The Chemical Basis of Life 2

You may have read something like "The value of all the chemicals in the human body is about 97 cents." This sounds pretty cheap, but putting a price tag on our chemicals misses an important point. This book was written on a computer. If you hit the computer with a sledgehammer, the chemicals in the pile of junk would be worth a lot less than I paid for the computer. But the value of the computer has less to do with the kinds of materials that go into it than how the materials are arranged. Like computers, living things are made from a few kinds of atoms obtained from water, soil, and air. These atoms, following a few basic laws, form the molecules and cells of a human being or a pine tree. What is special about life is not the chemicals themselves but the way they are organized to do what living things do—from the DNA that controls every cell to the valves that regulate the flow of blood through the heart. It is easy to believe that a human being is made up of 97 cents' worth of chemicals; the truly amazing thing is that 97 cents' worth of chemicals can make a human being. This chapter is about the chemicals of life and the rules they follow in shaping a living thing.

Organizing Your Knowledge

Exercise 1 (Introduction)

Thomas Eisner's research has revealed some of the roles of chemical messages in the lives of plants and animals. Review some of them by stating whether each of the following statements is true or false.

_____ 1. The rattletrap moth is protected from predators by a chemical it obtains from a plant.

_____ 2. Chemicals secreted by ovulating human females attract human males.

_____ 3. A plant might secrete a chemical that discourages a butterfly from laying its eggs.

_____ 4. A mating male moth might give a female a chemical that protects her and her offspring.

_____ 5. A plant might use a chemical to attract a pollinating insect.

_____ 6. Beetles are the only insects that do not use chemical signals.

_____ 7. Human males secrete a chemical that affects ovulation in females.

_____ 8. A female moth might choose a mate based on a male's chemical abilities.

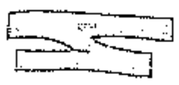
_____ 9. Chemical signals within an organism are called hormones.

_____ 10. Insects embryos obtain protective chemicals from their mothers.

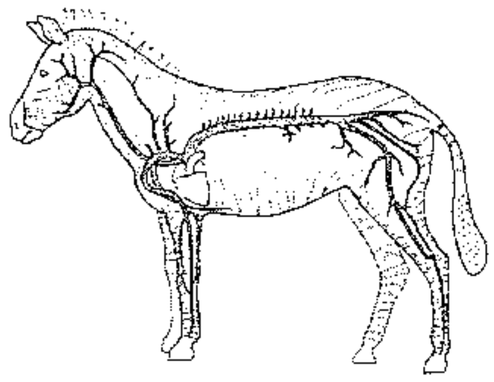
Exercise 2 (Module 2.1)

Web/CD Activity 2A *The Levels of Life Card Game*

These diagrams illustrate the same biological levels of organization discussed in connection with the moth in the introduction and in Module 2.1. In this case, the organism depicted is a zebra, but the concepts are the same. Name and number the levels, starting with the smallest. Use the names **tissue, molecule, cell, organism, system,** and **organ**.



1. _____



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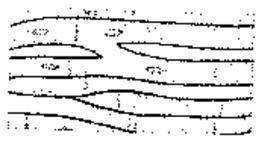
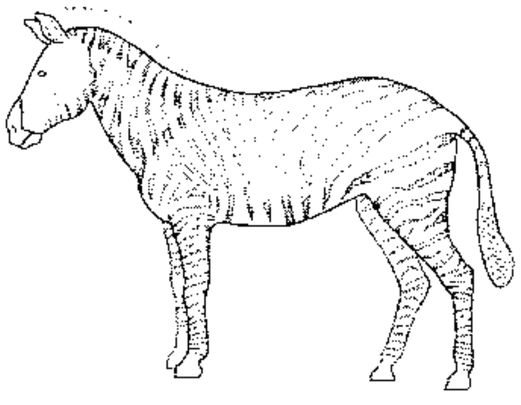
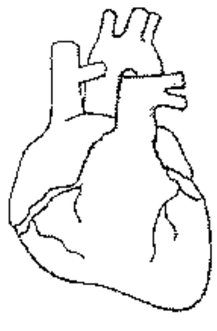


3. _____

4. _____



5. _____



6. _____

Exercise 3 (Module 2.2)

Write the chemical symbol for each of the following elements, and state whether it is used by living things in large (L), moderate (M), or trace (T) amounts.

Symbol	*Amount*	*Element*
		1. Magnesium
		2. Oxygen
		3. Zinc
		4. Hydrogen
		5. Copper
		6. Iodine

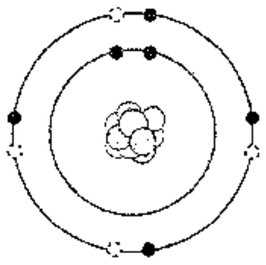
Symbol	*Amount*	*Element*
		7. Carbon
		8. Calcium
		9. Phosphorus
		10. Nitrogen
		11. Sodium
		12. Iron

Exercise 4 (Modules 2.4 – 2.6)

Web/CD Activity 2B *Structure of the Atomic Nucleus*
Web/CD Activity 2C *Electron Arrangement*
Web/CD Activity 2D *Build an Atom*

These modules introduce atoms. It is most important to know what the subatomic particles are, where they are located in an atom, and that atoms of different elements differ because they contain different numbers of protons. Some atoms not covered in these modules are compared below. You can figure out the subatomic particles they contain based on the concepts in the modules. First, fill in the blanks. Then sketch each atom, labeling and coloring **protons** red, **neutrons** gray, and **electrons** blue.

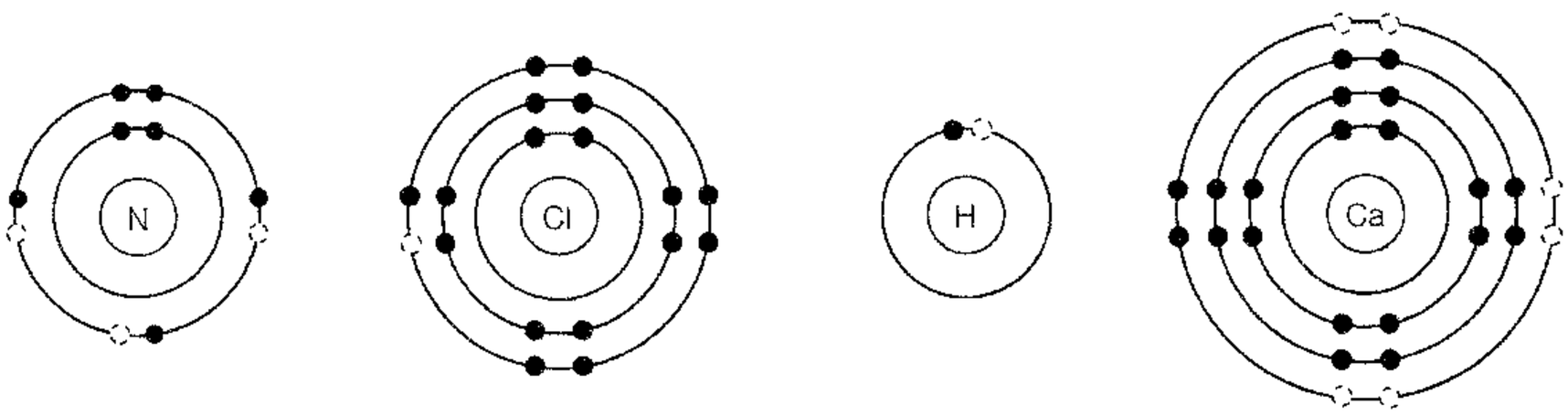
Element	*Symbol*	*Atomic Number*	*Mass Number*	*Number of Protons*	*Number of Neutrons*	*Number of Electrons*
1. Carbon-12	C	6	12	6	6	6
2. Nitrogen-14	____	7	14	____	____	____
3. Chlorine-35	____	____	35	17	____	____
4. Oxygen-16	____	____	____	____	____	8
5. Oxygen-17	____	____	____	____	____	____



Exercise 5 (Modules 2.7 – 2.8)

Web/CD Activity 2E *Ionic Bonds*
Web/CD Activity 2F *Covalent Bonds*

The atoms of four elements important to life are diagrammed below. Pay particular attention to their electron shells. Remember that atoms with incomplete outer electron shells participate in chemical reactions that allow them to attain complete outer shells: 2 electrons for a hydrogen atom, 8 electrons for most other elements important to life.



NITROGEN (N)
Atomic number = 7

CHLORINE (Cl)
Atomic number = 17

HYDROGEN (H)
Atomic number = 1

CALCIUM (Ca)
Atomic number = 20

1. Given the information and diagrams above, show how electrons would be transferred between calcium and chlorine atoms to form calcium and chloride ions, which would then attract each other to form calcium chloride, $CaCl_2$. (Hint: An atom can gain or lose more than one electron.)

2. Using the information and diagrams above, show how nitrogen could form covalent bonds with several hydrogen atoms, forming a molecule of ammonia. What would be the molecular formula for ammonia?

Exercise 6 (Modules 2.9 – 2.14)

Web/CD Activity 2G *Nonpolar and Polar Molecules*
Web/CD Activity 2H *Water's Polarity and Hydrogen Bonding*
Web/CD Activity 2I *Cohesion of Water*

Review the properties of water by filling in the blanks in the following story.

When Amy came through the door, she found Liz poised over a glass of water, ready to drop a needle into the glass. Amy asked, "Liz, what are you trying to do?"

"We're studying the [1]_____ basis of life in my biology class," Liz replied. "I don't believe some of this stuff she's teaching us, so I need to do some experiments to figure it out."

Liz gently placed the needle on the water surface. "Watch this," she said. The needle rested in a dimple on the surface of the liquid.

"How did you do that?"

"I didn't. The water did. Water molecules have a tendency to stick together, which is called [2]_____. The water molecules are stuck together so tightly at the surface that they form a film that can support the weight of the needle. Bugs can walk on it. It's called [3]_____."

Amy was getting interested. She asked, "So how do the water molecules do it? What's so special about water?"

Liz explained, "A water molecule is H_2O, right? It is made up of one [4]_____ atom and two [5]_____ atoms. The atoms stay together because they [6]_____ electrons. This holds them together. A shared pair of electrons forms a chemical bond called a [7]_____ bond between each hydrogen atom and the oxygen atom. Now, if the electrons were shared evenly, the bond would be called a [8]_____ covalent bond. But they are not shared evenly. The oxygen tends to 'hog' the electrons away from the hydrogens. It has a greater attraction for electrons; it is more [9]_____ than hydrogen."

"So what does this have to do with floating needles?"

"Well, because the oxygen atom attracts the electrons more strongly, the shared electrons are closer to the oxygen than to the hydrogens, giving the oxygen a slight [10]_____ charge. Because the electrons are pulled away from the protons in the nuclei of the hydrogen atoms, the hydrogens are left with slight [11]_____ charges. So the bonding electrons are shared unevenly, producing a [12]_____ covalent bond between each hydrogen atom and the oxygen atom. In fact, the whole water molecule is polar, even though the molecule as a whole is electrically [13]_____."

Amy was getting impatient. "So what does that have to do with surface tension? And what's the biology connection?"

Liz went on, "Well, it is their polarity that causes water molecules to stick together. The [14]_____ charged oxygen of one water molecule is attracted to the [15]_____ charged hydrogens of other water molecules. These special

bonds between water molecules are called [16]_____ bonds. These bonds form a network at the water's surface, creating surface tension strong enough to support the needle. Each water molecule is connected to [17]_____ others. Hydrogen bonds give water some other peculiar properties. For example, water is the only common substance on earth that naturally exists in all three states of matter—[18]_____, [19]_____, and [20]_____. And lots of things will dissolve in water; it is a versatile [21]_____. Blood plasma, for example, is an [22]_____ solution containing many different [23]_____, or dissolved substances, such as salt and blood sugar."

Amy got up and opened the bathroom door, looked inside, and said, "It's steamy in there. Are you going to take a bath?"

Liz replied, "No, that's just another experiment. I'm trying to figure out the difference between heat and temperature."

"Are they different?"

"Yes. [24]_____ is the total amount of energy resulting from the movement of molecules in a body of matter, like a bathtub full of water. [25]_____ measures the intensity of movement. I compared the amount of heat in a cup of water at 98°C and a bathtub of water at 45°C. In the [26]_____, the intensity of movement of water molecules was greater, but the [27]_____ held more heat energy. I knew it did because the bathtub of water added more heat to the room as it cooled, warming up the room more than the cup of hot water did.

"Water has a great capacity to store heat, by the way. When water is heated, a lot of the energy goes into breaking the [28]_____ between water molecules before the molecules can move faster. For instance, if you had a kilogram of water and a kilogram of rock, the same amount of heat would raise the temperature of the water [29]_____ than the temperature of the rock. This means water can soak up a lot of heat, and its temperature will go up only a few degrees."

"And when water cools a few degrees, it [30]_____ a lot of heat."

"Correct. And since animals are mostly water, this helps us control our body temperature. It also stabilizes the temperatures of the ocean and coastal areas. In the summer, the ocean [31]_____ heat, and in the winter, it [32]_____ heat."

Amy's eyes narrowed. "So why do we sweat when we are hot? Wouldn't we want to hang onto all that good water?"

Liz was ready with an answer. "No, not necessarily. Because of their strong hydrogen bonds, it takes a lot of heat energy to get a water molecule moving [33]_____ enough to [34]_____, to separate from its neighbors. This gives water an unusually high [35]_____, but it also makes [36]_____ cooling possible. The hottest—or fastest moving—water molecules evaporate first, taking a lot of heat energy with them and leaving the cooler—slower—molecules behind. So sweating cools you off on a hot day."

Amy looked at the clock and said, "It's 3:30. I told Sara I'd meet her at the ice rink at 3:30."

This inspired Liz anew. "Ice. Now, ice is very interesting. In ice the water molecules are locked into a crystal, linked by hydrogen bonds, but farther apart than they are in liquid water. This means that ice is [37]_____ dense than liquid water, so it [38]_____. This is important to life, because . . ."

But Amy was already out the door. Liz had a puzzled expression on her face as she got up and slid an ice tray out of the freezer.

Exercise 7 (Modules 2.15 – 2.16)

Web/CD Activity 2J *Acids, Bases, and pH*

Practice using the pH scale by giving the approximate pH of each of the following. Some are listed in the modules; others you can estimate from the information given.

____ 1. Tomato juice
____ 2. Human blood
____ 3. Vinegar (moderately acidic)
____ 4. Pure water
____ 5. Cola (mildly acidic)
____ 6. Household ammonia
____ 7. Concentrated nitric acid (very acidic)
____ 8. Acid precipitation
____ 9. Drain cleaner (very basic)
____10. Antacid pills (mildly basic)
____11. Urine
____12. Gastric juice

Exercise 8 (Module 2.17)

This module introduces chemical reactions, chemical processes that change matter. A common chemical reaction in many cells is one that changes hydrogen peroxide (H_2O_2) into water and oxygen gas:

$$\underline{\quad 2H_2O_2 \quad} \longrightarrow \underline{\quad H_2O + O_2 \quad}$$

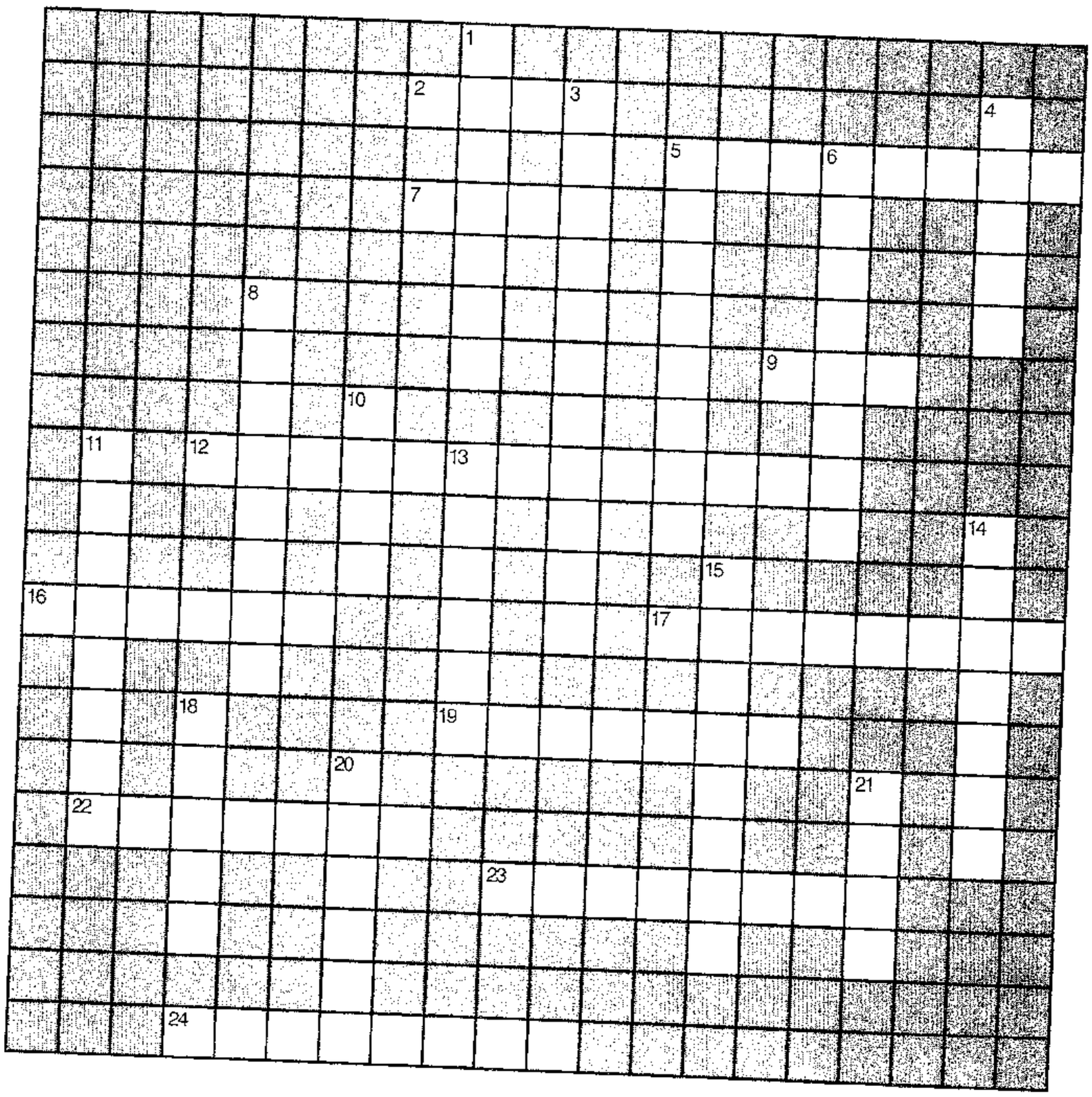
Hydrogen peroxide is a harmful by-product of many reactions. Cells get rid of it by carrying out the above reaction, converting it to harmless water and oxygen. What are the reactants in this reaction? What are the products? Label them in the blanks below the equation. Note that the equation for a chemical reaction must be "balanced." Since atoms cannot be created or destroyed in a chemical reaction—only rearranged—the numbers of atoms on both sides must be equal. In this example, there are four hydrogen atoms in the two hydrogen peroxide molecules on the left. After the reaction occurs, the hydrogen atoms reappear in the water on the right. Similarly, the four oxygen atoms in the hydrogen peroxide molecules on the left reappear in the water and oxygen molecule on the right. How many water molecules must be formed to account for all the atoms in the H_2O_2 molecules? Write the correct number in the small blank in front of H_2O.

Exercise 9 (Summary)

Review basic chemical terminology by completing this crossword puzzle.

Across

2. ____ is the energy due to movement of molecules in a body of matter.
5. An ____ is a subatomic particle that circles an atom's nucleus.
7. The smallest particle of an element is called an ____.
9. An ____ is a charged atom or molecule.
12. Acid ____ is caused by pollutants that combine with water in the air.
16. ____ is anything that occupies space and has mass.
17. Two or more atoms held together by covalent bonds form a ____.
19. Neutrons and protons are found in an atom's ____.
22. The cohesion of water molecules is responsible for surface ____.
23. Variant forms of an element with different numbers of neutrons are called ____.
24. ____ is the tendency of water molecules to stick together.



Down

1. A ____ is a subatomic particle with no electrical charge.
3. ____ measures the intensity of heat.
4. Electrons are shared unequally in a ____ covalent bond.
5. There are 92 naturally occurring ____.
6. A ____ contains two or more elements in a fixed ratio.
8. Weak bonds between water molecules are called ____ bonds.
10. An ____ donates H^+ ions to solutions.
11. A ____ bond is formed when two atoms share electrons.
13. A ____ is a positively charged particle from the nucleus of an atom.
14. In a solution, the dissolving agent is called the ____.
15. A ____ is a liquid containing a homogeneous mixture of substances.
18. When two ions of opposite charges attract each other, an ____ bond forms.
20. The ____ is the substance dissolved in a solution.
21. A ____ accepts H^- ions and removes them from solution.