CHAPTER 1

MOLECULAR REASONS

ANSWERS TO QUESTIONS:

1. All natural phenomena in the world we can see are the result of invisible molecular interactions.

   Examples are numerous. Some suggestions are as follows:

   a) Ice melting to water.

   b) A match being struck produces a flame.

   c) A shirt fading when exposed to light or too many washings.

2. There are three principal reasons for a non-scientist to study science.

   a) Science influences society in very profound ways. In order to be able to make informed and intelligent decisions about ethically complex problems like human cloning, genetic engineering, or climate change, it is essential to have at least some understanding of the workings of scientific principles.

   b) Everyone has to some degree a responsibility in sustaining the variability of the planet for future generations. Important decisions regarding science policy and funding are political decisions generally made by nonscientists. An informed public can influence these decisions and can help minimize the potential for misguided or perverted applications of science by ignorant or evil governments.

   c) Science can be described as a particular way to understand the workings of the world and the universe. Lacking appreciation of scientific principles, an uninformed observer will fail to appreciate completely the beauty, complexity and subtlety of nature. Learning some of the basics of science leads to a deeper, richer, and more fulfilled life.

3.

   a) The bright color of the rug is the result of particular molecules in the rug. When particles of sunlight, photons, hit the rug, the bright color molecules are destroyed or altered in some way.

   b) Because water molecules are attracted to the salt crystals, the water breaks up the salt crystals, and surrounds the individual particles of the salt, a process observed as dissolving.

4. Chemistry is the science that investigates the molecular reason for the processes occurring in our macroscopic world.

5. The scientific method involves first making observations of nature, from which patterns are identified. From these patterns, broadly applicable generalizations called scientific laws are established. A theory or model is then constructed to provide an interpretation of the behavior of nature. The theory is then tested by further experiments and modified if necessary to correct for any errors in the theory exposed by the experiments.

6. A law is a concise statement or equation that summarizes a great variety of observations, while a theory explains the cause of the observations. A theory has been tested by experiment over a length of time and has more predictive power than a law.

7. Science and art are similar mostly in their creativity and observations of the world. The difference lies in what they do with their observations and how they are judged. Scientists take their observations and create a model of reality that is judged by experimentation for its validity. Artists observe the world and create a painting or sculpture that is judged by its creativity and workmanship.

8. The Greek approach to scientific knowledge was through pure reason and intuition. Today we approach science through experimentation.

9.

Galileo	Inquisition
Democritus	Atomos
John Dalton	The atomic theory
Andreas Vesalius	Human anatomy
Empedocles	Four basic elements
Joseph Proust	Constant composition
Copernicus	Sun-centered universe
Ernest Rutherford	The nuclear atom
Thales	All things are water
Lavoisier	Conservation of mass
Boyle	Criticized idea of four elements

10. The two main pursuits of alchemists were the transmutation of ordinary materials into gold and the discovery of the “elixir of life”. Alchemists contributed to modern chemistry their understanding of metals, specifically how metals combine to form alloys. Alchemists also contributed laboratory separation and purification methods, including the isolation of natural substances (pharmacological) used to treat various ailments.

11. The scientific revolution began in 1543, signaled by the publication of two books. The first book by Copernicus announced his sun-centered universe theory. The second book by Vesalius gave an accurate description of human anatomy. The reason these books mark the beginning of the scientific revolution is the methods Copernicus and Vesalius used to learn about the natural world – they both used observation instead of pure reason.

12. An element is a substance that cannot be separated into simpler substances by chemical means. A compound can be separated into simpler substances by chemical means. All compounds are made from two or more elements combined.

The gas nitrogen and the metal gold are examples of elements; they cannot be separated into anything simpler. Sugar and salt (sodium chloride) are examples of compounds; they can, with more or less difficulty, be subdivided into their elements. Heating sugar in a pan is a degree to that as one is left with a black carbonaceous deposit.

13. A pure substance cannot be separated into simpler substances by physical means, such as filtration, chromatography, crystallization or distillation. A mixture consists of two or more pure substances, and can be separated into those individual components by selection of the appropriate physical methods.

    The compounds sugar and sodium chloride in question 12 are examples of pure substances; they cannot be further purified by any method. A mixture could be made by dissolving sugar in water. We could recover the sugar simply by evaporating the water away. Another example of a mixture is air, which is composed of several gases – nitrogen, oxygen etc.

14. A homogeneous mixture is completely uniform on the molecular scale. Air and a solution of sugar in water are examples of homogeneous mixtures. Heterogeneous mixtures are not uniform on a molecular scale. If sand is thrown into the solution of sugar, the sandy regions are clearly distinguishable from the non-sandy ones.

15. The three states of matter are distinguished by the strength of the interactions between the molecules relative to their thermal energy. (For the sake of brevity we will refer here only to molecules, but it should be remembered that substances may be composed of atoms, molecules or ions) The relative strength of the molecular interactions decreases in the sequence solid – liquid – gas. In a solid, the interactions are strong enough to prevent free movement of the molecules and they are locked into rigid arrangements (lattices). In a liquid, the molecular energies are strong enough to loosen the grip of the intermolecular forces sufficiently to allow free movement of molecules; but the intermolecular forces still maintain enough control to keep the molecules together. In a gas, molecular energies have increased to the extent that now all inter-molecular shackles are broken and gas molecules behave completely independently. This molecular picture explains the obvious properties of solids, liquids and gases. Solids are rigid and dense; liquids flow freely yet have a density similar to the solid; gases have a very low density and are confined only by their container.

16.
    a) Solid: incompressible, fixed volume, fixed shape
    b) Liquid: incompressible, fixed volume, variable shape
    c) Gas: compressible, variable shape, variable volume

17. John Dalton, using the laws of Lavoisier and Proust and the data from his own experiments, combined a number of ideas to formulate the “atomic theory.” Dalton’s atomic theory was based on three parts:

    - First, each element is composed of particles called atoms, which can neither be created nor destroyed.
    - Second, all atoms of the same element have the same mass and other properties. These properties are unique characteristics of each element, and thus differ from other elements.

- Third, atoms of different types can combine to form compounds in simple whole number ratios. For example, the compound carbon dioxide is formed from one carbon atom and two oxygen atoms. The numbers, 1 and 2, are simple whole numbers.

18. Rutherford examined atomic structure through his gold foil experiment. By shooting alpha particles at a thin sheet of gold foil, Rutherford tested his idea that atoms were either soft, like blueberry muffins, or hard, like billiard balls. The results of his experiment were surprising. The majority of particles passed though the gold foil without deflection (as expected), but some deflected, scattering at angles both large and small. A small portion bounced back in the direction they had come from.

19. The only way to explain the results of the gold foil experiment was to propose a new model of the atom in which most of the atom must be empty space. This structure would allow most of the alpha particles to pass through the gold foil with little or no deflection. However, the atom must also contain a nucleus, a dense positively charged central core containing most of the mass. In the experiment, whenever an alpha particle came close to a nucleus, or hit it head on, it experienced a large repulsive force causing it to be scattered. Furthermore, since the atom is electrically neutral, it must contain an equal number of negative charges (electrons) and positive charges. The exact identity of the positive charge was later established to be the proton. Rutherford purposed the electrons were outside the nucleus.

20. A black hole is a very dense form of matter where the structures of atoms have broken down, to form "solid" matter. The large mass and small size associated with the black hole causes a strong gravitational field, which allows mass and light to enter but not leave the black hole. Thus, because black holes neither reflect nor emit light, they are referred to as "black". If atoms did not have their characteristic structure of a tiny dense nucleus surrounded by a large volume of "empty" space, then all matter should have the enormous density of a black hole.

SOLUTIONS TO PROBLEMS:

21.

a) Water boiling and bubbles forming represent an observation. It would be made during an experiment on heating water.

b) "Two grams of hydrogen combine with sixteen grams of oxygen to form eighteen grams of water" represents an observation. It would be the result of one experiment.

c) "Chlorine and sodium readily combine in a chemical reaction that emits much heat and light" is also an observation.

d) "The properties of elements vary periodically with the mass of their atoms" is a law. The relationship between element properties and size statement was derived from examination of many observations. It is often referred to as the periodic law.

a) "Energy is neither created nor destroyed in a chemical reaction" is a law. It is known commonly as the law of conservation of energy. It was established through experimental observation of the movement of energy in many experiments and does not rely on any hypothesis.

b) “All matter is composed of atoms” is a statement of theory. We do not observe atoms directly by experimental observation, although it could be argued that techniques like scanning tunneling microscopy or atomic force microscopy reveal atoms. Experimental data provided the basis for establishing the atomic theory as a viable description of matter.

c) “When the temperature of a gas is increased, the volume of the gas increases” is a law. Experiments on the behavior of gases led directly to the derivation of this law. No assumptions or hypotheses are required.

d) “Gases are composed of particles in constant motion” is a theory. This statement formed the basis of the kinetic theory, which provides a mathematical description of the behavior of gases.

23.

a) A silver coin is composed of the element silver.

b) Air is a homogeneous mixture of different gases.

c) Coffee is a homogeneous mixture of many different substances.

d) Soil is a heterogeneous mixture since it may be composed of dirt, sand, and rocks that can be separated into distinct regions with different compositions.

24.

a) Pure water would be classified a compound because it is composed of two or more elements in a fixed definite proportion.

b) Copper wire is composed of the element copper.

c) Graphite is composed of carbon atoms only and thus would be an element.

d) Oil and water would be classified a heterogeneous mixture since a separation would occur into two distinct regions with different compositions.

25. a. Lemonade is a liquid mixture. While the others are all mixtures, brass and wood are solids, and air is a gas.

26. b. Dry ice is solid carbon dioxide. Helium is a gas, while vegetable oil and shampoo are liquids.

27.

a) Physical property. The transition of dry ice (solid CO_2) to the gas phase is sublimation, which is a physical property of a substance just like the melting point and boiling point.

b) Chemical property. Flammability is the reaction of the substance with oxygen in the air. This involves a change in the composition.

c) Physical property. The boiling point is a physical property since no change in composition is involved in boiling.

d) Physical property. The smell of a substance is due to its vapor. Conversion of a liquid into vapor is a physical process since there is no change in its composition. Of course, it could be argued that the complex process of detection of the smell involves numerous chemical processes in the body and brain.

28.

a) Chemical property. Tarnishing of silver is a chemical property since it involves reaction of the silver with chemicals in the air such as sulfur; a change in composition is involved.

b) Chemical property. The flammability of alcohol is a chemical property since it involves reaction of the alcohol with oxygen, which involves a change in composition.

c) Physical property. Vaporization is the change of state from liquid to gas. No change in composition is involved.

d) Physical property. Malleability involves bending of the material, which occurs without change in composition.

29. Physical and chemical changes are distinguished by whether or not a change in composition occurs.

a) The crushing of salt is a physical change. There is no change in composition.

b) The rusting of iron represents a chemical change. Rust results from combination of the iron with the element oxygen to form iron oxide.

c) The burning of natural gas in a stove is a chemical change. Burning involves combination of oxygen in the air with the carbon and hydrogen atoms of the natural gas. The energy released in the reaction provides the all-important heat we use.

d) The vaporization of gasoline is a physical change. All changes of state are physical changes: intermolecular forces may be gained or lost, but there are no changes in the chemical bonds between the atoms of the substances. Gasoline in the vapor or in the liquid is still gasoline, and if it was condensed it would be indistinguishable from the original liquid.

30.

a) The burning of butane is a chemical change. The heat and light of the flame results from the hydrocarbon reacting with oxygen.

b) The freezing of water is a physical change. Changes of state do not involve a change in composition.

c) The bending of a copper rod is a physical change; no change in composition is involved.

d) The fading of a carpet upon exposure to sunlight represents a chemical change. The ultraviolet radiation causes chemical changes to the dye molecules that provide the color, and this is manifested in the fading of the colors.

31. When gasoline is burned in an automobile engine, it does so in the presence of oxygen gas. This chemical reaction of gasoline plus oxygen produces energy, water, carbon dioxide, and carbon monoxide gases. The mass of the products is equal to the combined starting masses of gasoline and oxygen.

32. The reaction of wood plus oxygen results in ash plus a variety of gases. As the reaction proceeds, the mass of the wood is decreasing, at the same time the mass of the products is increasing. The wood in a campfire eventually disappears but the mass is conserved because the products weigh exactly that of the wood plus oxygen.

33.
   a) 6 grams of hydrogen react with 48 grams of oxygen to form 54 grams of water This is consistent with the law of conservation of mass: 6 g + 48 g = 54 g.
   b) 10.0 grams of gasoline react with 4.0 grams of oxygen to form 9.0 grams of carbon dioxide and 5.0 grams of water. This is consistent with the law of conservation of mass: 10.0 g + 4.0 g = 9.0 g + 5.0 g.

34. Apply the law of conservation of mass:
   mass of reactants = mass of products
   a) 8.0 g natural gas + 32 g oxygen $\longrightarrow$ 17 g carbon dioxide + 16 g water
   40 g reactants ≠ 33 g products: this is inconsistent with the law of conservation of mass.
   b) 5.7 g sodium + 8.9 g chlorine $\longrightarrow$ 14.6 g sodium chloride
   14.6 g reactants = 14.6 g products: this is consistent with the law of conservation of mass.

35. The reaction must follow the law of conservation of mass.
   22 g sodium + 28 g chlorine $\longrightarrow$ _?_ g sodium chloride + 4 g excess sodium
   50 g reactants = 50 g products
   Therefore the amount of sodium chloride formed must be 46 grams.

36. The reaction must follow the law of conservation of mass
   6 g hydrogen + 52 g oxygen $\longrightarrow$ _?_ g water + 4 g excess oxygen
   58 g reactants = 58 g products
   Therefore, the amount of water formed must be 54 g.

37. The law of constant composition says the ratio of carbon to oxygen must always be the same.
   a) $\frac{12\text{ g carbon}}{32\text{ g oxygen}} = 0.38$
   b) $\frac{4.0\text{ g carbon}}{16.0\text{ g oxygen}} = 0.25$ inconsistent, therefore incorrect
   c) $\frac{1.5\text{ g carbon}}{4.0\text{ g oxygen}} = 0.38$

d) $\dfrac{22.3\,\text{g carbon}}{59.4\,\text{g oxygen}} = 0.38$

38. The law of constant composition says the ratio of hydrogen to carbon must always be the same.

a) $\dfrac{4.0\,\text{g hydrogen}}{12\,\text{g carbon}} = 0.33$

b) $\dfrac{1.5\,\text{g hydrogen}}{4.5\,\text{g carbon}} = 0.33$

c) $\dfrac{7.0\,\text{g hydrogen}}{17.0\,\text{g carbon}} = 0.41$

d) $\dfrac{10.\text{g hydrogen}}{30.\text{g carbon}} = 0.33$

Answer c) is inconsistent with the other three and is therefore incorrect.

39. To preserve electrical neutrality in the Rutherford atom the number of electrons will be equal to the number of protons in the nucleus (the atomic number).

a) An atom of sodium contains 11 electrons (atomic number of sodium = 11)

b) An atom of calcium contains 20 electrons (atomic number of calcium = 20)

40. As described in the answer to question 39, the number of electrons = the number of protons.

a) An atom of fluorine contains 9 electrons

b) An atom of sulfur contains 16 electrons

POINTS TO PONDER

41. The bubbles might suggest that a gas is being formed, so the hypothesis could be something along the lines of a liquid transforming into a gas when it boils. To test the hypothesis it would be necessary to collect the gas from the bubbles to determine what it was made of. If the gas bubbles were water it would prove the hypothesis.

42. Beginning with Robert Boyle, who defined an element as something that could not be decomposed into simpler substances, it became clear that there were many more than four substances that are elements, such as carbon, oxygen and copper, and so the Greek four element theory was inadequated.

43. Answers will vary.

44. Answers will vary.

45. This is really a question about what matter is and the nature of experiencing it. On a macroscopic scale an object appears hard, impenetrable and dense, and yet the atoms that comprise it our mostly empty space. Our fingers that touch the objects are also made of those atoms that are mainly empty space. The sensation of touch is the electrostatic interaction between the atoms on the surface of our finger and the surface of the object. Reduced to the level of particles, all our sensations, and all of chemistry, are comprised of electrostatic interactions between particles.

46.
   a. For a given element, the nucleus contains the same number of neutrons and protons.
   b. The nuclei of other elements should be investigated in the same way to see if the law has broader application to heavier elements.
   c. An example might be that in situations where the number of neutrons is higher or lower than the proton number, the nucleus is unstable. We could postulate that, since protons are positively charged and repel each other, the neutrons are required to hold them together; and this only happens when the neutron:proton ratio is one.
   d. Clearly, for larger elements this simple law no longer holds. At least for larger atoms, neutron:proton ratios larger than 1 are stable. Our initial law has to be revised to include an upper limit, beyond which the neutron:proton ratio exceeds 1.

47. Answers will vary.

SOLUTIONS TO FEATURE PROBLEMS:

48.
   a) Salt is made up of the two elements sodium and chloride; it is a compound.
   b) Diamond is made up of only carbon; it is an element.
   c) Seawater consists of water, sodium ions, and chlorine ions; it is a homogeneous mixture.
   d) Snow is frozen water molecules; water consists of hydrogen and oxygen. Therefore, snow is a compound.

49. Answers may vary

50. The technique of scanning tunneling microscopy enables the imaging of individual atoms. Thus, it is possible to say that atoms, which were once theoretical constructs of Dalton and others, are now made visible. Do the STM images constitute “proof” of the atomic theory? This could be argued either way depending on how one treats the reality of the images. After all, the atoms seen in the STM are indirect images generated by the interaction of the atom with the probe. Is this evidence any more convincing than other experimental evidence for the existence of atoms such as Brownian motion? Certainly, we can say that STM provides evidence that is entirely consistent with the atomic theory.

51. Answers may vary