POWER BASICS®

Chemistry

Robert Taggart

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UNIT 2

Properties of Matter

LESSON 5: The Structure of Matter

GOAL: To learn about the internal structure of atoms

WORDS TO KNOW

atomic mass	coulombs	molecular mass
atomic mass unit	electrons	neutrons
atomic number	isotopes	protons
cathode-ray tube	mass number	

Dalton's Atomic Theory

The ancient Greek philosopher Leucippus and his follower, Democritus, proposed more than 2000 years ago that matter is made up of extremely small particles that cannot be divided further. Democritus called these bits of matter *atomos*. *Atomos* means "indivisible" and is the source of our word *atoms* today.

Many contemporaries of Leucippus and Democritus, including Plato and Aristotle, did not accept the idea that matter was made up of particles that have distinct properties of their own. Instead, they believed that all matter was uniform in composition, no matter how small the piece of matter.

These two opposing ideas were not tested until the 1700s. That is when scientists began doing careful experiments on the changes that matter undergoes. In 1808, an English schoolteacher named John Dalton proposed his own atomic view of matter. It has since become known as Dalton's atomic theory.

Dalton's atomic theory can be summarized as follows:

1. All matter is composed of tiny particles called atoms.
2. All atoms of a given element are identical. They all have the same mass, size, and chemical properties.

3. All atoms of a given element are distinct from all atoms of any other element. The mass, size, and chemical properties of the atoms of one element are different from the mass, size, and chemical properties of the atoms of any other element.

4. Chemical compounds form when atoms combine in whole-number ratios. A pure compound has the same combination of atoms, no matter how it was prepared. For example, pure water always contains two hydrogen atoms chemically joined to one oxygen atom. If some compound contains a different combination of hydrogen and oxygen atoms, then it is not water. It is a different compound altogether.

5. Atoms cannot be created from nothing or destroyed in a chemical reaction. Instead, atoms retain their identities but change the way they are combined or arranged.

PRACTICE 20: Dalton's Atomic Theory

Decide if each statement that follows is true (**T**) or false (**F**). Write the correct letter on each line.

_____ **1.** The Greek word *atomos* means "indivisible" and is the source of the word *atoms* today.

_____ **2.** Dalton's atomic theory is named for the ancient Greek philosopher Leucippus and his follower, Democritus.

_____ **3.** According to Dalton's atomic theory, all atoms of a given element are identical.

_____ **4.** According to Dalton's atomic theory, a pure compound has a different combination of atoms depending on how it was prepared.

_____ **5.** According to Dalton's atomic theory, atoms cannot be created from nothing or destroyed in a chemical reaction.

_____ **6.** According to Dalton's atomic theory, the mass, size, and chemical properties of the atoms of one element are different from the mass, size, and chemical properties of the atoms of any other element.

_____ **7.** According to Dalton's atomic theory, atoms CAN be created or destroyed in a chemical reaction.

_____ **8.** According to Dalton's atomic theory, chemical compounds form when atoms combine in whole-number ratios.

Electrons, Protons, and Neutrons

Although matter is composed of atoms, atoms are not as indivisible as Democritus or Dalton suggested. Thanks to the careful experiments of physicists such as J. J. Thomson, Robert Millikan, Hans Geiger, Ernest Marsden, Ernest Rutherford, and James Chadwick, it is now known that atoms are made up of electrons, protons, and neutrons.

Electrons are negatively charged particles that have very little mass but take up most of the volume of an atom. **Protons** are positively charged particles that have more than 1800 times the mass of an electron, but take up very little of the volume of an atom. The charge on a proton is equal and opposite to the charge on an electron. **Neutrons** have no charge and have a mass that is only slightly greater than the mass of a proton. Electrons, protons, and neutrons are called subatomic particles because they are the building blocks of atoms. The mass of a subatomic particle is measured in kilograms. The charge of a subatomic particle is measured in units called **coulombs.**

Name	Symbol	Charge	Mass
Electron	e	-1.6022×10^{-19} coulomb	9.1094×10^{-31} kg
Proton	p	$+1.6022 \times 10^{-19}$ coulomb	1.6726×10^{-27} kg
Neutron	n	0	1.6749×10^{-27} kg

J. J. Thomson's experiments in 1897 measured the ratio of the electron's mass to the electron's charge. Thomson was unable to determine the exact mass of an electron, but he estimated it to be less than $\frac{1}{1000}$ as much as hydrogen, the lightest element known. Thomson's experiments showed that atoms were divisible into smaller particles, after all.

Robert Millikan's experiments in 1909 determined the exact charge on an electron. From his value for the charge, and Thomson's value for the electron's mass-to-charge ratio, Millikan was able to determine the mass of an electron:

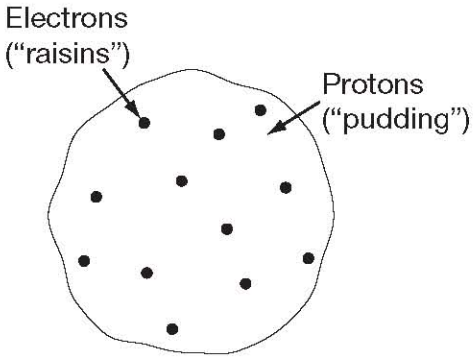
$$\text{Mass of electron} = \frac{\text{mass}}{\text{charge} \times \text{charge}}$$

$$= \left(5.686 \times \frac{10^{-12}\,\text{kg}}{\text{coulomb}}\right)(1.602 \times 10^{-19}\ \text{coulomb})$$

$$= 9.109 \times 10^{-31}\ \text{kg}$$

At this point, scientists knew two things about atoms. First, they knew that atoms are electrically neutral overall. Second, they knew that atoms contain negatively charged electrons. In order to be electrically neutral overall, atoms must also contain some positively charged particles (protons) to balance the negative charge of the electrons. Thomson proposed that atoms could be thought of as positively charged spheres of matter in which electrons are embedded like raisins in plum pudding.

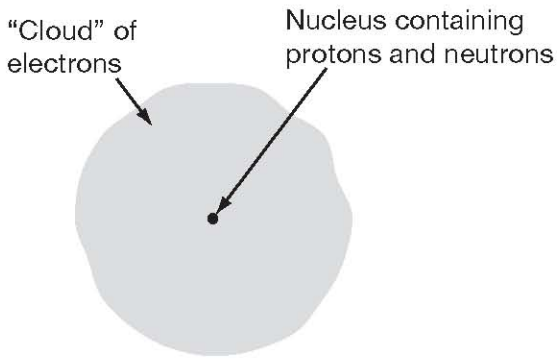
Another way to think of Thomson's "plum pudding" model of the atom is to imagine a chocolate-chip cookie. The chocolate chips are the electrons, and the cookie is the "positively charged sphere of matter." Together, the cookie and the chips make up an atom.



Thomson's "Plum Pudding" Model

The experiments of Hans Geiger and Ernest Marsden in Ernest Rutherford's lab in 1911 suggested, however, that the protons are concentrated in the core of the atom, not spread throughout the atom. Rutherford proposed that an atom consists of a positively charged nucleus surrounded by a cloud of electrons. The nucleus is the central core of the atom where most of the mass is. Thus, the protons of an atom are in the nucleus. Rutherford's theory is often called the nuclear model of the atom.

In the nuclear model of the atom, the volume of the cloud of electrons is huge compared to the volume of the nucleus. In fact, if a golf ball were the nucleus of an atom, the electron cloud would measure 3 miles across. The mass of an electron is so small compared to the mass of a proton that the electron cloud is mostly empty space.



Rutherford's Nuclear Model

Finally, in 1932, James Chadwick conducted experiments that led to the discovery of the neutron. Because the mass of a neutron is slightly greater than the mass of a proton, neutrons must be located in the nucleus, too.

PRACTICE 21: Electrons, Protons, and Neutrons

Decide if each statement that follows is true (T) or false (F). Write the correct letter on each line.

_____ **1.** The nucleus of an atom is where the electrons are.

_____ **2.** The nucleus of an atom is where the protons and neutrons are.

_____ **3.** The mass of a neutron is slightly greater than the mass of a proton, and the mass of a proton is more than 1800 times greater than the mass of an electron.

_____ **4.** J. J. Thomson's experiments measured the ratio of the electron's mass to the electron's charge.

_____ **5.** Hans Geiger proposed the "plum pudding" model of the atom.

_____ **6.** James Chadwick discovered the electron.

_____ **7.** In Rutherford's nuclear model of the atom, protons have most of the mass, but electrons have most of the volume of an atom.

_____ **8.** Robert Millikan's experiments determined the exact charge on an electron.

POWER BASICS PLUS

Chemistry

Workbook

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UNIT 2 • ACTIVITY 24
Dalton's Atomic Theory

John Dalton was an English schoolteacher who was serious about his search for an atomic theory. The following is a brief summary of his atomic theory:

1. All matter is composed of tiny particles called atoms, which are indivisible.
2. All atoms of a given element are identical; in particular, they have the same mass.
3. All atoms of a given element are distinct from all atoms of any other element; in particular, they have different masses.
4. Chemical compounds form when atoms combine in whole-number ratios.
5. Atoms cannot be created or destroyed in a chemical reaction.

Although Dalton's theory was quite an advance for its time, it has flaws that were corrected when new information became available.

Research the three major differences between Dalton's atomic theory and modern atomic theory. Describe those differences in a brief essay on another sheet of paper. In the space below, write research notes, brainstorm ideas, or organize information.

NAME:

UNIT 2 • ACTIVITY 25
John Dalton

John Dalton was an English chemist, physicist, schoolteacher, meteorologist, and college professor who lived from 1766 to 1844. Dalton made an impressive number of contributions to fields such as chemistry, optics, and meteorology. The following are some of Dalton's contributions:

- constructed his atomic theory in chemistry
- discovered color blindness, which is still called Daltonism
- stated what is now known as Gay-Lussac's gas law before Gay-Lussac himself did
- stated his law of partial pressures
- created his own table of atomic weights
- stated the law of multiple proportions, which contradicted a popular theory that had existed for at least 2200 years
- explained the law of definite proportions
- discovered that when some kinds of salts were added to water, the volume of the solution did not increase

Write two analogies that describe the law of definite proportions and the law of multiple proportions.

Example: The law of definite proportions is similar to when you take apart the ingredients in a bottle of cola. There will always be a fixed amount of sugar, a fixed amount of water, and a fixed amount of caffeine. The ratios are always the same.

1. _____

_____

_____

_____

2. _____

_____

_____

_____

NAME:

UNIT 2 • ACTIVITY 26
Joseph Proust

Joseph Proust was a French chemist who lived from 1754 to 1826. Like many academics of the time, he worked in many fields. He was a hot-air balloon flight instructor and a chemistry teacher at an artillery school, for example.

Proust's claim to fame in chemistry was his formulation of the law of definite proportions. This law states that the proportion by mass of the elements in a given compound is always the same. Using this law, he was able to show that there were actually three different kinds of sugars in some vegetables and thereby discovered glucose, fructose, and sucrose. Proust spent a fair amount of time defending his law against a well-known scientist of the day named C. L. Berthollet, who believed that elements could combine in any combination given the correct conditions. (In the time of Proust and Berthollet, the equipment needed to make the incredibly small measurements did not exist. Much of the equipment was constructed by chemists who were often inventing the laboratory equipment they needed as they went along.)

On another sheet of paper, write a brief essay describing how the law of definite proportions makes it easier to determine the products formed by a chemical reaction. In the space below, brainstorm ideas, organize information, or write a first draft.

NAME:

UNIT 2 • ACTIVITY 27
Electrons, Protons, and Neutrons

The particles that make up most atoms include protons, neutrons, and electrons. These particles are quite small and have tiny amounts of electric charge associated with them. In the case of the neutron, the charge is zero. Below is a chart that summarizes the properties of these particles.

Particle	Symbol	Charge	Mass
electron	e	-1.6022×10^{-19} C	9.1094×10^{-31} kg
proton	p	$+1.6022 \times 10^{-19}$ C	1.6726×10^{-27} kg
neutron	n	0	1.6749×10^{-27} kg

Using the chart above and the periodic table, answer the following questions.

1. How many protons are there in a carbon-12 atom? _____
2. How many electrons are in a carbon-12 atom? _____
3. How many neutrons are in a carbon-12 atom? _____
4. How many particles make up a carbon-12 atom? _____
5. What is the mass of the protons in an oxygen-16 atom? _____
6. What is the mass of the neutrons in an oxygen-16 atom? _____
7. What is the mass of the electrons in an oxygen-16 atom? _____
8. What is the total mass of one oxygen-16 atom? _____
9. What is the charge on the electrons in a calcium atom? _____
10. What is the charge of the protons in a calcium atom? _____
11. What is the charge of the neutrons in a calcium atom? _____
12. What is the total charge on a calcium atom? _____

POWER BASICS PLUS

Chemistry

Test Pack

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NAME: DATE:

CHEMISTRY • PRETEST

Circle the correct answer to each of the following questions.

1. Which of the following is NOT an example of matter?
   a. air
   b. asteroids
   c. gravity
   d. water

---

2. Which of the following is a substance?
   a. air
   b. brass
   c. gold
   d. tap water

---

3. What is a homogeneous mixture?
   a. a mixture in which one substance makes up more than 90 percent of the mixture
   b. a mixture in which substances are unevenly divided
   c. a mixture with visible boundaries between substances
   d. a solution

---

4. Which of the following is least likely to go into solution in pure water?
   a. corn starch
   b. salt
   c. sugar
   d. baking soda

---

5. Which of the following has a fixed volume, but not a fixed shape?
   a. a gas
   b. a liquid
   c. a solid
   d. a vapor

UNIT 2 TEST • PROPERTIES OF MATTER

Circle the correct answer to each of the following questions.

1. The atomic number of an atom of lithium is 3, and its mass number is 7. How many neutrons does this atom contain?
   a. three
   b. four
   c. seven
   d. ten

---

2. Which of the following is NOT a subatomic particle?
   a. an electron
   b. an ion
   c. a neutron
   d. a proton

---

3. In what way do the various isotopes of the same element differ?
   a. They have different atomic numbers.
   b. They have different mass numbers.
   c. They have different numbers of electrons.
   d. They have different numbers of protons.

---

4. Under what circumstances do the elements of Group 2 of the periodic table form stable ionic compounds?
   a. when they appear as anions with a –1 charge
   b. when they appear as anions with a –2 charge
   c. when they appear as cations with a +1 charge
   d. when they appear as cations with a +2 charge

---

5. What does it mean to say that the natural abundance of ^{48}Ti is 5.5 percent?
   a. In a naturally occurring sample of titanium, ^{48}Ti will account for 5.5 percent of the sample.
   b. In a naturally occurring sample of titanium, ^{48}Ti will account for 48 percent of the sample 5.5 percent of the time.
   c. In nature, ^{48}Ti is only 5.5 percent pure.
   d. In nature, ^{48}Ti is 5.5 percent heavier than the other isotopes of titanium.

6. Z = 1 for hydrogen; Z = 2 for helium; Z = 3 for lithium. What is Z?
   a. the atomic number
   b. the mass number
   c. the number of neutrons in each
   d. the relative abundance of the elements in nature

---

7. How is the modern periodic table of the elements organized?
   a. by atomic number
   b. by mass number
   c. by melting point
   d. by physical state at room temperature (20°C)

---

8. Which parts of the periodic table are called periods?
   a. the horizontal rows
   b. the lanthanides
   c. the transition elements
   d. the vertical columns

---

9. Which group of the periodic table is known for being highly unreactive?
   a. group 1
   b. group 6
   c. group 9
   d. group 18

---

10. Which of the following elements is the least reactive?
    a. lithium
    b. magnesium
    c. neon
    d. sodium

11. Which of the following is NOT a metalloid?
    a. arsenic (As)
    b. boron (B)
    c. silicon (Si)
    d. sodium (Na)

---

12. In the formula MOH, what does M stand for?
    a. any alkali metal
    b. any alkaline earth metal
    c. any halogen
    d. any noble gas

---

13. What happens when an element becomes a cation?
    a. Electrons are held tighter and closer to the nucleus.
    b. It gains an electron.
    c. Its atomic mass increases.
    d. Its atomic radius increases.

---

14. Which is true of a cation?
    a. It is attracted to an anode during electrolysis.
    b. It is a free radical.
    c. It is a positively charged ion.
    d. It is a negatively charged ion.

---

15. Which is true of an anion?
    a. It is a negatively charged ion.
    b. It is attracted to a cathode.
    c. It is held tightly by the nucleus of an atom.
    d. It is unreactive.

16. Which of the following may be highly stable?

a. a large collection of anions

b. a large collection of cations

c. a large collection of both anions and cations

d. Anions and cations are never stable, under any conditions.

---

17. Which of the following is a diatomic homonuclear molecule?

a. Br_2

b. CO_2

c. HCl

d. HF

---

18. The molecular formula for caffeine is $C_8H_{10}N_4O_2$. What is its empirical formula?

a. CHNO

b. $C_4H_5N_2O$

c. $C_6H_8N_2O$

d. $C_8H_{10}N_4O_2$

---

19. When there is a double bond between two atoms, how many electrons do they share?

a. two

b. four

c. six

d. eight

---

20. The atomic mass of boron is 10.81 amu. What will be the mass of 1 mole of boron atoms?

a. 1.081 grams

b. 10.81 grams

c. 108.1 grams

d. 1.081 kilograms

21. Which of the following is NOT the result of a reaction between a Group 1 element and a halogen?

    a. CsCl

    b. CsF

    c. LiCl

    d. Li_2O

---

22. What happens when the outer shell of an element is completely filled with electrons?

    a. The element is highly reactive.

    b. The element is moderately reactive.

    c. The element is slightly reactive.

    d. The element is highly unreactive.

---

23. Lithium has three protons and one valence electron. What is the effective nuclear charge on this electron?

    a. +1

    b. +2

    c. +3

    d. +4

---

24. How big is the radius of a cation compared to the corresponding neutral atom?

    a. The radius of the cation is smaller.

    b. The radius of the cation is unchanged.

    c. The radius of the cation is somewhat larger.

    d. The radius of the cation is much larger.

---

25. When sodium reacts with chlorine to form table salt (NaCl), how big is the radius of the sodium ion compared to the radius of the sodium atom?

    a. smaller

    b. the same

    c. somewhat larger

    d. much larger

Circle the correct answer to each of the following questions.

1. Which of the following is the first step in the scientific method?
   a. conducting an experiment
   b. defining a problem
   c. developing a theory
   d. gathering information

---

2. Which of the following is a mixture?
   a. air
   b. gold
   c. oxygen
   d. pure water

---

3. You brew a pot of coffee. Chemically, what have you made?
   a. a solution
   b. a suspension
   c. a chemical reaction
   d. a solute

---

4. You have washed your kitchen floor with a liquid cleaner. Chemically, what is the cleaner?
   a. a solution
   b. a suspension
   c. a solvent
   d. a solute

---

5. Which of the following is a compound?
   a. copper
   b. helium
   c. nitrogen
   d. table salt