Review Questions
Water

1. Diagram a water molecule.

![Water Molecule Diagram]

Bohr Model of H₂O

2. What kind of intramolecular chemical bond holds the hydrogen atoms to the oxygen?
   Each hydrogen atom bonds to the oxygen with a polar covalent bond. These hydrogen atoms are each sharing a pair of electrons with oxygen. Since hydrogen needs one more electron to fill its valence shell and oxygen needs two, the oxygen shares two pairs of electrons with its hydrogen companions. This arrangement involves the shared electrons alternately orbiting the hydrogen nucleus and oxygen nucleus.

3. What causes the unequal sharing of electrons between the hydrogen atoms and the oxygen?

The atom of each type of element has a different level of attractiveness to electrons. This attractiveness is called electronegativity (see figure to the left). Electrons are very strongly attracted to
an oxygen atom. Oxygen is said to have a high electronegativity. Hydrogen, on the other hand, has a lower electronegativity than oxygen. Electrons are not as attracted to a hydrogen atom. Remember, in a covalent bond electrons are shared between atoms. What happens when there is a difference in electronegativity between the atoms? Well, the electrons will spend more time orbiting the nucleus of the more electronegative one and less time orbiting around the nucleus of the less electronegative atom. This unequal sharing is called a polar covalent bond.

4. Why is water a polar molecule?

Water is polar because of the unequal sharing of electrons between oxygen and the hydrogen atoms. Electrons have a negative charge and since they are spending more time orbiting the oxygen nucleus than the hydrogen nucleus a slight difference of charge results on either end of the molecule. Near the oxygen end, there is a slight negative charge. The electrons are spending more time with oxygen. Near the hydrogen end there is a slight positive charge. The electrons are spending less time with hydrogen. So now we have a molecule with a slightly negative pole and a slightly positive pole. Molecules that have this unequal sharing, like water, are called polar molecules. Ammonia (NH₃) is a good example.

5. Why can two water molecules stick to each other? What kind of intermolecular chemical bond is this?

Since the water molecule is polar, meaning it has a positive end and a negative end, it will bond to other polar molecules or things that are charged because of electrostatic attraction (opposite charges attract). When a polar molecule bonds to another polar molecule or a charged entity it will form a weak bond called a hydrogen bond. Since all water molecules are polar they easily hydrogen bond to each other. This polarity gives water some unique qualities that are important to living organisms. A single water molecule can form hydrogen bonds with four water molecules at the same time.
6. List the unique properties of water.
   - Powerful solvent
   - Cohesion
   - Adhesion
   - Capillary action
   - Surface tension
   - High specific heat
   - High heat of vaporization
   - Expansion upon freezing

7. Why should water really be a gas at room temperature and not a liquid?
   Water has a low molecular weight. If you add up all the protons and neutrons (these carry most of the mass) of the oxygen and the two hydrogens it equals 18 atomic mass units (amu). Molecular oxygen ($O_2$) is a gas at room temperature and weighs more than water; 32 amu. Since a molecule of water weighs less it should be a gas at room temperature. The reason water is a liquid at room temperature is that the water molecules stick to each other with hydrogen bonds and make it difficult for any one water molecule to break free and evaporate (become a gas). If water was non-polar, it could not form hydrogen bonds and therefore would be a gas at room temperature.

8. Why is water a powerful solvent?
   Since water is polar and will bond to most charged substances, it will often separate a solute’s mass into individual molecules and/or ions. A good example is a salt crystal. Water molecules will surround individual Na⁺ and Cl⁻ and break them off the crystal. Pretty soon the entire salt crystal is dissolved. Water dissolves more substances than any other. In geology, water is the major cause of erosion. Water dissolves the minerals that make up rocks. In biology, our blood and other body fluids are mostly water. The water in the blood dissolves nutrients, salts, proteins, hormones, respiratory gases, and waste and moves them from one cell to another. We require this property to maintain life.

9. Contrast adhesion and cohesion.
   Cohesion is “like sticking to like”. Adhesion is unlike substances sticking together. Since water is polar, it sticks to other polar molecules and other charged substances. Water molecules form hydrogen bonds with other water molecules. They cohere to one another.

   Water sticking to other things is adhesion. When you get wet, water is forming hydrogen bonds to the charged substances on the surface of your skin. Anything that is wetable has charges on its surface to which water can bond. Some substances are non-polar. Fats and oils, for example, don’t mix with water. They are electrically balanced and so no hydrogen bonding occurs and so no adhesion.
10. **Explain capillary action.**

Capillary action is the spontaneous movement of water up a small diameter tube against gravity. The smaller the diameter of the tube, the higher the water moves. There are two forces at work here. Water molecules adhere to the interior wall of the tube plus water molecules stick to each other inside the tube. It comes down to the idea that it is the adhering molecules that support (hold up) the cohering molecules. The reason that a smaller diameter tube has a higher water level is that the ratio of adhering molecules to cohering molecules is closer to being equal. Compared to a larger diameter tube, there are more adhering molecules relative to cohering molecules. The more adhesion relative to cohesion, the higher the water moves inside the tube.

![Diagram of capillary action](image)

11. **Explain the surface tension of water.**

When water is a liquid, the water molecules form hydrogen bonds with the water molecules surrounding them. However, at the air-water interface, the water molecules can’t bond to any water above themselves because there isn’t any. So these water molecules form extra hydrogen bonds with the water to the sides. This extra bonding creates a tough thin film at the surface of the water. It is strong enough to support small mass objects like insects. Surface tension also explains how a cup can be filled above the brim without spilling.

![Diagram of surface tension](image)
12. Explain the high specific heat of water.

Specific heat is a measure of the energy required to heat a substance one degree Celsius. Water has a fairly high specific heat. Water requires a lot of energy to raise its temperature. The reason for this is that all the hydrogen bonds holding water molecules to each other are tough to break. You really have to apply a lot of heat to break these bonds.

<table>
<thead>
<tr>
<th>Substance</th>
<th>cJ kg⁻¹ K⁻¹</th>
<th>Substance</th>
<th>cJ kg⁻¹ K⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>900</td>
<td>Ice</td>
<td>2100</td>
</tr>
<tr>
<td>Iron/steel</td>
<td>450</td>
<td>Wood</td>
<td>1700</td>
</tr>
<tr>
<td>Copper</td>
<td>390</td>
<td>Nylon</td>
<td>1700</td>
</tr>
<tr>
<td>Brass</td>
<td>380</td>
<td>Rubber</td>
<td>1700</td>
</tr>
<tr>
<td>Zinc</td>
<td>380</td>
<td>Marble</td>
<td>880</td>
</tr>
<tr>
<td>Silver</td>
<td>230</td>
<td>Concrete</td>
<td>850</td>
</tr>
<tr>
<td>Mercury</td>
<td>140</td>
<td>Granite</td>
<td>840</td>
</tr>
<tr>
<td>Tungsten</td>
<td>135</td>
<td>Sand</td>
<td>800</td>
</tr>
<tr>
<td>Platinum</td>
<td>130</td>
<td>Glass</td>
<td>670</td>
</tr>
<tr>
<td>Lead</td>
<td>130</td>
<td>Carbon</td>
<td>500</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>14000</td>
<td>Ethanol</td>
<td>2400</td>
</tr>
<tr>
<td>Air</td>
<td>716</td>
<td>Paraffin</td>
<td>2100</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1040</td>
<td>Water</td>
<td>4186</td>
</tr>
<tr>
<td>Steam</td>
<td>2000</td>
<td>Sea water</td>
<td>3900</td>
</tr>
</tbody>
</table>

If you are a cook, you know that it takes a long time to get water up to boiling and conversely it also takes a long time for water to cool down. For living organisms, water is a great way to prevent big temperature fluctuations. For example, air temperature may fluctuate 30 degrees Fahrenheit during the day but water in a pond or lake may only change a few degrees. This produces a fairly constant environment for aquatic life. Humans are mostly water too. The average adult male is 60% water and women are around 55%. Just like an aquatic environment, all this body water helps prevent temperature fluctuations. As we move into our golden years, our water content declines (45%) which makes us more susceptible to cold and heat. Another application of this property is climate. Seattle and Minneapolis are at the same latitude. Seattle has mild winters and cool summers. Minneapolis on the other hand has really cold winters and hot summers. Why the difference? Well, Seattle is near the Pacific Ocean. It takes a long time to cool off the ocean in the winter so the water retains heat. This makes winters in Seattle fairly mild. On the other hand, it takes a long time to warm up the ocean in the summer, the ocean stays cool longer. This makes summers in Seattle relatively cool.

13. Explain the high heat of vaporization of water

Similar to high specific heat, the heat of vaporization is a measurement of how much energy is required to turn a liquid into a gas. Water has a high heat of vaporization. Water requires a tremendous amount of heat energy to make it evaporate. Water is a great heat absorber. When we are hot and sweat. That thin layer of water can absorb a lot of heat energy coming off our bodies. As some water molecules move fast enough to break their hydrogen bonds and become a gas, the average
temperature of the water declines. A good analogy of this is a foot race. If we had everyone in school run a 100 meter dash. And we took the fastest 10% of the runners and transferred them to another school, what would happen to the average speed of the school? Of course, it would drop. In the same way, when water evaporates, the less energetic molecules are left behind and so the average kinetic energy is less and so the temperature decreases.

14. Explain the properties of ice
Water is one of the few compounds that become less dense as a solid. In fact, when water freezes, its’ volume increases by 9%. That means that ice floats in water. What happens is this. In the freezing process, the water molecules move farther away from each other than they were as a liquid.

Thank goodness ice floats! If ice were like most other substances and was denser as a solid; lakes, ponds, oceans would all freeze from the bottom up. We would be living in an ice-bound world with only the surface melting during the summer months.

So if water is less dense as ice, at what temperature is water the most dense? Four degrees Celsius. In fact, during the winter, the water at the bottom of the pond is warmer than the layer of ice at the top. When water becomes a solid, its expansion force is awesome: 36,000 lb/sq in. This force is strong enough to crush and split solid rock. Ice is one of the major eroding agents of landscapes.