-relieving effect of endorphin receptors in the brain.
Section 4

28. Write the chemical shorthand equation for photosynthesis. Label the reactants and the products.

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

Reactants

Products

29. For the equation you just wrote,
   How many molecules of carbon dioxide are there? __6__
   How many molecules of glucose? __1__
   How many elements in glucose? __3__

30. What is meant by dynamic equilibrium? Does this imply equal concentrations of each reactant and product?
   - Dynamic equilibrium means that reactions are still going on, but with no net effect on the concentrations of the reactions and products. Equilibrium does not mean that reactants and products are equal in concentration, but only that their concentrations have stabilized at a particular ratio.

Section 5

31. What is a polar molecule? Why is water considered polar?
   - A polar molecule is a molecule whose charge is unevenly distributed. Water is considered polar because of its unequal sharing of electrons and its V-like shape,

32. Explain hydrogen bonding. How many hydrogen bonds can a single water molecule form?
   - Hydrogen bonding occurs when the slightly positive hydrogen of one mole is attracted to the slightly negative oxygen of a nearby molecule, holding them together. Hydrogen bonds are fragile and at any given moment a substantial percentage of all the water molecules are hydrogen-bonded to their neighbors. Each water molecule can form 4 hydrogen bonds.

33. Distinguish between cohesion and adhesion.
   - Cohesion is the phenomenon of the collective hydrogen bonds holding water together.
   - Adhesion is the clinging of one substance to another.

34. Which is demonstrated when you see beads of water on a waxed car hood?
   - Adhesion: water molecules attached to other water molecules to form a bead

35. Which property explains the ability of a water strider to walk on water?
   - Surface Tension explains the ability of a water strider to walk on water.
36. The calorie is a unit of heat. Define calorie.
   - A calorie is the amount of heat it takes to raise the temperature of 1 kg of H₂O by 1°C

37. Water has high specific heat. What does this mean? How does water’s specific heat compare to alcohol’s specific heat?
   - The specific heat of a substance is defined as the amount of heat that must be absorbed or lost for 1 g of that substance to change its T by 1°C. Water’s specific heat is unusually high at 1 cal/g °C, whereas alcohol’s specific heat is 0.6 cal/g °C.

38. Explain how hydrogen bonding contributes to water’s high specific heat.
   - Heat is absorbed and released when hydrogen bonds form; therefore, a calorie of heat causes a relatively small change in the temperature of water because much of the heat is used to disrupt hydrogen bonds before water molecules can begin moving faster. Additionally when the temperature of water drops slightly, many additional hydrogen bonds form, releasing a considerable amount of energy in the form of heat.

39. Summarize how water’s high specific heat contributes to the moderation of temperature. How is this property important to life?
   - With a high specific heat, a large body of water can absorb and store a huge amount of heat from the sun in the daytime and during summer while warming up only a few degrees. As this water generally cools during the night and during winter, it warms the air, contributing to milder climates in coastal regions

40. Define evaporation. What is heat of vaporization? Explain at least three effects of this property on living organisms.
   - Evaporation is the transformation of a liquid to a gas. The evaporation of water from leaves of a plant helps keep the tissues in the leaves from becoming too warm in the sunlight. This evaporation of sweat from human skin dissipates body heat and helps prevent overheating on a hot day or as a result of excess heat created by strenuous activity.

41. Ice floats! So what? Consider what would happen if ponds and other bodies of water accumulated ice at the bottom. Describe why this property of water is important.
   - If ice sank, eventually ponds, lakes and oceans would freeze solid and only a few inches at the top would thaw during the summer. Because ice floats, the upper frozen layer insulates the liquid water below, keeping it from freezing and allowing life to exist beneath the surface. Additionally, the frozen layer provides a solid habitat for some animals, such as polar bears and seals.

42. Now, explain why ice floats. Why is 4°C the critical temperature?
   - As a result of hydrogen bonding, water expands as it solidifies. At 4°C water acts like other liquids, expanding as it warms and contracting as it cools. Below 4°C water begins to freeze as more and more hydrogen molecules are moving too slowly to break the hydrogen bonds. Hydrogen bonds keep the molecules far enough apart to make ice about 10% less dense than water at 4°C; it is the lower density of ice that allows it to float.

43. Review and define these terms:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>solvent:</td>
<td>The dissolving agent of a solution</td>
</tr>
<tr>
<td>solution:</td>
<td>A homogenous mixture of two or more substances</td>
</tr>
<tr>
<td>solute:</td>
<td>The substance that is dissolved</td>
</tr>
</tbody>
</table>
44. Consider coffee to which you have added sugar. Which of these is the solvent? Which is the solute?
   - Coffee is the solvent and sugar is the solute.

45. Explain why water is such a fine solvent.
   - Water is such a fine solvent because of the polarity of the water molecule. Water can dissolve ionic compounds, many compounds made up of nonionic polar molecules, as well as molecules such as proteins if they have polar and ionic regions on their surface.

46. Distinguish between hydrophobic and hydrophilic substances. Give an example of each.
   - Hydrophilic - any substance that has an affinity for water. Example; cotton
   - Hydrophobic - substances that are nonionic and repeal water. Example - vegetable oil.

47. You already know that some materials, such as olive oil, will not dissolve in water. In fact, oil will float on top of water. Explain this property in terms of hydrogen bonding.
   - Oil molecules cannot form hydrogen bonds with water and behave hydrophobically, because there is a prevalence of relatively nonpolar covalent bonds - in this case, bonds between the carbon and hydrogen, which share electrons almost equally.

48. Now, let’s do a little work that will enable you to prepare solutions. Read the section on solute concentrations carefully, and show the calculations here for preparing a 1-molar solution of sucrose. Steps to help you do this follow. The first step is done for you. Fill in the rest.

   **Steps to prepare a solution:**
   a. Write the molecular formula.  
      \[ \text{C}_{12}\text{H}_{22}\text{O}_{11} \]
   b. Use the periodic table (on Page B-1) to calculate the mass of each element. Multiply by the number of atoms of the element. (For example, O has a mass of 16. Therefore, one mole of O has a mass of 16 x 11 = 176 g/mole.)
      - \( \text{C}_{12} = 12 \times 12 = 144 \text{g/mol} \)
      - \( \text{H}_{22} = 22 \times 1 = 22 \text{g/mol} \)
      - \( \text{O}_{11} = 11 \times 16 = 176 \text{g/mol} \)
   c. Add the masses of each element in the molecule
      - 144 + 22 + 176 = 342 g.
   d. Add this mass of the compound to water to bring it to a volume of 1 liter. This makes 1 liter of a 1 M (1-molar) solution.
      - 342 g/mol to make 1 liter of a M
49. Can you prepare 1 liter of a 0.5-molar glucose solution? Show your work here.

\[ C_6H_{12}O_6 \]
- \( C_6 = 6 \cdot 12 = 72 \)
- \( H_{12} = 12 \cdot 1 = 12 \)
- \( O_6 = 6 \cdot 16 = 96 \)

\( 72 + 12 + 96 = 180 \) mole

0.5g = 90g. Add this mass of the compound to water, bring it to the volume of 1l. This makes 1l of 0.5M solution.

50. Define molarity.
- Molarity is the number of moles of solute per liter of solution-is the unit of concentration most often used by biologists for aqueous solution.

51. What two ions form when water dissociates?
- The two ions that form when water dissociates are hydronium ions \( H_3O^+ \) and hydroxide ions \( OH^- \).

52. What is the concentration of each ion in pure water at 25°C?
- The concentration of each ion in pure water at 25°C is \( 10^{-7} \)M.

53. \( pH \) is defined as the negative log of the hydrogen ion concentration \([H^+]\). Explain how water is assigned a \( pH \) of 7.
  - The concentration of \( H^+ \) is \( 10^{-7} \).
  - \( \log_{10}10^{-7} = -7 \log_{10}10 = -7 \). \( pH \) of water is 7.

54. To go a step further, the product of \( H^+ \) and \( OH^- \) concentrations is constant at \( 10^{-14} \).

\[ [H^+][OH^-] = 10^{-14} \]

Water, which is neutral with a \( pH \) of 7, has an equal number of \( H^+ \) and \( OH^- \) ions. Now, define

**Acid:** a substance that increases the hydrogen ion concentration of a solution.

**Base:** a substance that reduces the hydrogen ion concentration of a solution.

55. Because the \( pH \) scale is logarithmic, each numerical change represents a 10X change in ion concentration.

a. How many times more acidic is a \( pH \) of 3 compared to a \( pH \) of 5? \( 10^2 = 100 \)

b. How many times more basic is a \( pH \) of 12 compared to a \( pH \) of 8? \( 10^4 = 10000 \)

c. Explain the difference between a \( pH \) of 8 and a \( pH \) of 12 in terms of \( H^+ \) concentration.
  - The \( H^+ \) concentration of a \( pH \) 12 is \( 10^4 \) times greater than that of a \( pH \) of 8.
56. Even a slight change in pH can be harmful! How do buffers moderate pH change?
A buffer is a substance that minimizes changes in the concentration of H\(^+\) ions and OH\(^-\) in a solution. It does so by accepting hydronium ions from the solution when they are in excess and donating hydronium ions to the solution when they have depleted. Most buffer solutions contain a weak acid and its corresponding base, which combine reversibly with hydronium ions.

57. Exercise will result in the production of CO\(_2\), which will acidify the blood. Explain the buffering system that minimizes blood pH changes.
Carbonic acid H\(_2\)CO\(_3\) is formed when CO\(_2\) reacts with H\(_2\)O in the blood plasma. Carbonic acid dissociates to yield a bicarbonate ion HCO\(_3^-\) and hydrogen ion H\(^+\). The chemical equilibrium between carbonic acid and bicarbonate acts as a pH regulator, the reaction shifting from left or right as other processes in the solution add or remove hydrogen ions.

58. Acid precipitation is increasing. What is the pH of uncontaminated rain?
- The pH of uncontaminated rain is about 5.6.

59. Give two reasons precipitation is more acidic today compared to 1900.
- The burning of wood and fossil fuels releases oxides of sulfur and nitrogen that react with water in air, forming sulfuric and nitric acids. Post-industrial Revolution, the burning of fossil fuels and other industrial technology uses have increased the acidity of precipitation. For example the increase in automobile emissions alone.
- The burning and destruction of vast areas of forest, particularly tropical rain forest destruction, also contributes to the problem. The deforestation has the double-whammy effect of adding CO\(_2\) from the burning of organic material and the loss of huge numbers of photosynthetic plants, which remove CO\(_2\), from the atmosphere.

60. What products of fossil fuel burning contribute to acid precipitation?
- The burning of fossil fuels releases gaseous compounds into the atmosphere. When these compounds react with water, the water becomes more acidic, altering the delicate balance of conditions for life on Earth.

61. Discuss how CO\(_2\) emissions affect marine life and ecosystems.
- CO\(_2\) dissolves in seawater creating carbonic acid, which lowers the pH of the ocean causing ocean acidification. Ocean acidification decreases the carbonate concentration, which is required for calcification by many marine organisms. Additionally, CO\(_2\) emissions create acid precipitation that damages life in streams and lakes and adversely affects life on land by altering soil chemistry.