

F o u n d a t i o n s o f

# Physical Science











*Tom Hsu, Ph.D.*

FIRST EDITION

Cambridge Physics Outlet  
Peabody, Massachusetts 01960

**CPO**  
science

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## 19.1 Bonding and Molecules

Learning Goals	Reading Synopsis	Materials and Setup
<ul style="list-style-type: none"> <li>• Explain how and why atoms form chemical bonds.</li> <li>• Identify the types of bonds in molecules.</li> <li>• Build accurate models of atoms.</li> </ul> <p><b>Key question:</b> Why do atoms form chemical bonds?</p> <p><b>Leading questions:</b></p> <ul style="list-style-type: none"> <li>• Why do atoms form compounds?</li> <li>• What are the different types of chemical bonds?</li> <li>• How can you tell what kind of bonds a molecule has?</li> </ul>	<p>Most of the substances in the universe are in the form of compounds. If a substance is made of a pure element for example, an iron nail is made of pure iron, it will eventually react with another element to form a compound. This is why an iron nail will rust. Some elements are so reactive, that if they come into contact with air, they will react violently and cause an explosion. Some elements will not react with other elements very easily, for example, the Noble Gases. Students learn why and how elements react with other elements to form compounds, how electrons are involved in the formation of chemical bonds and how the organization of elements in the periodic table are related to the number of electrons an atom has in its outermost energy level. These outermost electrons are called valence electrons. The most stable atoms have eight valence electrons while unstable atoms have less than eight. Atoms will gain or lose electrons and form chemical bonds with other atoms to become stable.</p> <p><b>Sequence:</b> Students complete the reading after the Investigation.</p>	<ul style="list-style-type: none"> <li>• One Atom Building Game</li> <li>• One Periodic Table that comes with the game</li> <li>• For part of the Investigation, two groups will combine so that they have two Atom Building Games.</li> </ul> <p><b>Duration:</b> One class period</p>

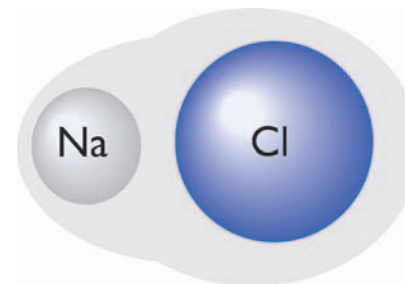
## 19.2 Chemical Formulas

Learning Goals	Reading Synopsis	Materials and Setup
<ul style="list-style-type: none"> <li>• Explain the relationship between the placement of elements on the periodic table and chemical formulas.</li> <li>• Explain how the charge of an ion is determined.</li> <li>• Write and name the formulas for compounds.</li> </ul> <p><b>Key question:</b> Why do atoms combine in certain ratios?</p> <p><b>Leading questions:</b></p> <ul style="list-style-type: none"> <li>• What is the relationship between the placement of elements on the periodic table and chemical formulas?</li> <li>• How is the charge of an ion determined?</li> </ul>	<p>When two atoms form a chemical bond, the ratio in which they combine is related to the number of valence electrons each atom has. The ratios which the atoms combine determines the chemical formula of the compound.</p> <p>Ionic compounds are made out of positive and negative ions. The chemical formulas of ionic compounds can be determined from the oxidation numbers of the ions from which they are made. For the elements, the most common oxidation numbers can be determined by identifying the group number for each element. Some ions are made out of more than one type of atom. These are called polyatomic ions.</p> <p>Naming ionic compounds involves writing the name of the positive ion first, followed by the name of the negative ion.</p> <p>Covalent compounds are made from covalently bonded atoms.</p> <p><b>Sequence:</b> Students complete the reading after the Investigation.</p>	<ul style="list-style-type: none"> <li>• One Periodic Puzzle</li> </ul> <p><b>Duration:</b> One class period</p>

## 19.1 Bonding and Molecules

*Key Question: Why do atoms form chemical bonds?*

In this Investigation, students are introduced to how and why atoms combine to form molecules. Concepts like valence electrons, the octet rule, and bond types will be challenging for students because the students can't see the atoms. The use of the Atom Building Game in the Investigation provides students with a fun and engaging way to conceptualize the parts of an atom and the arrangement of electrons in an atom. By using two games, they will be able to visualize how and why atoms form chemical bonds.



### Reading Synopsis

*Students read section 19.1 Bonding and Molecules after the Investigation*

Most of the substances in the universe are in the form of compounds. If a substance is made of a pure element—for example, an iron nail is made of pure iron—chances are it will eventually react with another element to form a compound. This is why an iron nail will rust. Some elements are so reactive that if they come into contact with air, they will react violently and cause an explosion. This is the case with sodium metal. Some elements (such as the noble gases) will not react with other elements very easily. In the reading, students learn why and how elements react with other elements to form compounds. They will learn how electrons are involved in the formation of chemical bonds and how the organization of elements in the periodic table is related to the number of electrons an atom of each element has in its outermost energy level. These outermost electrons are called valence electrons. The most stable atoms have eight valence electrons while unstable atoms have less than eight. Atoms will gain or lose electrons and form chemical bonds with other atoms to become stable.

### The Investigation

#### Leading Questions

- Why do atoms form compounds?
- What are the different types of chemical bonds?
- How can you tell what kind of bonds a molecule has?

#### Learning Goals

- By the end of the Investigation, students will be able to:
- Explain how and why atoms form chemical bonds.
  - Identify the types of bonds in molecules.
  - Build accurate models of atoms.

#### Key Vocabulary

energy levels, valence electrons, chemical bond, oxidation number, ionize, ion



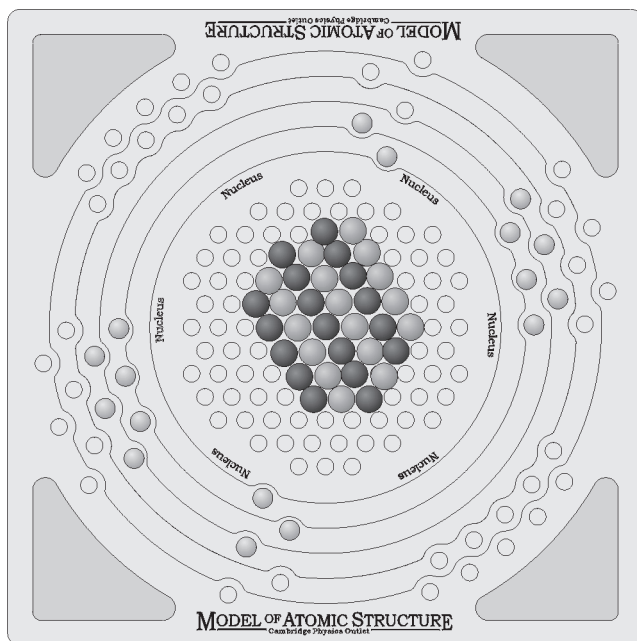
## Setup and Materials

Students work in groups of four or five at tables.

Each group should have:

- Atom building game
- A copy of the periodic table that comes with the game
- For part 4 of the Investigation, two groups will combine so that they have two atom building games.

A model of the chlorine atom using the Atom Building Game



- Blue marbles represent neutrons
- Red marbles represent protons
- Yellow marbles represent electrons

## Details

**Time** One class period

**Preparation** For hints on how to use the Atom Building Game II, read the **Reference Guide**.

**Assignments** Section 19.1 Bonding and Molecules in the **Student Edition** after the Investigation.

**Skill Sheets** 19-A Lewis Dot Diagrams

**Reference Guide** Equipment Setup: Atom Building Game

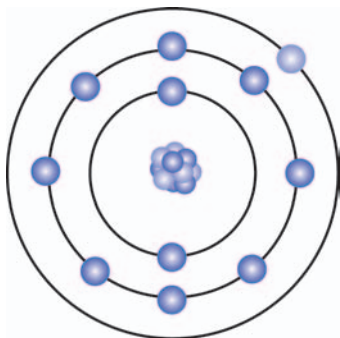
## Teaching the Investigation

- 1 Introducing the Investigation
- 2 Reviewing atomic structure
- 3 Building atoms and determining unoccupied spaces
- 4 Introducing valence electrons
- 5 Modeling a chemical bond
- 6 Determining oxidation numbers

## Introducing the Investigation

In this Investigation, you will use the Atom Building Game to show how electrons are involved in the formation of chemical bonds.

## Reviewing atomic structure



**SODIUM ATOM**

A sodium atom has two electrons in the first energy level, eight in the second, and only one in the third level.

## Building atoms and determining unoccupied spaces

Have you ever left an object made of iron (a nail, a skillet, a bicycle chain) out in the rain? What happens to it?

Students should respond that it rusts.

What is rust? How does it form?

Students may or may not know that rust is a chemical compound that is made out of iron atoms and oxygen atoms. Explain to them that when it rains, the iron metal gets wet and this allows the oxygen in the air to form a chemical bond with the iron metal to form rust.

When the iron atoms react with oxygen in the air to form a compound, a chemical bond is formed. Does anyone know what happens at an atomic level when a chemical bond is formed between two atoms?

Students will probably not have any ideas about this yet. Give them a hint that it has to do with electrons.

In this Investigation, you are going to use the Atom Building Game to answer the question: Why do atoms form chemical bonds with other atoms? You'll build models of atoms and discover how electrons are involved in the formation of chemical bonds.

**1**

Let's review what you already know about atoms. Let's use the example of a sodium atom to review. How many protons does a sodium atom have in its nucleus?

Students should know that the atomic number of sodium is 11, and this means that sodium has 11 protons.

How many neutrons does a sodium atom have in its nucleus?

Students should remember that the mass number is the number of protons plus neutrons. Have them look at the periodic table that came with their Atom Building Game. They can also use the periodic table in the back cover of the Student Book. If the mass number of a sodium atom is 23, then the atom will have 12 neutrons.

How many electrons does a sodium atom have?

Students should remember that a sodium atom has the same number of electrons as protons. Therefore, it has 11 electrons.

Do you remember how these electrons are arranged around the nucleus?

Students should remember that electrons fill energy levels around the nucleus. Draw the nucleus of a sodium atom on the board. Then, draw the first energy level as a ring. It holds two electrons. Have a student come up and draw in the two electrons. Draw the next level. It holds eight electrons. Have another student come up and add eight electrons. The total so far should be 10 electrons.

Where does the last electron go?

Students should respond that it goes in the next energy level which holds eight electrons. Draw another energy level and add the electron.

How many empty spaces are there in the third energy level? Remember, it holds eight electrons.

Students should answer that there are seven empty spaces in the third energy level.

Now I want you to build models of the atoms in question 2 on your Investigation sheet. Remember that blue marbles are neutrons, red are protons, and yellow are electrons. Fill in the table as you go.

Supervise groups as they work and review as necessary.

**2**

## 19.1

## Bonding and Molecules



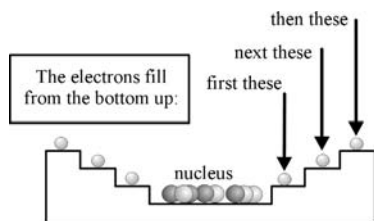
Question: Why do atoms form chemical bonds?

In this Investigation, you will:

1. Build models of atoms to gain an understanding of the arrangement of electrons.
2. Identify how atoms form chemical bonds and the role of electrons in bonding.

Most of the matter on Earth is in the form of compounds. Even when a substance exists as a pure element, it tends eventually to combine with other elements. For example, if you leave an iron nail outside in the rain, it will quickly combine with the oxygen in the air to form iron oxide, better known as rust. In this Investigation, you will build models of atoms and discover one of the fundamental ideas in chemistry: how electrons are involved in the formation of chemical bonds.

### 1 Reviewing atomic structure



Let's review what you already know about atoms:

- A neutral atom has the same number of electrons and protons.
- The electrons occupy energy levels surrounding the nucleus.
- Since electrons are attracted to the nucleus, they fill the lower energy levels first.

Once a given level is full, electrons start filling the next level.

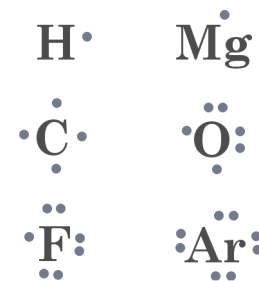
### 2 How many electrons are in the outermost level?

Using the atom building game, build each element in the table. For each element, record the number of electrons in the outermost energy level and the number of unoccupied spaces in the outermost energy level.

element	atomic number	electrons in outermost level	unoccupied spaces in outermost level
hydrogen	1	1	1
helium	2	2	0
lithium	3	1	7
fluorine	9	7	1
neon	10	8	0
sodium	11	1	7
chlorine	17	7	1
argon	18	8	0
potassium	19	1	7

## Dot Diagrams

After the Investigation, you may wish to introduce dot diagrams, also known as Lewis Dot Structures, after the chemist G.N. Lewis, who developed this system. The number of dots placed around the symbol of the element is equal to the number of valence electrons. This is helpful in visually representing why atoms combine with other atoms in certain ratios as in the example of sodium and chlorine. Here is a dot diagram of sodium, before and after ionization:



Here is a dot diagram of chlorine, before and after ionization:



Here is a dot diagram of sodium chloride showing the electrons involved in the chemical bond:



### Recycling plastics

Assign groups of students to find out about plastic recycling options in your community. Students can identify the options available for recycling all types of plastics. If time permits, your class can prepare and distribute an informational pamphlet, or organize a recycling effort in your school.

## Introducing valence electrons

*Valence electrons: The electrons in the outermost level that are involved in chemical bonding.*

*Sodium, potassium, lithium all have one valence electron.*

*The groups on the periodic table tell you how many valence electrons the elements have. Elements in Group 1 all have one valence electron. Elements in group 17 all have seven valence electrons.*

## Modeling a chemical bond

## Determining oxidation numbers

*When sodium loses one electron, it becomes an ion with a charge of +1.*

*Sodium's oxidation number is 1+.*

3

After students have finished building their models, have them answer questions 3(a) - 3(c) of the Investigation. Then go over the answers with the entire class.

You found that sodium, potassium, and lithium all had 1 electron in their outermost level, and seven empty spaces. Do you think this is important?

**Students should respond that they all need seven more electrons to fill their outermost levels.**

The electrons in the outermost level of an atom are called valence electrons. Lithium, potassium and sodium all have one valence electron. Now look at the periodic table. Where are these elements found?

**Students should see that they are all found in Group 1 on the periodic table. Review questions 3(b) and 3(c) and show students where these elements are found on the periodic table.**

So you can tell how many valence electrons an element has by looking at where it is found (which group it is in) on the periodic table. Stable atoms have eight valence electrons. Which group of the periodic table has eight valence electrons?

**Students should see that Group 18, the noble gases, all have eight valence electrons.**

Atoms will gain or lose electrons in order to have eight valence electrons in their outermost level. Which atoms need to lose electrons to have eight valence electrons in their outermost level?

**You may need to build a sodium atom to review this. Show that a sodium atom has one valence electron. If it loses that electron, it will have a full outermost level because the lower level holds eight. Show students that lithium is an exception to this rule because the first energy level only holds two electrons before it is full. Also review a chlorine atom and show how it will gain one electron instead of lose seven in order to complete its set of valence electrons.**

4

Now combine two groups so that each double group has two Atom Building Games. I would like each group to build a model of a sodium atom and a model of a chlorine atom. Then, discuss questions 4(a) through 4(c) on your Investigations sheets and record your answers.

**Supervise the double groups of students. Make sure that all students are actively involved in building the models and answering the questions. Go over the answers to the questions and make sure that all students understand that sodium loses one electron while chlorine gains one. This is why they will form a chemical bond.**

5

When sodium loses its electron, what happens to its electrical charge?

**Students should answer that when sodium loses one electron, it has 10 electrons and 11 protons, so its charge becomes +1.**

When sodium loses its electron, it becomes an ion with a positive charge. Its charge is positive one. An element's oxidation number is equal to its charge when it ionizes. What is sodium's oxidation number:

**Make sure that all students understand how its oxidation number is positive 1 (1+). Review the oxidation numbers of other elements on the periodic table.**

Why do sodium and chlorine combine in a one-to-one ratio?

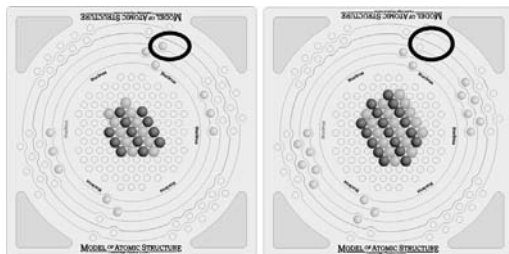
**Make sure students understand that it is because the sum of their oxidation numbers is zero.**

**3 What are valence electrons?**

Examine the table you just completed and record the answers to the following questions:

- What do lithium, sodium, and potassium have in common?
- What do fluorine and chlorine have in common?
- What do neon and argon have in common?

The electrons in the outermost energy level of an atom are called **valence electrons**. These are the electrons involved in chemical bonds. Lithium, sodium, and potassium each have one valence electron.

**4 Modeling a chemical bond**

Atoms that have a complete outermost energy level are stable. If there are empty holes, an atom will either gain, lose, or share electrons with another atom in order to complete its outermost level and become stable. When atoms gain, lose, or share electrons with another atom, they form **chemical bonds**.

Using two atom building games, build a sodium atom and a chlorine atom. Put them next to each other and answer the questions below.

- In order to complete its outermost energy level, do you think sodium will tend to lose its only valence electron, or gain seven? Explain your answer.
- In order to complete its outermost energy level, do you think chlorine will tend to lose all of its valence electrons or gain one electron? Explain your answer.
- Why might these two atoms bond together to form a molecule? In your answer, describe what you think might happen when sodium and chlorine form a chemical bond.

**5 Determining oxidation numbers**

An element's **oxidation number** is equal to the charge an atom has when it **ionizes**, that is, gains or loses electrons.

Use your models of sodium and chlorine to answer the questions below.

- Remove the valence electron from sodium. What has happened to the balance of positive and negative charges? What is sodium's oxidation number?
- Move the electron you took from sodium into the chlorine. What happens to chlorine's charge when it gains the electron from the sodium atom? What is chlorine's oxidation number?
- When sodium and chlorine form a chemical bond, what is the overall charge of the molecule? Why do you think sodium and chlorine combine in a 1:1 ratio?

**Example Answers**

- They all have 1 electron in their outermost levels. They also have 7 unoccupied spaces in their outermost levels.
- They each have 7 electrons in their outermost levels and 1 unoccupied space in their outermost levels.
- They each have 8 electrons in their outermost levels and no unoccupied spaces in their outermost levels.
- Sodium will tend to lose its only valence electron. It is easier to lose 1 electron than to gain 7. When sodium loses its valence electron, it will become more stable because its outermost level will be full.
- Chlorine has 7 valence electrons. By gaining 1 electron, chlorine will have 8 valence electrons and will become more stable.
- When sodium loses 1 electron, it will become positively charged, because it will have more positively-charged protons than negatively-charged electrons. When chlorine gains 1 electron, it will become negatively charged, because it will have more negatively-charged electrons than positively-charged protons. Sodium and chlorine will bond together because opposite electrical charges cause an attraction.
- When the valence electron was removed, there were 11 protons (positive charges) and 10 electrons (negative charges). This means that there was one more positive charge than negative. Sodium's oxidation number is therefore 1+.
- When I moved the electron from sodium to chlorine, chlorine gained an extra negative charge. It had 17 protons (positive charges) and 18 electrons (negative charges). Chlorine's oxidation number is therefore 1-.
- If sodium has a charge of 1+ and chlorine has a charge of 1-, their overall charge is neutral. This is because the charges add up to zero. Sodium and chlorine combine in a 1:1 ratio because the sum of the charges of 1 sodium atom plus 1 chlorine atom is equal to zero.

The cover is an evocative montage of historic scientific achievements that demonstrate the incredible persistence of the human intellect. Around the border, DaVinci's graphics represent the start of an evolving tapestry of conceptual thinking. His fantastical mechanisms become the modern bicycle, a quintessential machine, which rolls into a graphical interpretation of wavelength division multiplexing on a fiber optic. These images follow 500 years of scientific and technological innovation. The Earth and DNA serve to remind us that this technological innovation will always remain deeply connected to the natural world. On the back cover, the elegant geometry of the chambered nautilus folds into a spiral defined by the Golden Rectangle. The interplay of organic and architectural forms represents the balance we seek between the power of technology and the fragility of our lives and our world. I hope this colorful interplay of images will inspire interest and excitement about the discovery of science.

*Bruce Holloway - Senior Creative Designer*

Foundations of Physical Science  
Copyright © 2002 Cambridge Physics Outlet  
ISBN 1-58892-023-2  
1 2 3 4 5 6 7 8 9 - QWE- 05 04 03 02 01

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Cambridge Physics Outlet  
26 Howley Street  
Peabody, MA 01960  
(800) 932-5227  
<http://www.cpo.com>

Printed and Bound in the United States of America