
Welcome!

This is a chemistry lesson, covering *ionic and covalent compounds*.

I will guide you step-by-step.

I will be asking you many questions along the way.

Each time I ask a question, **you should attempt to answer the question on your own** before you scroll down to view my answer.

This is a lesson in the chapter “Atoms, Molecules, and Compounds”, which is part of the series, “Chemistry, Explained Step by Step”.

This lesson builds on the material we covered in the previous lesson on Ions.

You should complete that lesson before proceeding with this lesson.

The script for this lesson was written by Freelance-Teacher.

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Most elements rarely occur as separate atoms.
Instead, elements are usually found in combinations of atoms.

A *compound* is a combination of different elements,
in which the atoms of the elements occur in a fixed ratio.

We will discuss two types of compounds in this lesson:
ionic compounds, and
covalent compounds.

What are compounds composed of?

An ionic compound is composed of *ions*.

A covalent compound is composed of *molecules*.

You learned what ions are in the previous lesson, Ions.

We will discuss what “molecules” are later in this lesson.

1. What are the two types of compounds we will discuss in this lesson?

In this lesson we will be discussing ionic compounds and covalent compounds.

2. What parts is a covalent compound composed of?
What parts is an ionic compound composed of?

A covalent compound is composed of molecules.

An ionic compound is composed of ions.

3. What is an ion?

As we discussed in the previous lesson on Ions,
an ion is defined as:
an atom or group of atoms
with a positive or negative electric charge.

4. What is an anion?

An anion is defined as a negatively charged ion.

5. What do we call a positively charged ion?

A positively charged ion is called a cation.

If you got these questions wrong, you should work through the lesson on Ions.

In the lesson on Ions we discussed some memory aids that can help you to remember these definitions.

In the word “anion”, we can suppose that the letter “n” stands for “negative”.
So we can imagine that the letters of the word “A-N-ION” spell “A Negative ION”.

In the word “cation”, the letter “t” looks a little like a + symbol
So we can imagine that the last five letters of the word “c a-t-ion” spell “a + ion”;
i.e., “a positive ion”.

If an object with a net electric charge
is in the vicinity of another object with a net electric charge,
the two objects will either attract or repel each other.

The rule is:
like charges repel, and
unlike charges attract.

Positive and positive are like charges;
negative and negative are like charges;
positive and negative are unlike charges.

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6. Will an anion attract or repel another anion?

Like charges repel
and unlike charges attract.

Two anions have “like” charges (both negative)
so the two anions will *repel* each other.

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7. Will an anion and a cation attract or repel each other?

Like charges repel
and unlike charges attract.

An anion and a cation have “unlike” charges (one is negative, the other is positive)
so the anion and the cation will *attract* each other.

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8. Will a cation and another cation attract or repel each other?

Like charges repel
and unlike charges attract.

Two cations have “like” charges (both positive)
so the two cations will *repel* each other.

To review,
9. What parts is an ionic compound composed of?

An ionic compound is composed of ions.

It should be apparent from this definition that an ionic compound must be composed of both cations and anions.

Here's why.

If an ionic compound were composed of only cations,
the ionic compound would not "hold together",
because the cations would all repel one another.

Similarly, if an ionic compound were composed of only anions,
the ionic compound would not "hold together",
because the anions would all repel one another.

Therefore, in order for an ionic compound to hold together,
the ionic compound must be composed of both cations and anions.

10. What holds an ionic compound together?

An ionic compound is "held together"
by the attractions between the cations and the anions.

An ionic compound is described by a *chemical formula*.

Here are some examples of chemical formulas for different ionic compounds:
NaCl (table salt),
$MgSO_4$ (Epsom salt),
$NaHCO_3$ (baking soda),
$CaCO_3$ (chalk)
Al_2O_3
K_2S
$CaCl_2$

Recall that a *compound* is a combination of different elements,
in which the atoms of the elements occur in a *fixed ratio*.

For an *ionic* compound,
the subscripts in the chemical formula
describe the fixed ratio of the elements.

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11. For the ionic compound K_2S, what is the fixed ratio of the elements that appear in the compound?

In the chemical formula for an ionic compound,
the subscripts indicate the ratio of the elements.

In the formula K_2S,
the subscript for K is $_2$
and there is no subscript for S, which we should interpret as a subscript of $_1$

Therefore, for the compound K_2S,
potassium (K) and sulfur (S) appear in a 2:1 ratio.

This means that the compound contains twice as many K^+ cations as S^{2-} anions.

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12. For the ionic compound Al_2O_3, how do you interpret the chemical formula?

In the chemical formula for an ionic compound,
the subscripts indicate the ratio of the elements.

In the formula Al_2O_3,
the subscript for Al is $_2$
and the subscript for O is $_3$

Therefore, for the ionic compound Al_2O_3,
Al and O appear in a 2:3 ratio.

This means that the compound contains two-thirds as many Al^{3+} cations as O^{2-} anions.

(If you don't know how we figured out the charges on the Al ion and on the O ion,
you should work through the lesson on Ions.)

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13. For the ionic compound Na_2SO_4, how do you interpret the chemical formula?

In the chemical formula for an ionic compound,
the subscripts indicate the ratio of the elements.

In the formula Na_2SO_4,
the subscript for Na is $_2$
and the subscript for S is missing, which should be interpreted as a subscript of $_1$
and the subscript for O is $_4$

Therefore, for the ionic compound Na_2SO_4,
Na, S, and O appear in a 2:1:4 ratio.

This means that the compound contains twice as many sodium atoms as sulfur atoms,
and four times as many oxygen atoms as sulfur atoms.

(We will discuss how to determine the ions and the charges for a complicated ionic compound like this in a later lesson.)

Now let's describe the structure of an ionic compound:

An ionic compound is a continuous, solid, three-dimensional array of cations and anions;
the array is held together by the attractions between the cations and the anions.

For example, the structure of the ionic compound NaCl (table salt) consists of
a continuous, solid, three-dimensional array of Na^+ cations and Cl^- anions
in a 1:1 ratio (i.e., equal numbers of Na^+ cations and Cl^- anions);
the array is held together by the attractions between the Na^+ cations and the Cl^- anions.

Click this link for a diagram of the structure of NaCl:
https://simple.wikipedia.org/wiki/Ionic_compound#/media/File:Sodium-chloride-3D-ionic.png

14. What is the structure of the ionic compound $CaCl_2$?

The structure of $CaCl_2$ consists of
a solid array of Ca^{2+} cations and Cl^- anions
in a 1:2 ratio (i.e., twice as many Cl- anions as Ca2+ cations);
the array is held together by the attractions between the Ca^{2+} cations and the Cl^- anions.

(If you don't know how we figured out the charges on the calcium and chloride ions,
you should work through the previous lesson on Ions.)

In this lesson we are discussing ionic compounds and covalent compounds.

An *ionic* compound is based on
transferring electrons from one atom to another.

A *covalent* compound is based on
sharing electrons between atoms.

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15. In what sense do you think an ionic compound is "based" on "transferring" electrons from one atom to another?

Well, consider the ionic compound NaCl (table salt).

Let's imagine that you begin with a bunch of *neutral* Na and Cl atoms.

Because they are neutral, they won't attract each other yet.

But now, suppose each Na atom *transfers* one electron to one of the Cl atoms,
so that each Na ends up losing one electron to become a Na^+ cation,
and each Cl ends up gaining one electron to become a Cl^- anion ...

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16. Why would the neutral Na atoms and the neutral Cl atoms want to make this electron transfer?

In the previous lesson on Ions,
we learned that neutral elements tend to adjust their electron configurations
to match the electron configuration of the nearest noble gas in the periodic table.

So a neutral Na tends to lose one electron,
in order to adopt the favorable electron configuration of neon;
and a neutral Cl tends to gain one electron,
in order to adopt the favorable electron configuration of argon.

This explains why each neutral Na atom would tend to transfer 1 electron to a Cl atom,
and why each neutral Cl atom would tend to receive 1 electron from an Na atom.

… Once this *transfer* of electrons has taken place,
the neutral Na atoms and Cl atoms will have turned into Na^+ cations and Cl^- anions.

At that point, the ionic compound NaCl can form;
the ionic compound will be held together
by the attractions between the Na^+ cations and the Cl^- anions.

Thus, we have explained in what sense an ionic compound like NaCl is “based” on “transferring” electrons from one atom to another.

Let’s review what we have learned so far.

17. What is a compound?

A compound is a combination of different elements,
in which the atoms of the elements occur in a fixed ratio.

18. What are the two types of compound we are discussing in this lesson?

In this lesson we are discussing
ionic compounds, and
covalent compounds.

19. What parts is an ionic compound composed of?
What parts is a covalent compound composed of?

An ionic compound is composed of ions.

A covalent compound is composed of molecules.

20. What holds an ionic compound together?

An ionic compound is “held together”
by the attractions between the cations and the anions.

21. What is the structure of an ionic compound?

An ionic compound is a continuous, solid, three-dimensional array of cations and anions;
the array is held together by the attractions between the cations and the anions.

The cations and anions appear in the fixed ratio
that is indicated by the chemical formula for the compound.

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22. What is a covalent compound "based" on?
What is an ionic compound "based" on?

A covalent compound is based on
sharing electrons between atoms.

An ionic compound is based on
transferring electrons from one atom to another.

We have seen that
an ionic compound is composed of *ions*, and
a covalent compound is composed of *molecules*.

Now, what is a “molecule”?

A *molecule* is a group of atoms
which is held together by *covalent bonds*.

A *covalent bond* consists of a pair of electrons
that is *shared* between two atoms in the molecule.

Let’s review.

23. What parts is a covalent compound composed of?

A covalent compound is composed of molecules.

24. What are molecules?

A molecule is a group of atoms,
which is held together by *covalent bonds*.

25. What is a covalent bond?

A covalent bond consists of a pair of electrons
that is *shared* between two atoms in the molecule.

26. True or False? If false, how could you rewrite the statement so that it is true?
Both covalent compounds and ionic compounds are composed of molecules.

False.

Only covalent compounds are composed of molecules.
Ionic compounds are not composed of molecules; instead, an ionic compound is composed of cations and anions,
arranged in a continuous, solid, three-dimensional array which is held together by the attractions between the cations and the anions.

Every covalent compound is associated with a *chemical formula*.

Here are some examples of chemical formulas for covalent compounds:

H_2O (water),
CO_2 (carbon dioxide),
CO (carbon monoxide),
O_2 (oxygen gas),
NH_3 (ammonia),
CH_4 (methane),
$C_6H_{12}O_6$ (table sugar)

The chemical formula for a *covalent* compound describes
both the covalent compound as a whole,
and each individual molecule inside the compound.

The subscripts in the chemical formula for a covalent compound tell you
the *actual number* of atoms of each element that are contained in *one molecule* of the compound.

This should make it obvious that
the subscripts in the chemical formula for a covalent compound *also* tell you
the *ratio* of the elements in the *compound as a whole*.

In contrast, an *ionic* compound does not contain separate molecules.
So the subscripts in the chemical formula for an ionic compound
simply tell you the ratio of the elements in the compound as a whole.

For example:
27. How would you interpret the chemical formula for the covalent compound, ammonia, NH_3?

For a covalent compound,
the chemical formula describes
both the compound as a whole,
and a single molecule of the compound.

The subscripts from the chemical formula for a covalent compound
tell you the *actual number* of atoms of each element that are contained in one molecule of the compound;
and therefore they also tell you the *ratio* of the atoms of each element that are contained in the compound as a whole.

In the chemical formula NH_3,
the subscript for N is missing, which we interpret as a subscript of $_1$
and the subscript for H is $_3$

So, the chemical formula for the covalent compound ammonia, NH_3,
tells us that *a single molecule* of ammonia is composed of 1 nitrogen atom, and 3 hydrogen atoms;
which means that, *in the compound ammonia as a whole*, the atoms N and H must appear in a 1:3 ratio.

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28. How would you interpret the chemical formula for the covalent compound, ethanol, which is C_2H_6O?
(Ethanol is the alcoholic component of alcoholic beverages such as beer and wine.)

The chemical formula for the covalent compound, ethanol, which is C_2H_6O,
tells us that a *single molecule of ethanol* is composed of 2 atoms of carbon, 6 atoms of hydrogen, and 1 atom of oxygen;
which means that, *in the compound ethanol as a whole*, atoms of carbon, hydrogen, and oxygen must appear in a 2:6:1 ratio.

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29. How would you interpret the chemical formula for the covalent substance, oxygen gas, O_2?

The chemical formula for the covalent substance, oxygen gas, is O_2, which tells us
that a single molecule of oxygen is composed of 2 oxygen atoms;
and that, in the substance oxygen gas as a whole, 100% of the atoms consist of oxygen atoms.

Notice that a *molecule* of oxygen gas is different from an *atom* of oxygen:
the chemical formula for a *molecule* of oxygen gas is O_2;
the atomic symbol for an oxygen *atom* is O.

(For the sake of completeness, I will mention that a “compound” is defined as a combination of two or more *different* elements, in which the elements occur in a fixed ratio. Oxygen gas contains only one element, the element oxygen; so, oxygen gas is not considered to be a covalent *compound*. Instead, oxygen gas can be referred to as a “covalent *substance*”. But this distinction probably will not be important in your course.)

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30. How would you interpret the chemical formula for the ionic compound $AlBr_3$ (aluminum bromide).

Notice that, to keep you on your toes, this problem deals with an *ionic* compound, not a covalent compound.

The chemical formula $AlBr_3$ tells us that
in the compound aluminum bromide as a whole,
Al^{3+} cations and Br^- anions appear in a 1:3 ratio.

Ionic compounds do not contain separate molecules,
so it would be wrong to try to interpret the formula $AlBr_3$ in terms of a single molecule.

Now let's describe the structure of a covalent compound:

A covalent compound is a collection of *separate molecules*, each with the same chemical formula;
each molecule is composed of atoms;
each molecule is held together by *covalent bonds* between the atoms;
the number of atoms for each element in the molecule is indicated by the chemical formula for the molecule.

For example:
31. What is the structure of the covalent compound, water (H_2O)?

A glass of water is a collection of many, many, many separate molecules.

Each molecule of water has the chemical formula H_2O,
so each molecule of water is composed of two atoms of hydrogen and one atom of oxygen;
each molecule of water is held together by the covalent bonds between the atoms.

H_2O is the chemical formula for the entire *covalent compound*, water;
and H_2O is also the chemical formula for a single *molecule* of water.

32. What is the structure of the covalent compound, table sugar, whose chemical formula is $C_6H_{12}O_6$?

A single granule of table sugar is a collection of many, many, many separate molecules.

Each molecule of table sugar has the chemical formula $C_6H_{12}O_6$,
so each molecule of table sugar is composed of six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen;
each molecule of table sugar is held together by covalent bonds between the atoms.

$C_6H_{12}O_6$ is the chemical formula for the entire *covalent compound*, table sugar;
and $C_6H_{12}O_6$ is also the chemical formula for a single *molecule* of table sugar.

33. What is the structure of the ionic compound, magnesium nitride, whose chemical formula is Mg_3N_2?

Notice that this problem asks for the structure of an *ionic* compound, not a covalent compound.

The structure of magnesium nitride (Mg_3N_2) consists of
a solid array of Mg^{2+} cations and N^{3-} anions
in a 3:2 ratio (i.e., two-thirds as many N^{3-} anions as Mg^{2+} cations);
the array is held together by the attractions between the Mg^{2+} cations and the N^{3-} anions.

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34. What is an ionic compound “based” on?
What is a covalent compound “based” on?

An ionic compound is based on
transferring electrons from one atom to another.

A covalent compound is based on
sharing electrons between atoms.

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35. In what sense do you think a covalent compound is “based” on “sharing” electrons between atoms?

Well, consider the covalent compound CO_2 (carbon dioxide gas).

Because carbon dioxide is a covalent compound,
we know that it is composed of many, many, many separate CO_2 molecules.
Each molecule consists of 1 carbon atom and 2 oxygen atoms.
Each molecule is held together by *covalent bonds* between the atoms.

A covalent bond consists of a pair of electrons
that are *shared* between two atoms in the molecule.

So, each molecule of carbon dioxide holds together
because of covalent bonds between the atoms in the molecule.

That is to say, each molecule of carbon dioxide holds together
because of pairs of electrons that are *shared* between the atoms in the molecule.

Thus, we have explained in what sense a covalent compound like CO_2 is “based” on “sharing” electrons between atoms.

We will discuss covalent bonds in more detail in a later chapter.

Let’s review what we have learned in this lesson.

36. What is a compound?

A compound is a combination of different elements,
in which the atoms of the elements occur in a fixed ratio.

37. What types of compounds did we discuss in this lesson?

In this lesson we discussed covalent compounds and ionic compounds.

38. What parts are covalent compounds composed of?
What parts are ionic compounds composed of?

Covalent compounds are composed of molecules.

Ionic compounds are composed of ions.

39. What holds an ionic compound together?

An ionic compound is “held together”
by the attractions between the cations and the anions.

40. What are molecules composed of?

Molecules are composed of atoms.

41. What “holds together” each molecule?

Each molecule is held together
by *covalent bonds* between the atoms in the molecule.

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42. What is a covalent bond?

A covalent bond consists of a pair of electrons
that is *shared* between two atoms in the molecule.

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43. What is the structure of a covalent compound?
What is the structure of an ionic compound?

A covalent compound is a collection of separate molecules, each with the same chemical formula;
each molecule is composed of atoms;
each molecule is held together by covalent bonds between the atoms;
the number of atoms for each element in the molecule is indicated by the chemical formula for the molecule.

An ionic compound is a continuous, solid, three-dimensional array of cations and anions;
the array is held together by the attractions between the cations and the anions;
the atoms for each element in the array appear in the ratio indicated by the chemical formula for the compound.

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44. True or False? If false, how could you rewrite the statement so that it is true?
Both covalent compounds and ionic compounds are composed of molecules.

False.

Only covalent compounds are composed of molecules.
Ionic compounds are not composed of molecules; instead, an ionic compound is composed of cations and anions,
arranged in a continuous, solid array which is held together by the attractions between the cations and the anions.

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45. What is an ionic compound “based” on?
What is a covalent compound “based” on?

An ionic compound is based on
transferring electrons from one atom to another.

A covalent compound is based on
sharing electrons between atoms.

Notice that *both* types of chemical compound are based on
interactions between the *electrons* of the atoms.

Recall that in an earlier lesson (on Isotopes), we said that the chemical properties of an atom are based on the number of electrons contained in the atom.

Now you can begin to see the reason for that statement:
The number of electrons in an atom determines how the electrons will interact with other atoms.
And the interactions between electrons determine the compounds that the atom can form.

We will discuss these ideas in more detail in later chapters.

You have reached the end of this lesson.

You’re ready now to proceed to the next lesson for this chapter:
Distinguishing Ionic and Covalent Compounds