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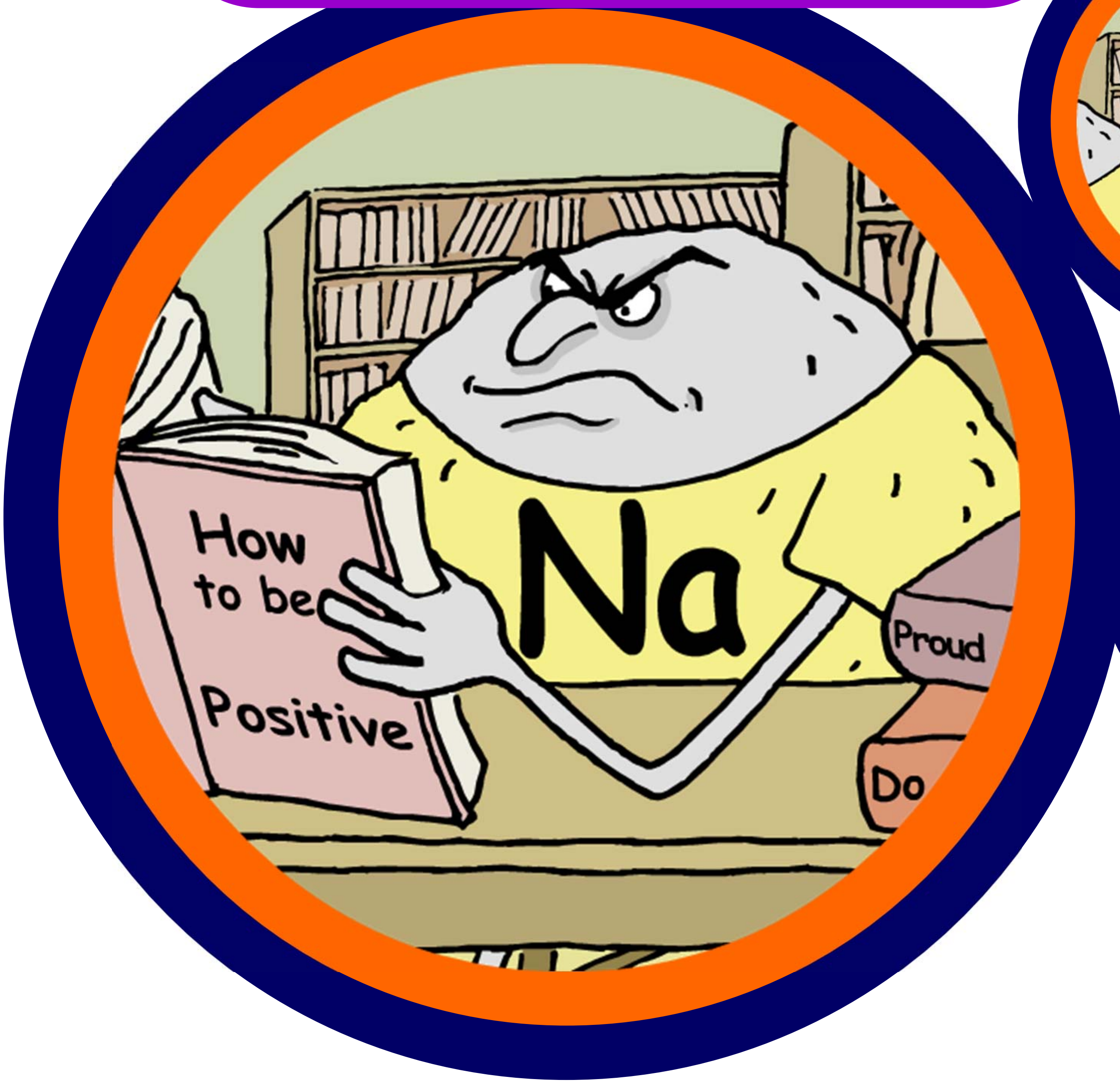
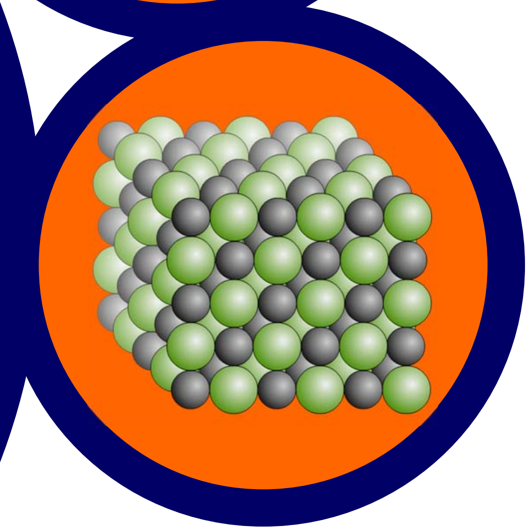
Ionic Bonding





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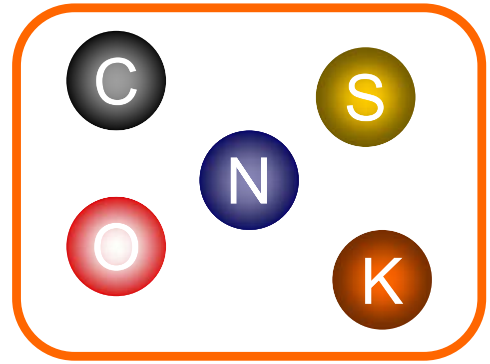
Elements

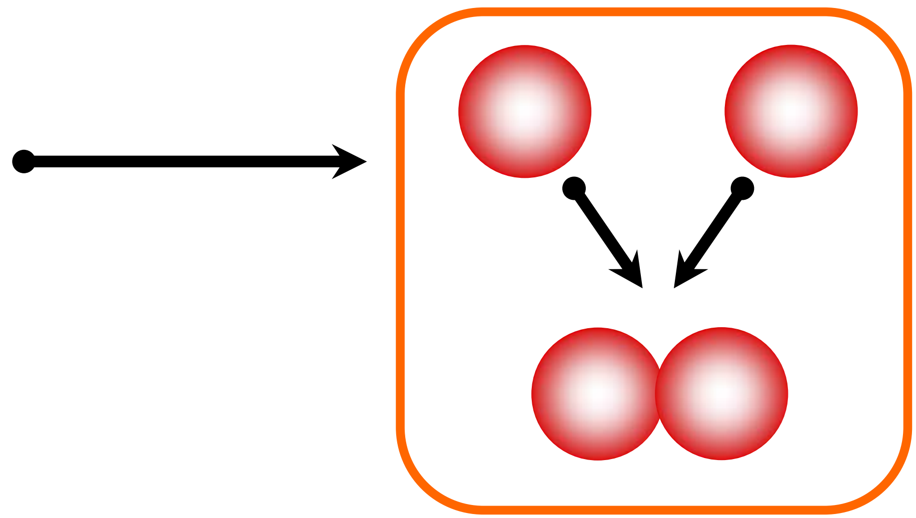
- Elements are the simplest substances. There are about 100 different elements.

Each element is made up of just one particular type of atom, which is different to the atoms in any other element.



Atoms usually join together. This is called **bonding**.

In some elements, atoms bond to form small, simple structures. In other elements, atoms bond into giant structures with millions of atoms.



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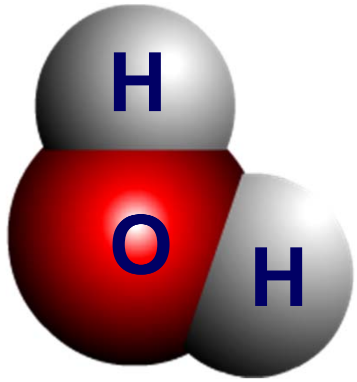
Compounds

- **Compounds** are formed when different elements chemically react with each other. In these reactions different types of atom become chemically bonded.

Some compounds, like water, have **small, simple structures** with just a few atoms bonded together.



Others compounds, like DNA, have **large, complex structures** containing thousands or even millions of bonded atoms.

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Properties of compounds

- A compound has different properties to the elements from which it is made because the atoms are joined differently.

carbon + **oxygen** → **carbon dioxide**

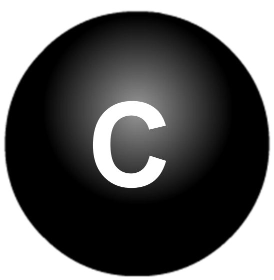
Black solid used as fuel.

+

Colourless gas in which many substances burn.

→

Colourless gas used in fizzy drinks and fire extinguishers.



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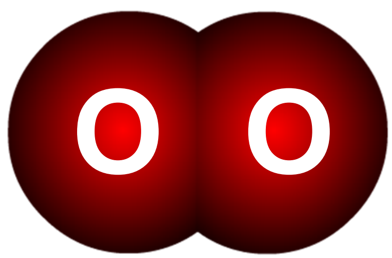

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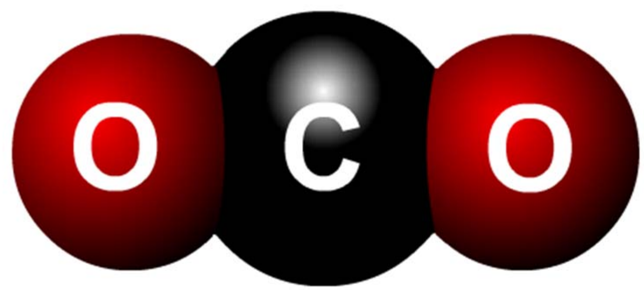

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Element or compound?

Decide if each substance is an element or compound.

sodium chloride	NaCl	
carbon	C	
nitric acid	HNO_3	
water	H_2O	
oxygen	O_2	
rust	Fe_2O_3	
mercury	Hg	

element compound

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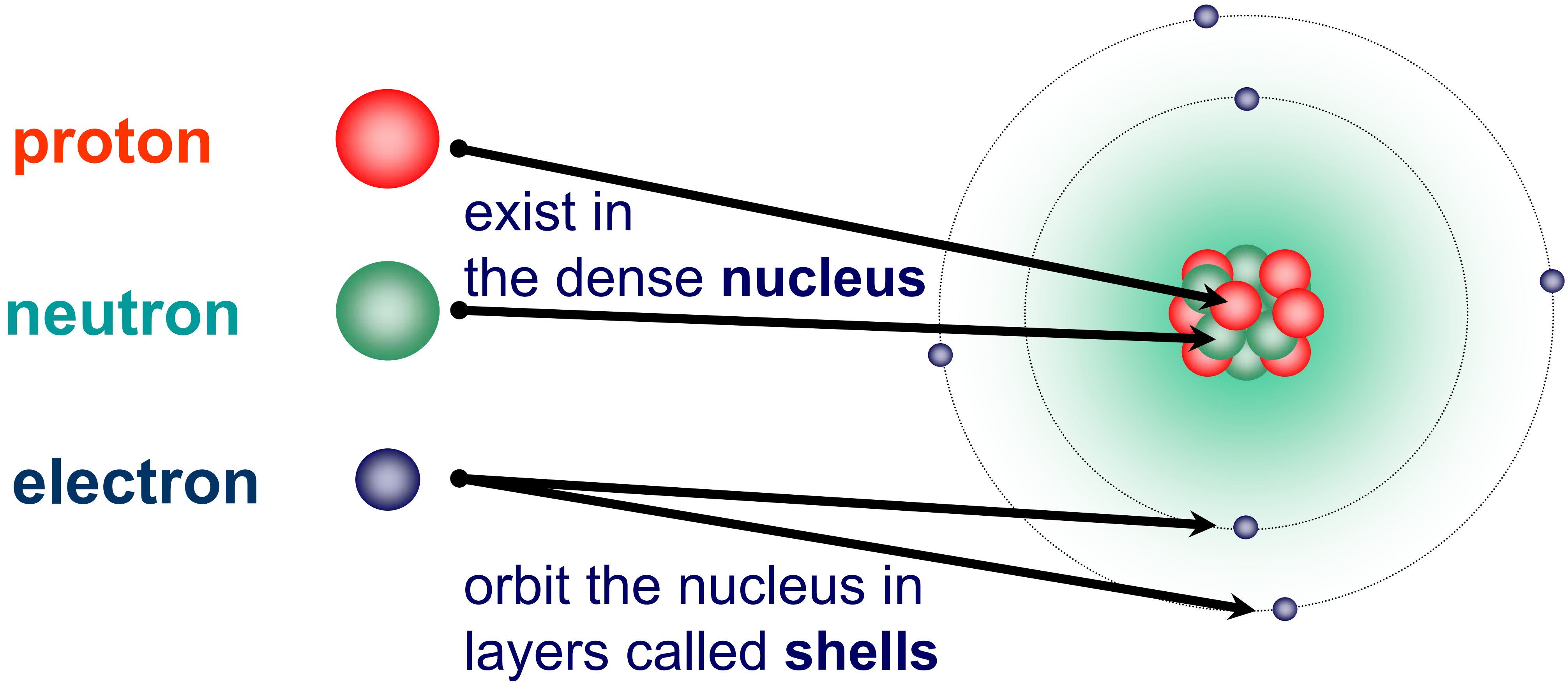
Subatomic particles

- Atoms consist of three types of subatomic particles:



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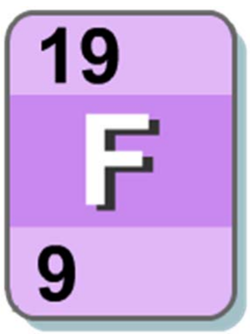
Atoms and electrical charge

- An important feature of subatomic particles is their electrical charge:

Particle	proton	neutron	electron
Charge	+1	0	-1

Atoms have **equal numbers** of protons and electrons, which means their overall charge is **zero**.

For example, fluorine:

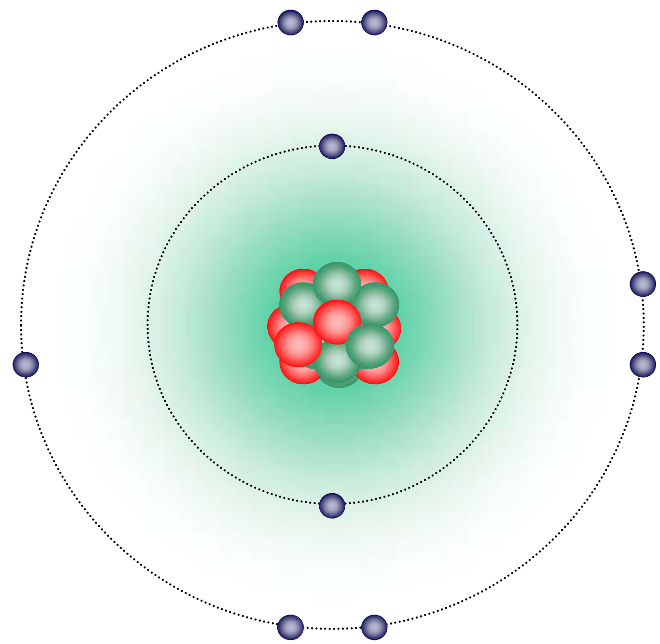


9 protons = +9

9 electrons = -9

10 neutrons = 0

Total charge = 0



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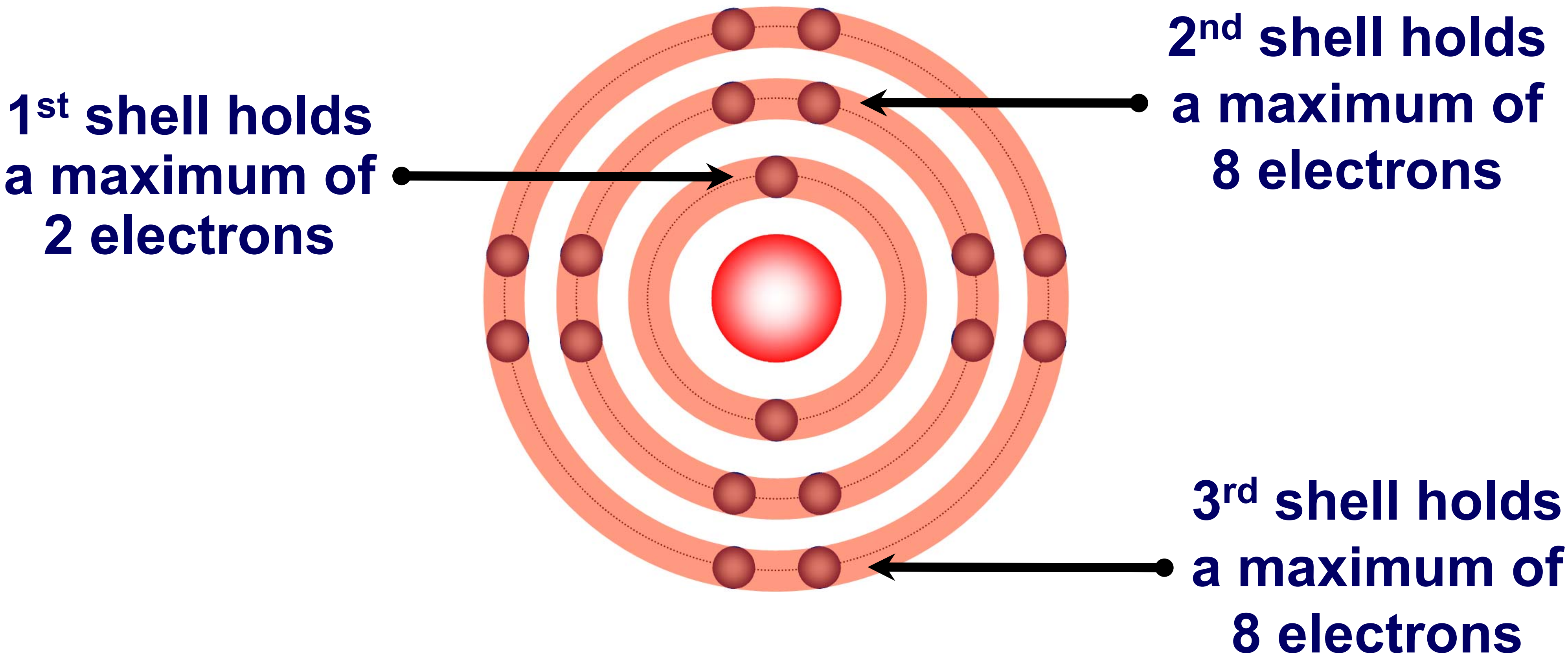
Full electron shells

- Each shell has a maximum number of electrons that it can hold. Electrons will fill the shells nearest the nucleus first.



- Atoms of **noble gases** have completely full outer shells. This makes them very **unreactive** or **stable**.

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Types of bonding

- Atoms can be bonded in three different ways:

Ionic bonding → **Metal and non-metal atoms**

Covalent bonding → **Non-metal atoms only**

Metallic bonding → **Metal atoms only**

- Bonding occurs because atoms with incomplete outer electron shells are unstable. By forming bonds, atoms completely fill their outer shells and become stable.

  All types of bonding involve changes in the number of electrons in the outer shells of atoms.

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Making ions

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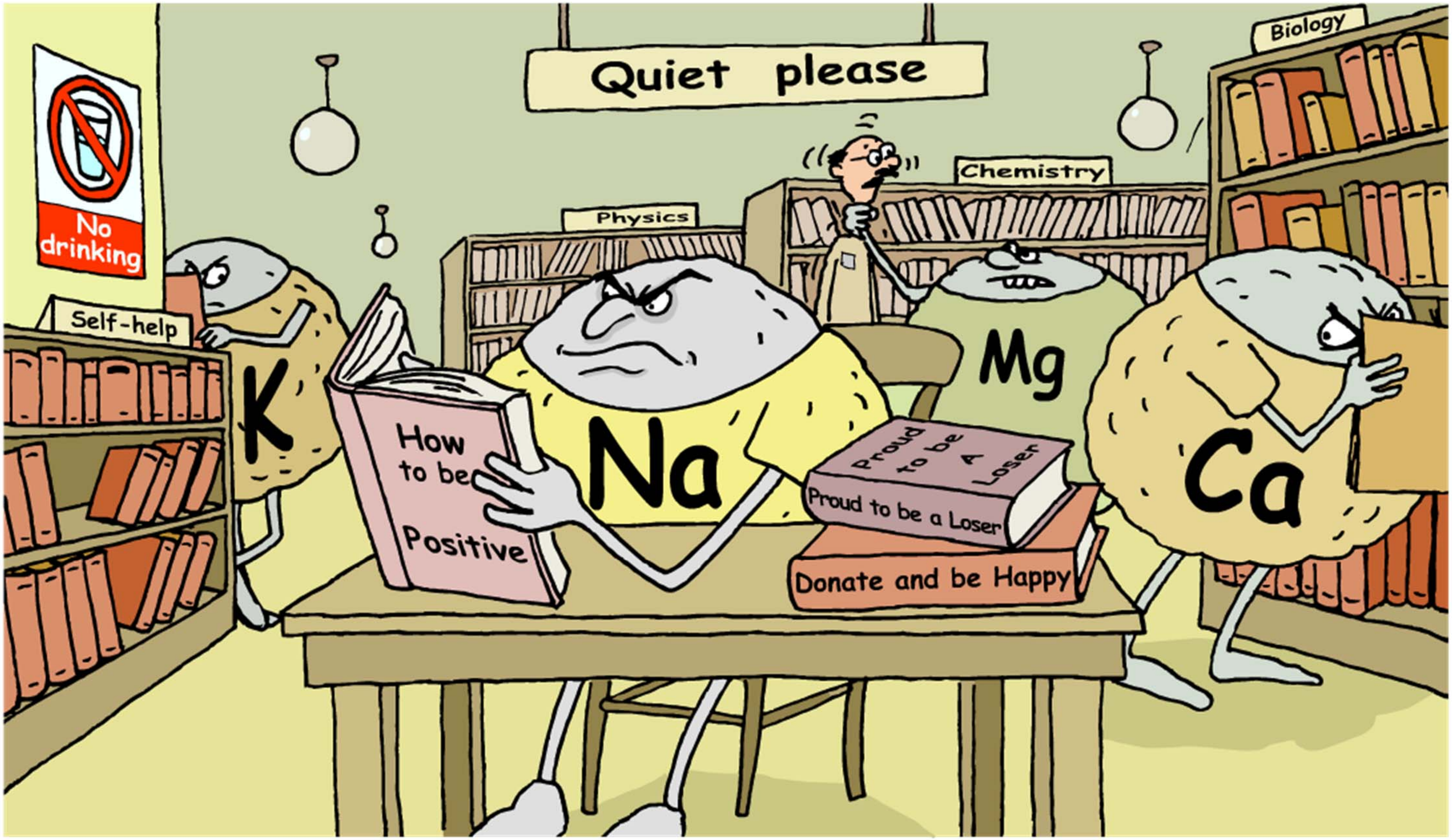
From atoms to ions

- How can reactive metal atoms become stable positive ions?



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Atoms and electron changes

- Atoms can obtain completely full outer electron shells by either gaining or losing electrons when they react with other atoms. When this happens, atoms become **ions**.

  Unlike atoms, ions have an electrical charge because they contain an unequal number of protons and electrons.

Atoms that **lose** electrons have more protons than electrons and so have a positive charge. They are called **positive ions** or **cations**.

Atoms that **gain** electrons have more electrons than protons and so have a negative charge. They are called **negative ions** or **anions**.

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Charges on ions

- When atoms form ions they obtain an outer electron shell that is either completely full or completely empty.
  - For atoms with a nearly empty outer shell, it takes less energy to **lose** electrons to have a full outer shell than it does to gain electrons.
  - For atoms with a nearly full outer shell, it takes less energy to **gain** electrons to have a full outer shell than it does to lose electrons.

The **electron configuration** of an atom gives information about how many electrons it must lose or gain to achieve a stable, noble gas configuration.

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Positive ions

- An atom that loses one or more electrons forms a positive ion. **Metal atoms**, such as sodium, magnesium and iron, form positive ions.

  Positive ions have a small '+' symbol and a number by them to indicate how many electrons they have lost.

  This number is usually the same as the number of electrons in the atom's outer shell. For example:

lithium atom	**= 2.1**	**ion**	**= Li^{+} (not Li^{1+})**
magnesium atom	**= 2.8.2**	**ion**	**= Mg^{2+}**
aluminium atom	**= 2.8.3**	**ion**	**= Al^{3+}**

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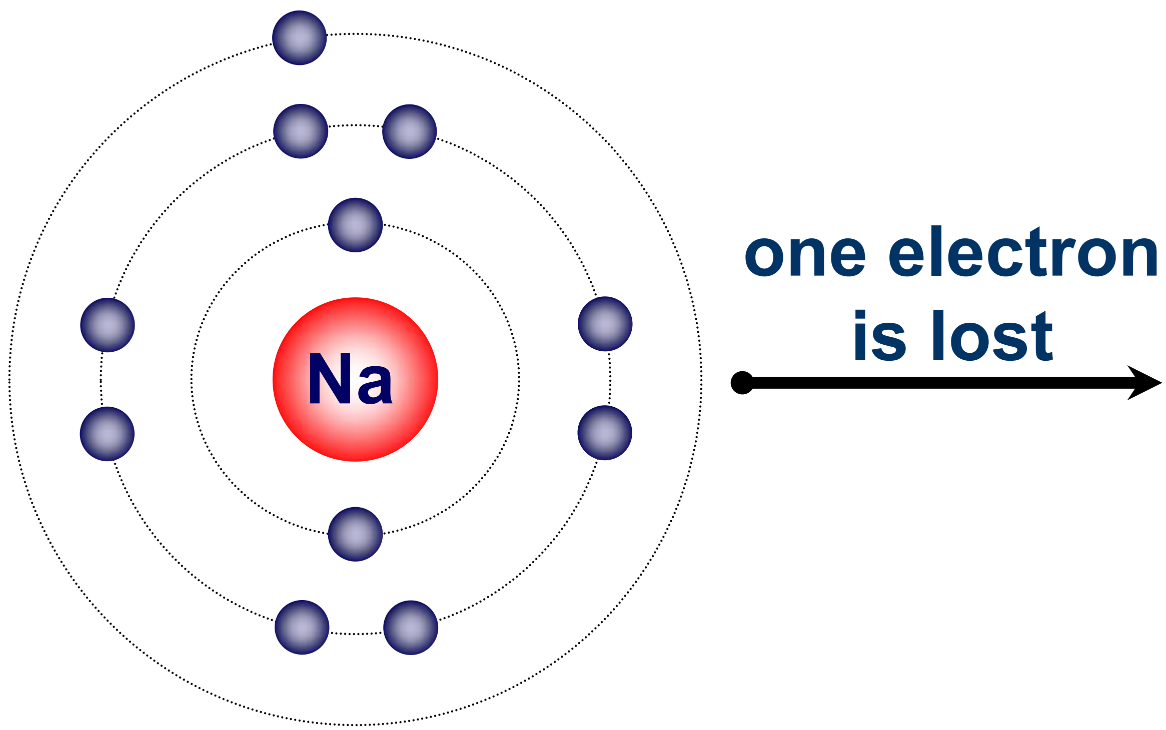
The sodium ion

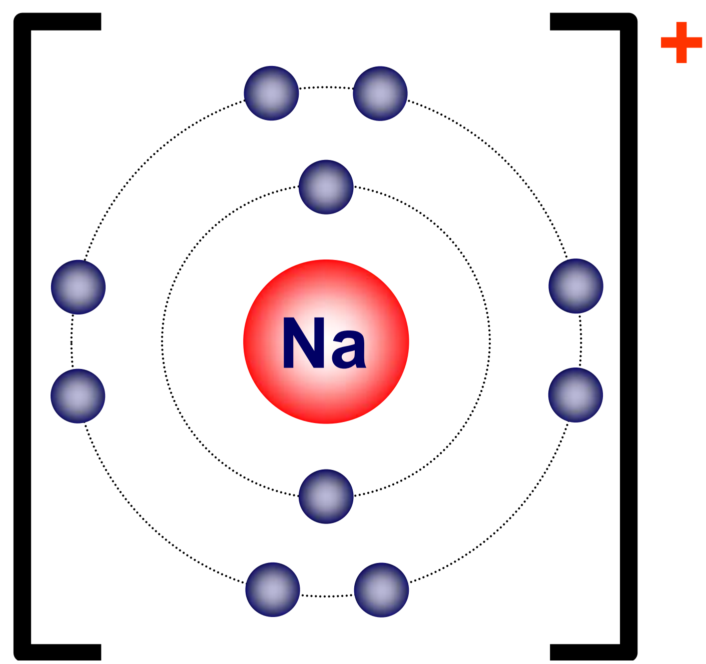
- Sodium atom:

11 protons	=	+11
11 electrons	=	-11
Total charge	=	0

Sodium ion:

11 protons	=	+11
10 electrons	=	-10
Total charge	=	+1





Electron arrangement: **2.8.1**
(partially full outer shell)

Electron arrangement: **$[2.8]^+$**
(full outer shell)

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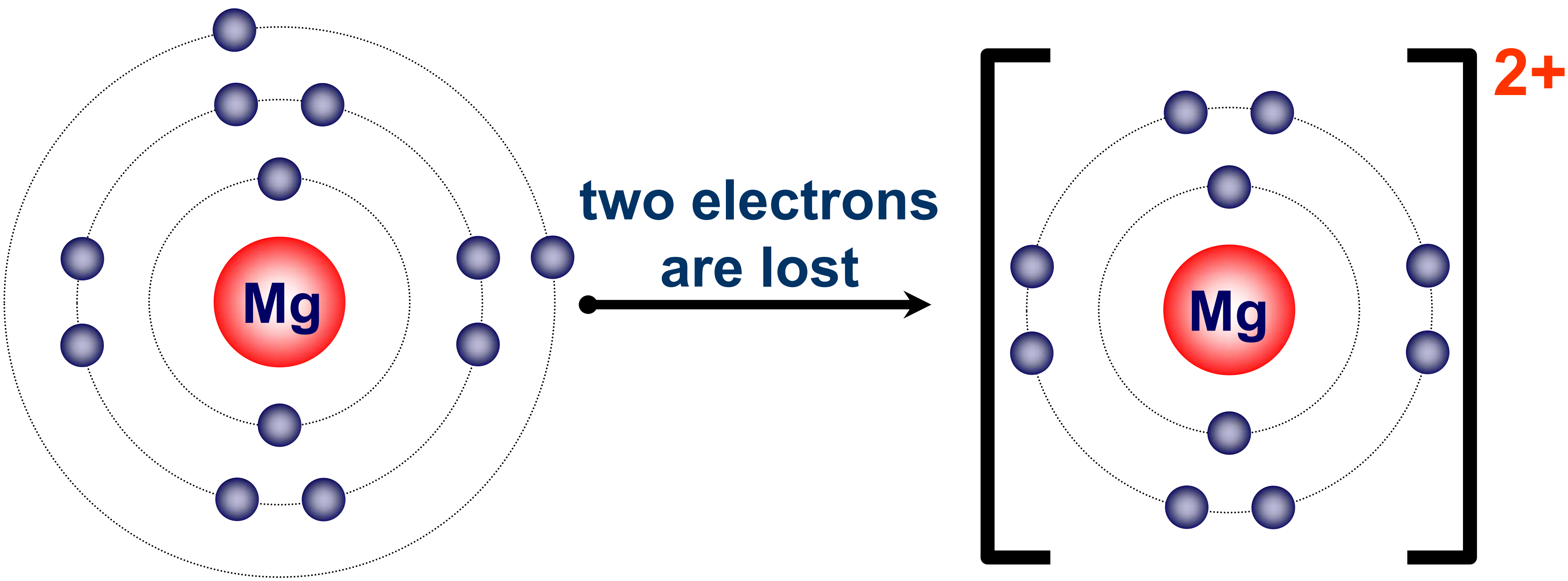
The magnesium ion

Magnesium atom:

12 protons	=	+12
12 electrons	=	-12
Total charge	**=**	**0**

Magnesium ion:

12 protons	=	+12
10 electrons	=	-10
Total charge	**=**	**+2**



Electron arrangement: **2.8.2**
(partially full outer shell)

Electron arrangement: **$[2.8]^{2+}$**
(full outer shell)

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Negative ions

- An atom that gains one or more electrons forms a negative ion. **Non-metal atoms**, such as chlorine, oxygen and nitrogen, form positive ions.

  Negative ions have a small '-' symbol and a number by them to indicate how many electrons they have gained to fill their outer shell. For example:

chlorine atom = 2.8.7	**chloride ion = Cl^- (not Cl^{1-})**
oxygen atom = 2.6	**oxide ion = O^{2-}**
nitrogen atom = 2.5	**nitride ion = N^{3-}**

  The name of the ion is slightly different to that of the atom – it ends '**–ide**'.

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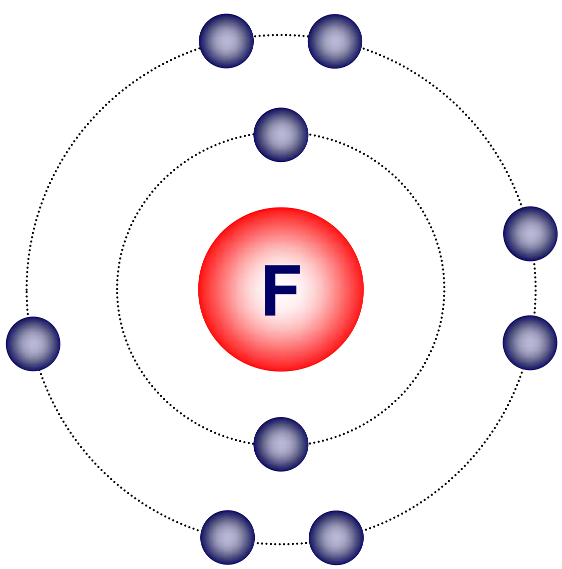
The fluoride ion

- Fluorine atom:

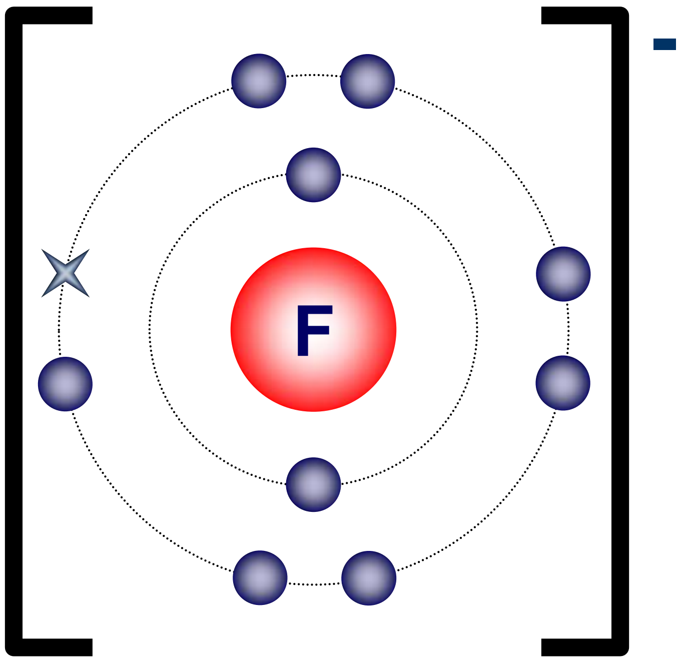
9 protons	=	+9
9 electrons	=	-9
Total charge	=	**0**

Fluoride ion:

9 protons	=	+9
10 electrons	=	-10
Total charge	=	**- 1**



one electron is gained



Electron arrangement: **2.7**
(partially full outer shell)

Electron arrangement: **$[2.8]^-$**
(full outer shell)

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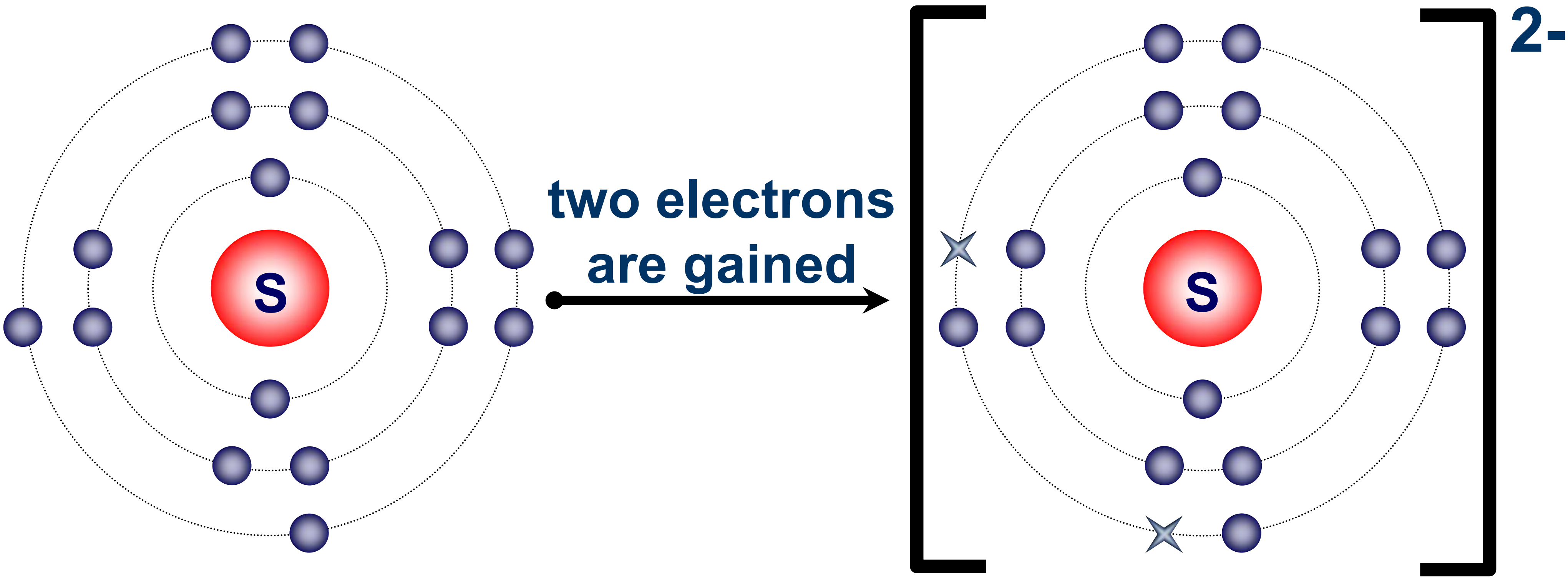
The sulfide ion

- Sulfur atom:

16 protons	=	+16
16 electrons	=	-16
Total charge	**=**	**0**

Sulfide ion:

16 protons	=	+16
18 electrons	=	-18
Total charge	**=**	**- 2**



Electron arrangement: **2.8.6**
(partially full outer shell)

Electron arrangement: **$[2.8.8]^{2-}$**
(full outer shell)

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Building an ion

Select an element to investigate its ion.

7 Li 3	9 Be 4	16 O 8	19 F 9
23 Na 11	24 Mg 12	32 S 16	35.5 Cl 17

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Calculating ion charges

- What charges will the ions of these elements have?

Element	calcium 40 Ca 20	hydrogen 1 H 1	phosphorus 31 P 15	fluorine 19 F 9	beryllium 9 Be 4
Electrons	2.8.8.2	1	2.8.5	2.7	2.2
Charge	2+	+	3-	1-	2+

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Transition metal ions

- Some transition metals only make one type of ion. For example:
  - silver only forms Ag^{+} ions;
  - zinc only forms Zn^{2+} ions.

However, most transition metals make more than one type of ion by losing different numbers of electrons. For example:

Metal	Ion	Example of compound
copper	Cu^{+}	copper (I) oxide – Cu_2O
	Cu^{2+}	copper (II) oxide – CuO
iron	Fe^{2+}	iron (II) chloride – $FeCl_2$
	Fe^{3+}	iron (III) chloride – $FeCl_3$

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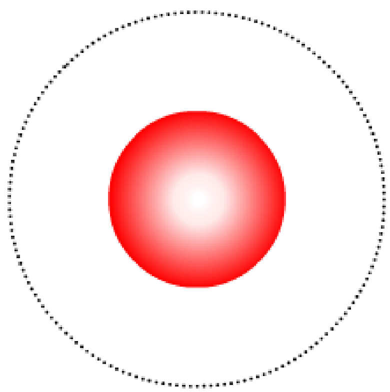
Comparing electron configurations

Which particles have this stable electron configuration?



B^{3+}	Na^{+}	Cl^{-}
He	O^{2-}	Al^{3+}
Be^{2+}	Li^{+}	N^{3-}
Mg^{2+}	F^{-}	Ne
Br^{-}	H^{+}	S^{2-}

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Comparing positive and negative ions

What are the correct facts about positive and negative ions?

Property	Positive ions	Negative ions
Electron change	?	?
Element type	?	?
Also known as	?	?
Element ion example	?	?
Compound ion example	?	?

SO_4^{2-}

? C solve

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Ionic Bonding

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Ionic compounds

- Compounds that contain ions are called **ionic compounds**. These compounds are usually formed by a reaction between a **metal** and a **non-metal**.

Why do these substances react?

Both the metal and non-metal atoms have incomplete outer electron shells and so are **unstable**.

One or more electrons are transferred from each metal atom to each non-metal atom. The metal and the non-metal atoms end up with completely full outer shells and become very stable.

The positive and negative ions are strongly attracted to each other. This **electrostatic** attraction is called an **ionic bond**.

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Sodium chloride: part 1

- Sodium chloride is an ionic compound formed by the reaction between the metal sodium and the non-metal chlorine.

sodium	+	chlorine	→	sodium chloride
Na		Cl		$NaCl$

During the reaction, one electron is transferred from each sodium atom to each chlorine atom.

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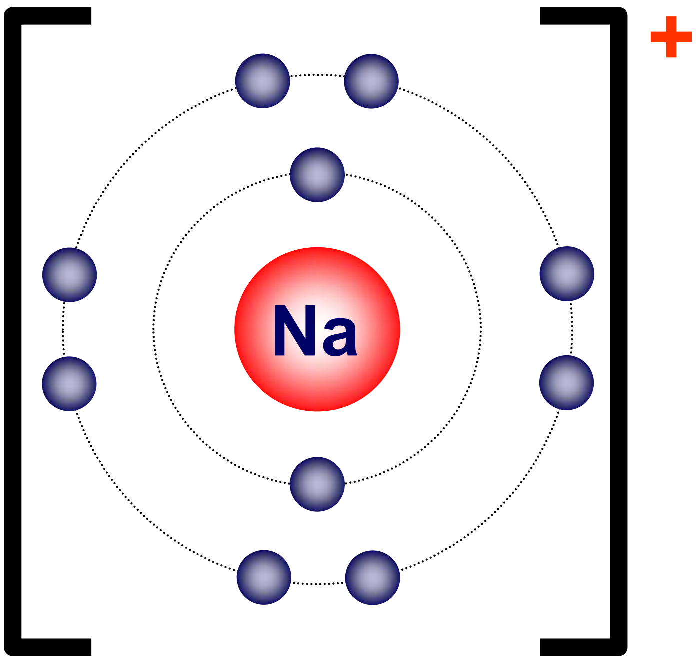
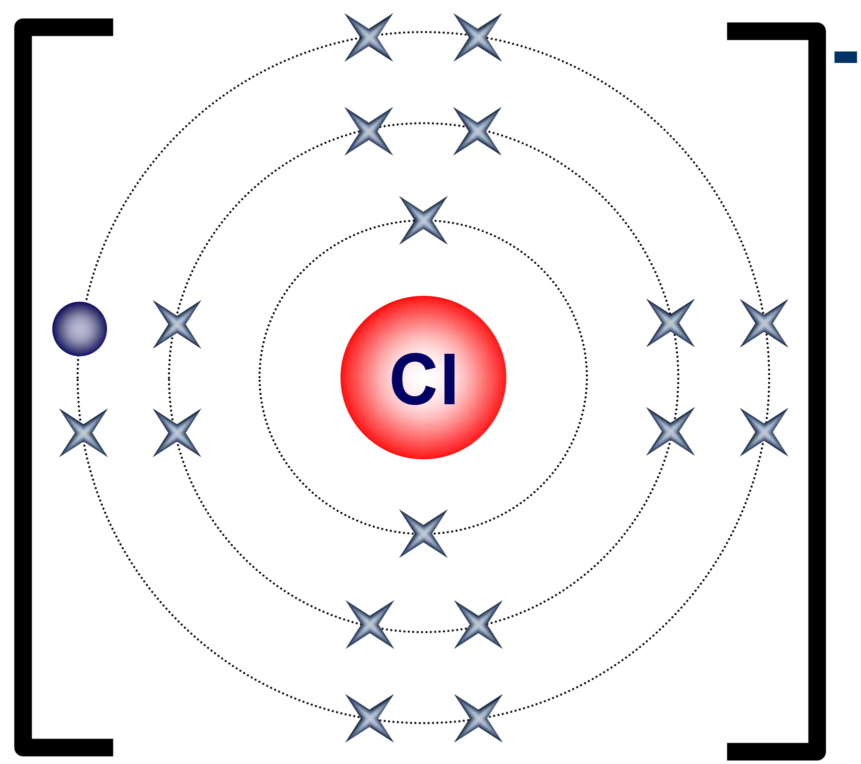
Sodium chloride: part 2

- Sodium has 1 electron in its outer shell. If it loses this electron, it will have no partially-filled shells.

Chlorine has 7 electrons in its outer shell. If it gains 1 electron, it will completely fill its outer shell.





2.8.1 → $[2.8]^+$

2.8.7 → $[2.8.8]^-$

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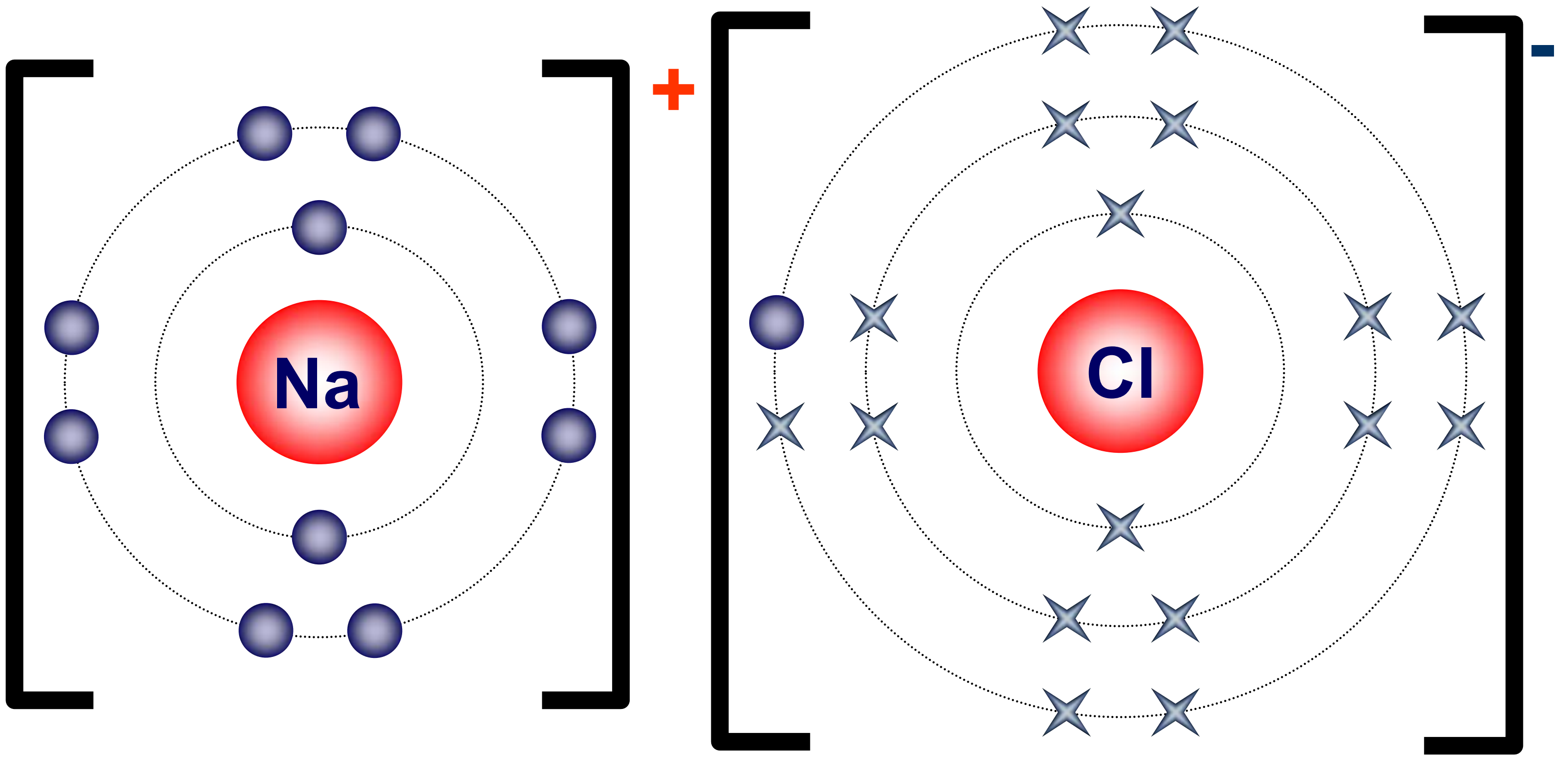
Sodium chloride: part 3

- The positive sodium ions and the negative chloride ions are strongly attracted to each other and form an ionic bond.



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Magnesium oxide: part 1

- More than one electron can be transferred during ionic bonding.

  Magnesium oxide is another ionic compound, formed by the reaction between magnesium and oxygen.

magnesium + **oxygen** → **magnesium oxide**

Mg + **O** → **MgO**

During this reaction, two electrons are transferred from each magnesium atom to each oxygen atom.

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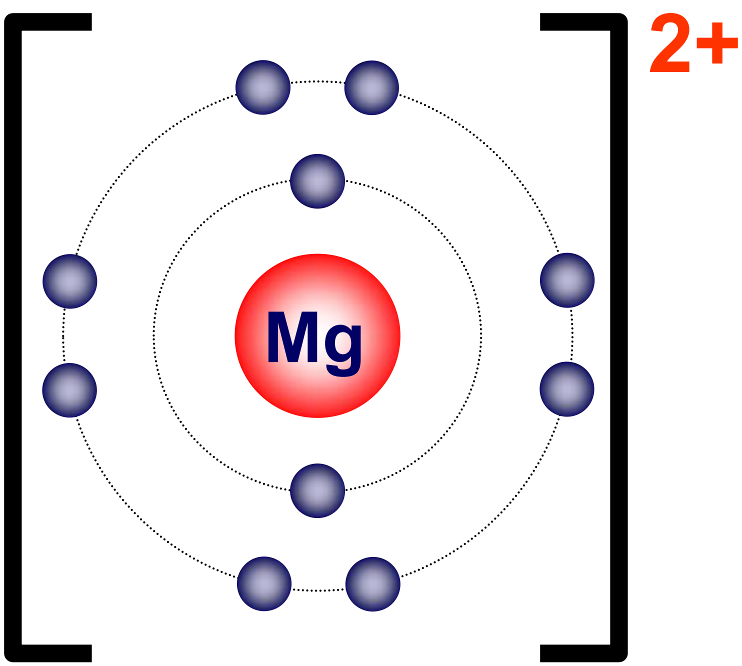
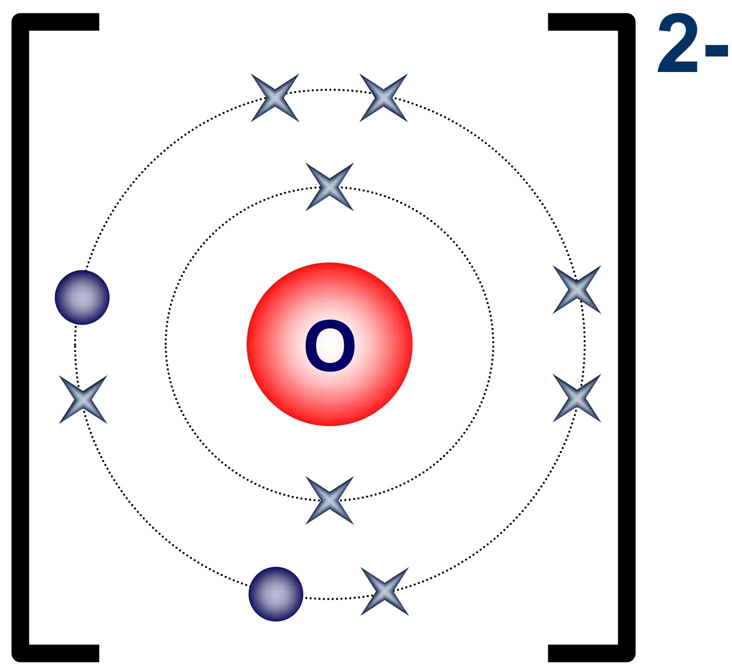
Magnesium oxide: part 2

- Magnesium has 2 electrons in its outer shell. If it loses these, it will have no partially-filled shells.

Oxygen has 6 electrons in its outer shell. If it gains two electrons, it will completely fill its outer shell.





$2.8.2 \rightarrow [2.8]^{2+}$

$2.6 \rightarrow [2.8]^{2-}$

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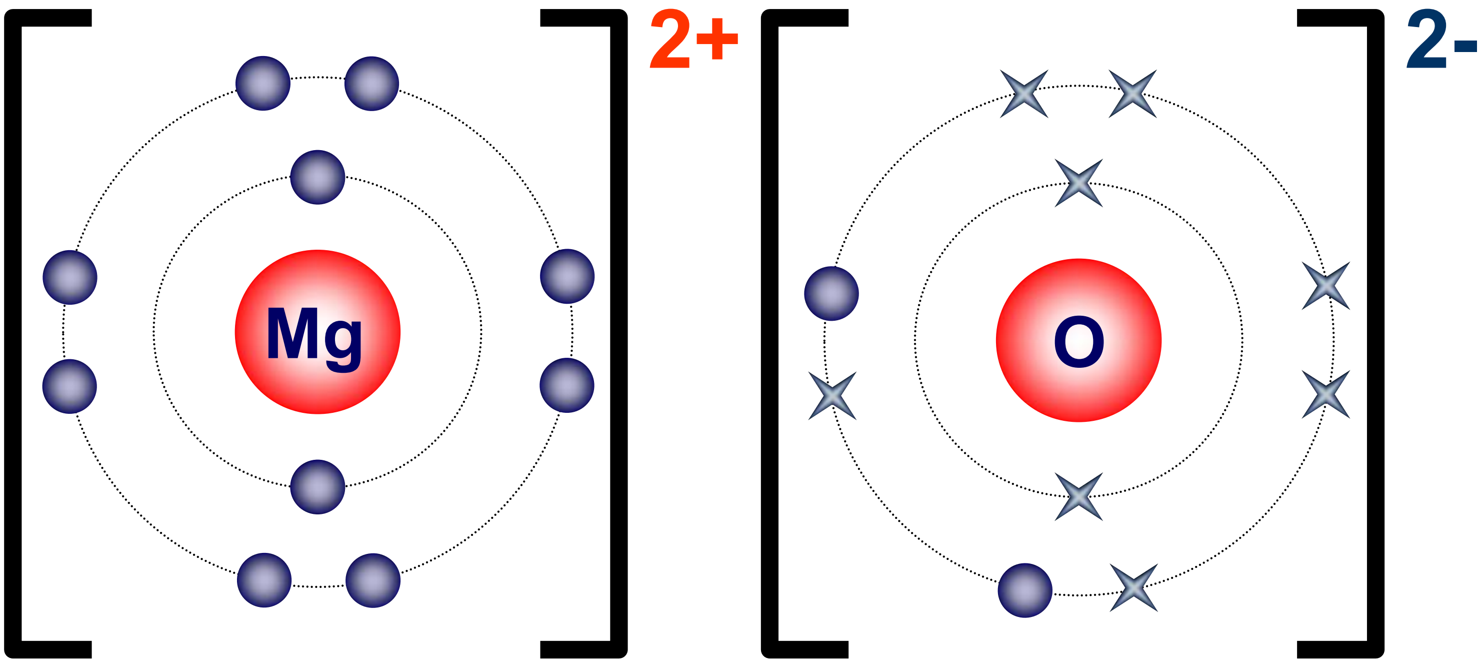
Magnesium oxide: part 3

- The positive magnesium ions and the negative oxide ions are strongly attracted to each other and form an ionic bond.



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Formation of an ionic bond

Select an ionic compound to investigate its bonding.

23	35.5
Na	Cl
11	17

sodium chloride

24	16
Mg	O
12	8

magnesium oxide

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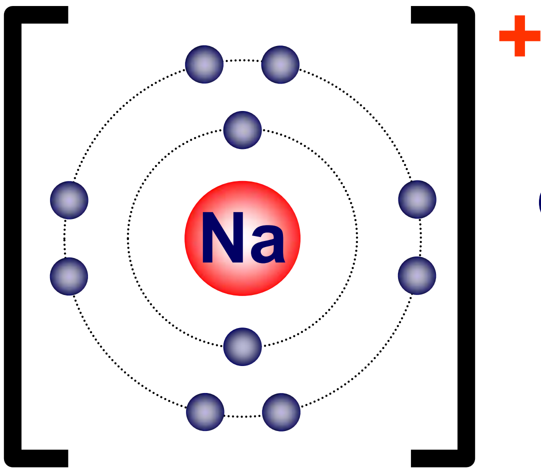
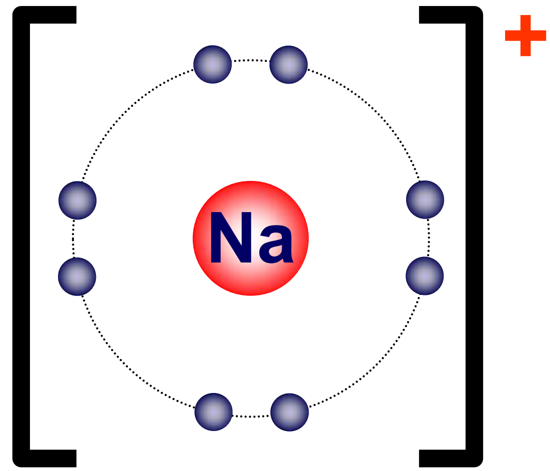
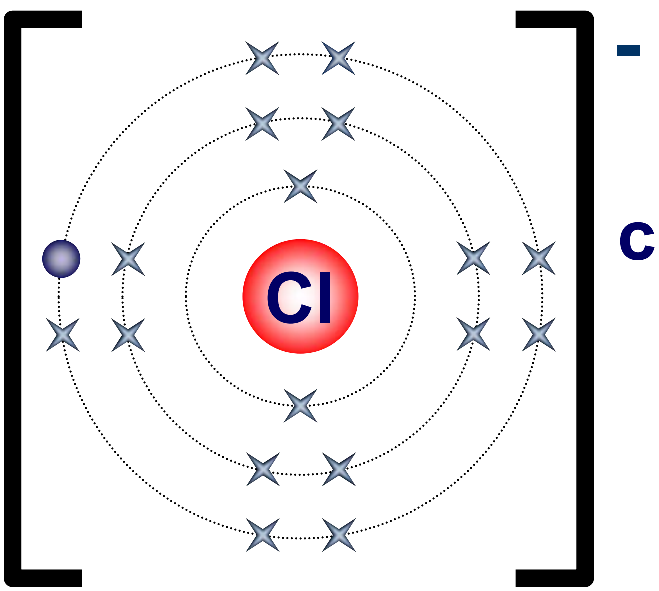
Simplified bonding diagrams

- The inner electron shells can sometimes be left out of bonding diagrams because they are not involved in bonding.

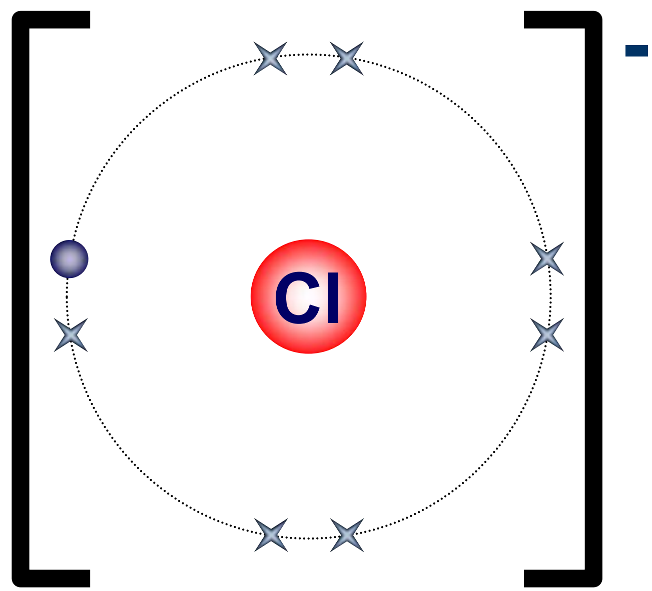


can also be drawn as





can also be drawn as



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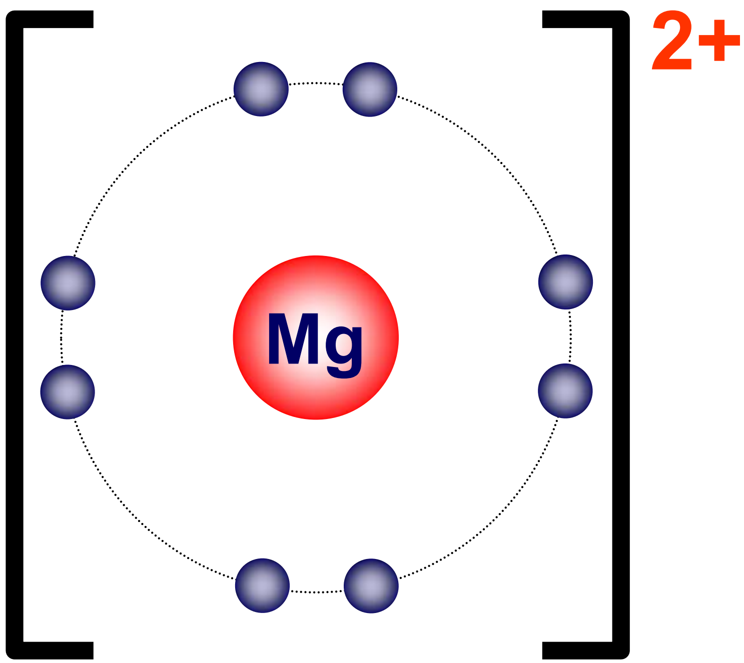
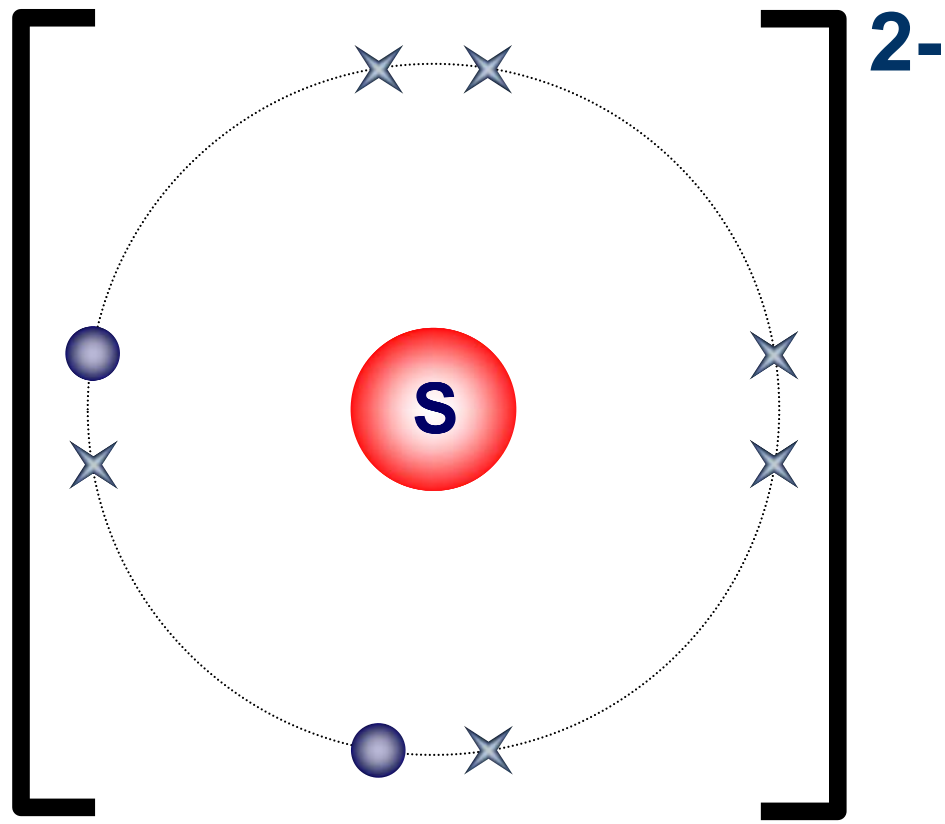
Drawing simplified bonding diagrams

- Draw a simplified electron bonding diagram for magnesium sulfide.





2.8.2 ➡ $[2.8]^{2+}$

2.8.6 ➡ $[2.8.8]^{2-}$

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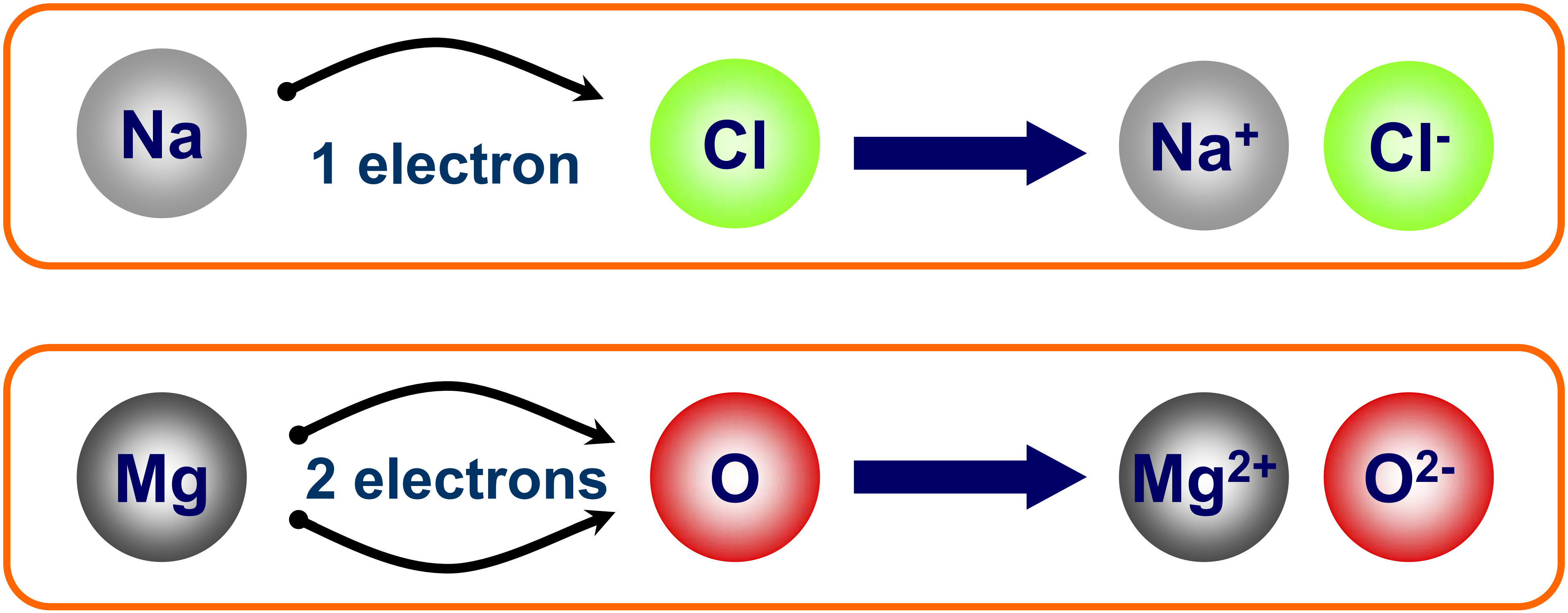
More complicated ionic bonding

- Sodium chloride and magnesium oxide are **simple** ionic compounds. In each case, the metal and non-metal need to lose and gain the same number of electrons.



This is not always the case.

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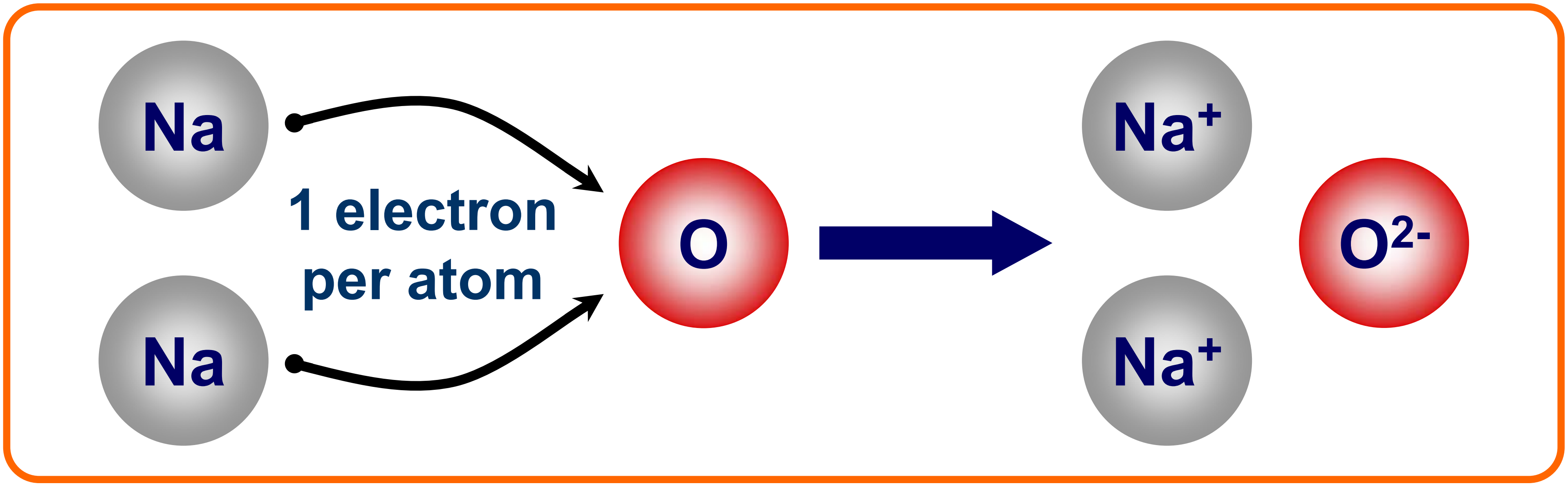
Sodium oxide

- What happens in the reaction between sodium and oxygen?

Sodium (2.8.1) needs to lose 1 electron but oxygen (2.6) needs to gain 2 electrons. Therefore, two sodium atoms are required for each oxygen atom.



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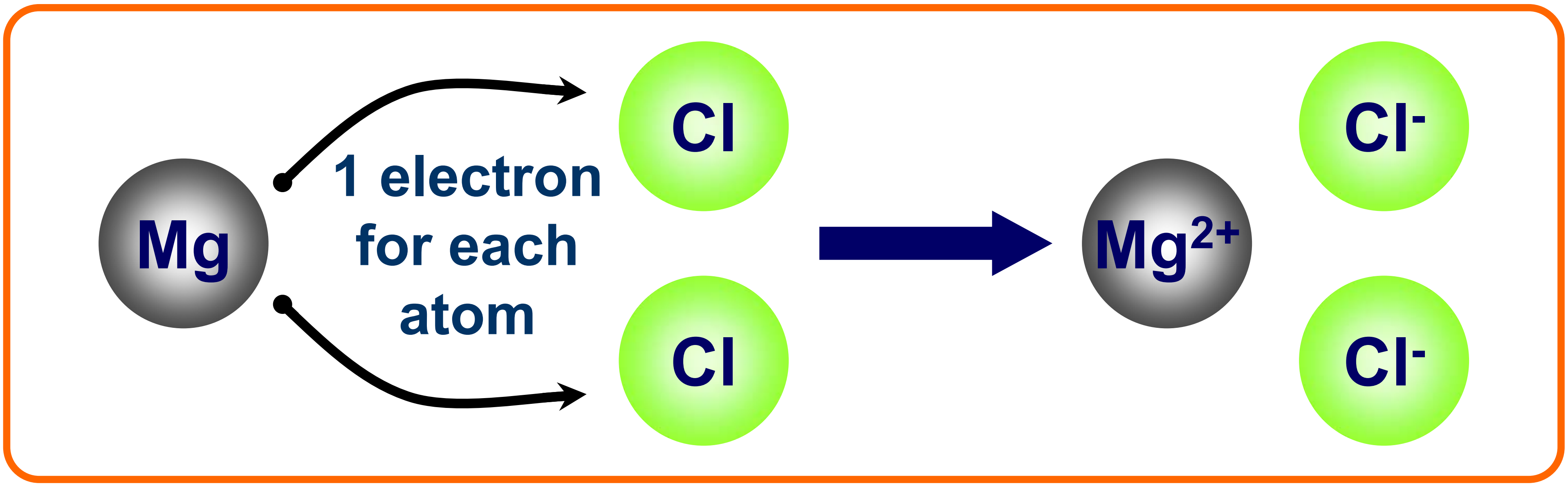
Magnesium chloride

- What happens in the reaction between magnesium and chlorine?

  Magnesium (2.8.2) needs to lose 2 electrons but chlorine (2.8.7) needs to gain 1 electron. Therefore, two chlorine atoms are required for each magnesium atom.



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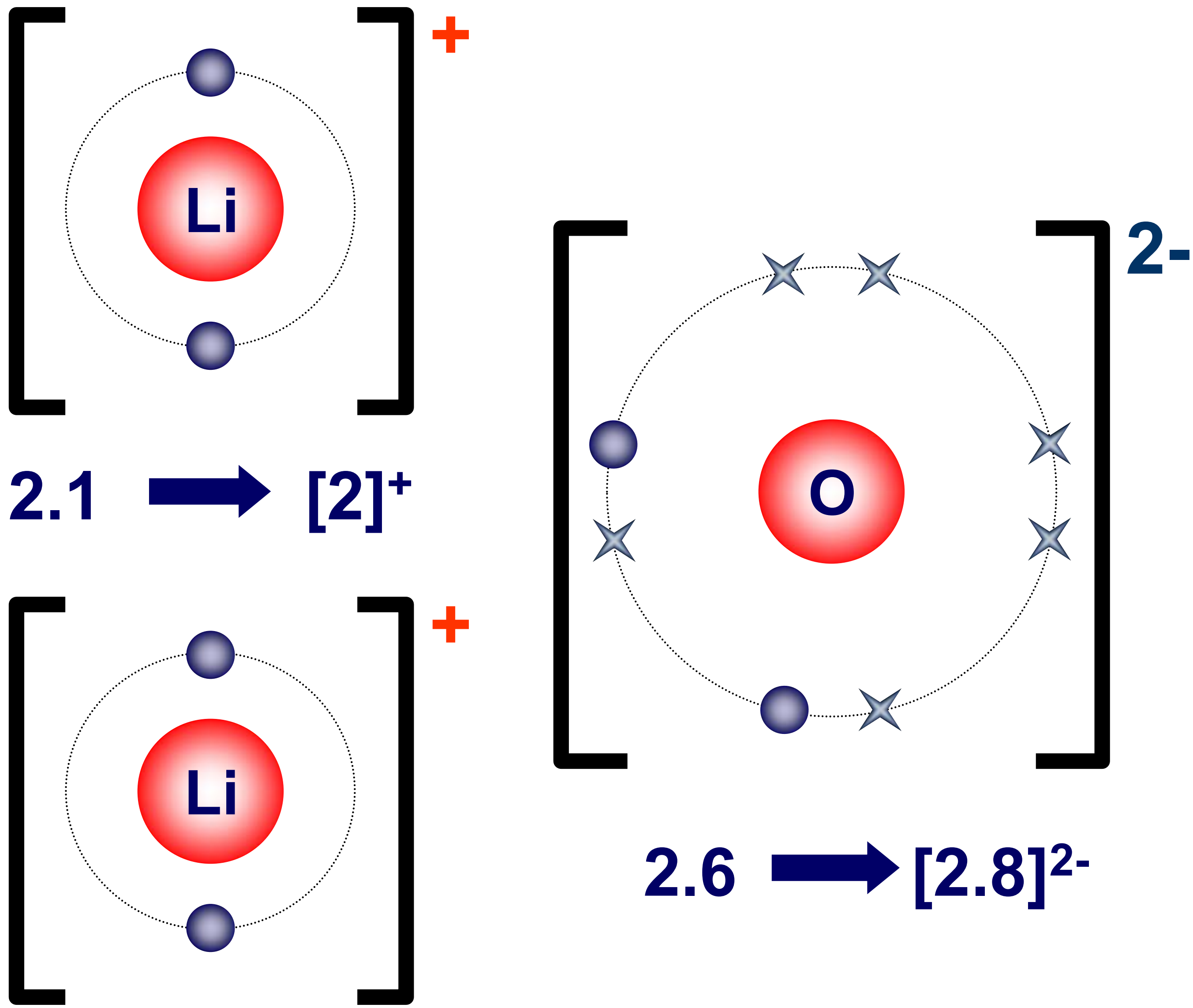
Bonding in lithium oxide

- Draw a simplified electron bonding diagram for lithium oxide.



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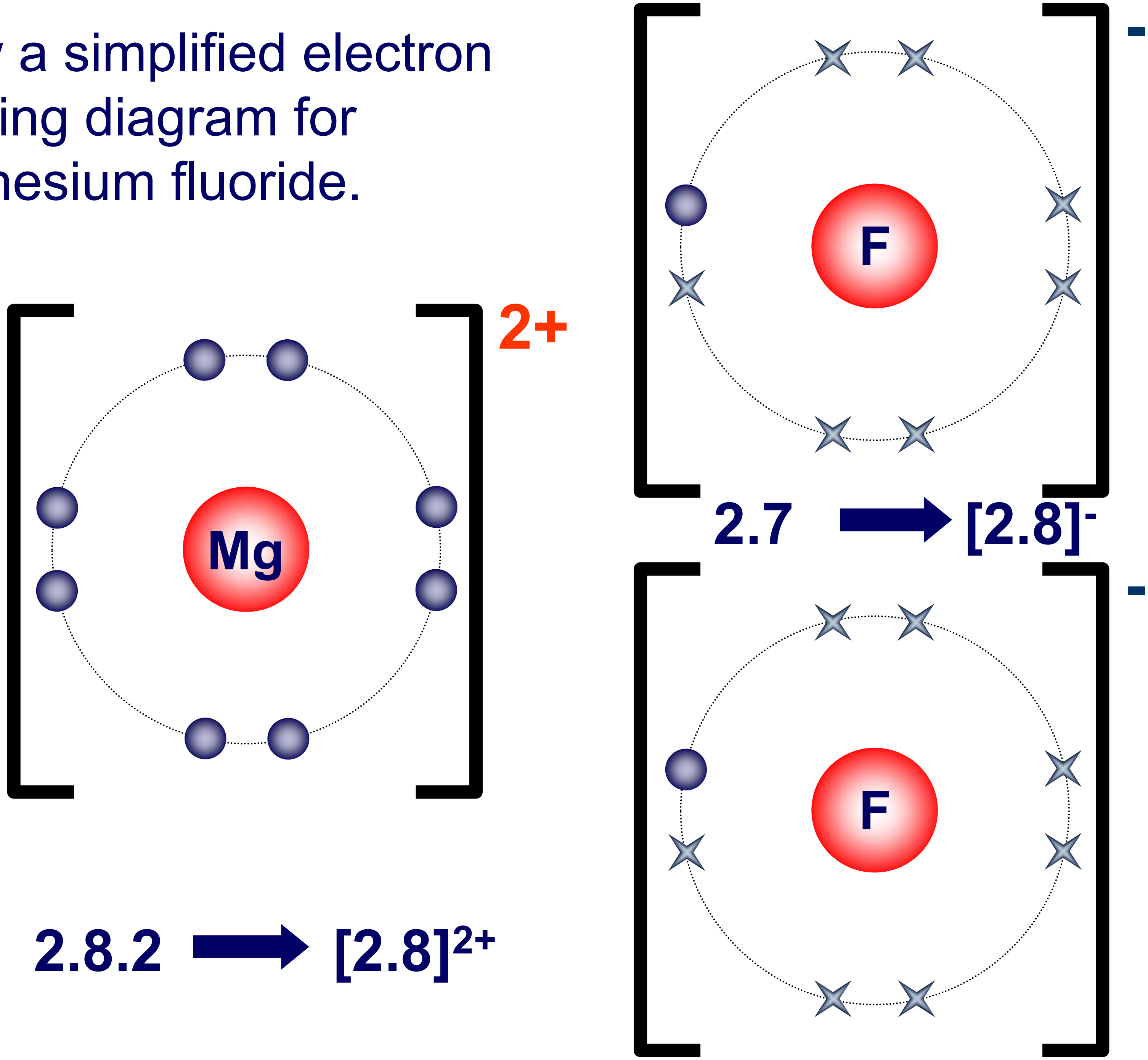
Bonding in magnesium fluoride

- Draw a simplified electron bonding diagram for magnesium fluoride.



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Further ionic bonding

- Draw simplified electron bonding diagrams for the following atoms:

1. Lithium (2.1) and fluorine (2.7)
2. Sodium (2.8.1) and sulfur (2.8.6)
3. Magnesium (2.8.2) and sulfur (2.8.6)
4. Magnesium (2.8.2) and fluorine (2.7)
5. Aluminium (2.8.3) and nitrogen (2.5)

total number of electrons lost by the metal = total number of electrons gained by the non-metal

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Formulae of ionic compounds

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Formulae of ionic compounds

- A formula uses chemical symbols and numbers to show the ratio of atoms of each element present in the compound.

  To work out the formula of an ionic compound, follow this procedure:

1. Write down the symbol for each atom.
2. Calculate the charge for each ion.
3 Balance the number of ions so the positive and negative charges equal zero. This gives a ratio of ions.
4. Write down the formula without the ion charges – the metal is always written first.

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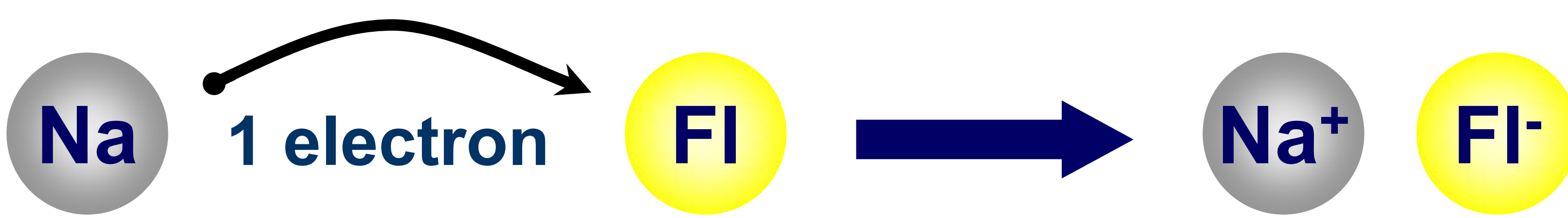
Formula of sodium fluoride

- What is the formula of sodium fluoride?

Symbol	Na	F
Ion charge	1+	1-
Balance the number of ions	1 sodium ion is needed for each fluoride ion	
Ratio of ions	1 : 1	
Formula	NaF	



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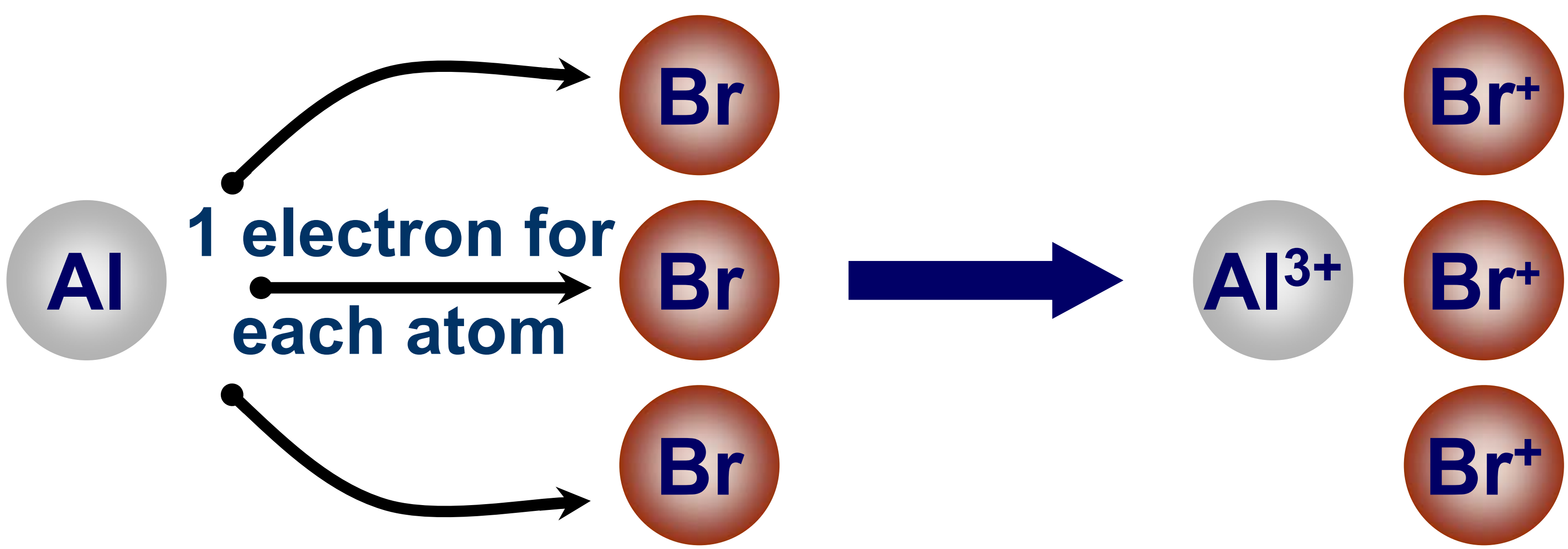
Formula of aluminium bromide

- What is the formula of aluminium bromide?

Symbol	Al	Br
Ion charge	3+	1-
Balance the number of ions	3 bromide ions are needed for each aluminium ion	
Ratio of ions	1 : 3	
Formula	$AlBr_3$	



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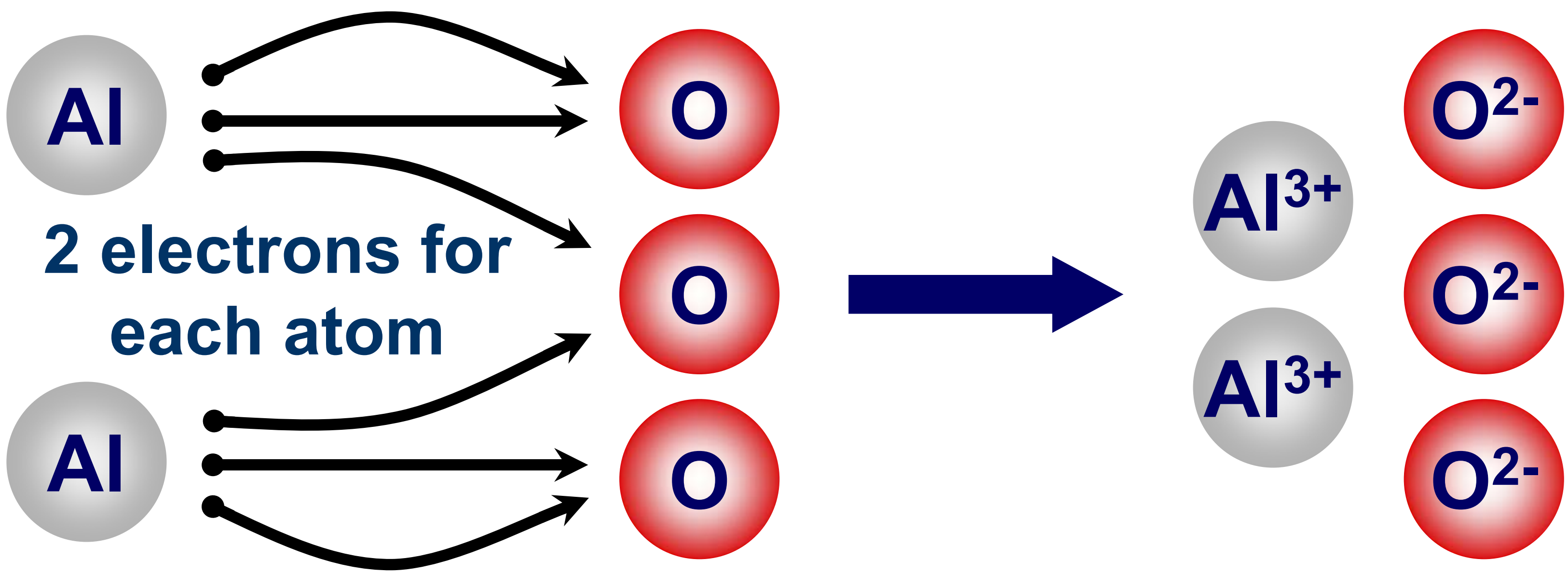
Formula of aluminium oxide

- What is the formula of aluminium oxide?

Symbol	Al	O
Ion charge	3+	2-
Balance the number of ions	2 aluminium ions are needed for 3 oxide ions	
Ratio of ions	2 : 3	
Formula	Al_2O_3	



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More ionic formulae

- Work out the formulae of **all** the possible ionic compounds from combinations of these metals and non-metals.

metals / non-metals	Li	Ca	Na	Mg	Al	K
F	LiF	CaF_2	NaF	MgF_2	AlF_3	KF
O	Li_2O	CaO	Na_2O	MgO	Al_2O_3	K_2O
N	Li_3N	Ca_3N_2	Na_3N	Mg_3N_2	AlN	K_3N
Br	$LiBr$	$CaBr_2$	$NaBr$	$MgBr_2$	$AlBr_3$	KBr
S	Li_2S	CaS	Na_2S	MgS	Al_2S_3	K_2S
Cl	$LiCl$	$CaCl_2$	$NaCl$	$MgCl_2$	$AlCl_3$	KCl

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Compound ions

- Ionic compounds can contain ions consisting of groups of atoms rather than a single atom. These are **compound ions**.

Ion	Formula	Charge	Atoms present
hydroxide	OH^-	1-	O H
sulfate	SO_4^{2-}	2-	S O O O O
nitrate	NO_3^-	3-	N O O O
carbonate	CO_3^{2-}	2-	C O O O
ammonium	NH_4^+	1+	N H H H H
hydrogen-carbonate	HCO_3^-	3-	H C O O O

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More complicated formulae

- Working out the formulae for compounds containing compound ions is the same as for simple ionic compounds. The compound ion is treated as a **single particle**, not individual particles.

1. Write down the symbol for each atom.
2. Calculate the charge for each ion.
3 Balance the number of ions so the positive and negative charges equal zero. This gives a ratio of ions.
4. Write down the formula without the ion charges. If more than one compound ion is required, brackets must be put around the ion, before the number.

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Formula of lithium nitrate

- What is the formula of lithium nitrate?

Symbol	Li	NO_3
Ion charge	1+	1-
Balance the number of ions	1 lithium ion is needed for each nitrate ion	
Ratio of ions	1 : 1	
Formula	$LiNO_3$	

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Formula of magnesium nitrate

- What is the formula of magnesium nitrate?

Symbol	Mg	NO_3
Ion charge	2+	1-
Balance the number of ions	2 nitrate ions are needed for each magnesium ion	
Ratio of ions	1 : 2	
Formula	$Mg(NO_3)_2$	

- The brackets around NO_3 indicate that the ‘2’ refers to a complete nitrate ion.

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Formula of sodium sulfate

- What is the formula of sodium sulfate?

Symbol	Na	SO_4
Ion charge	1+	2-
Balance the number of ions	2 sodium ions are needed for each sulfate ion	
Ratio of ions	2 : 1	
Formula	Na_2SO_4	

- Although 'Na' contains 2 letters, it represents a single atom, so no brackets are required.

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Formula of aluminium hydroxide

- What is the formula of aluminium hydroxide?

Symbol	Al	OH
Ion charge	3+	1-
Balance the number of ions	3 hydroxide ions are needed for each aluminium ion	
Ratio of ions	1 : 3	
Formula	$Al(OH)_3$	

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Formula of ammonium sulfate

- What is the formula of ammonium sulfate?

Symbol	NH_4	SO_4
Ion charge	1+	2-
Balance the number of ions	2 ammonium ions are needed for each sulfate ion	
Ratio of ions	2 : 1	
Formula	$(NH_4)_2SO_4$	

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Formula of aluminium carbonate

- What is the formula of aluminium carbonate?

Symbol	Al	CO_3
Ion charge	3+	2-
Balance the number of ions	2 aluminium ions are needed for 3 carbonate ions	
Ratio of ions	2 : 3	
Formula	$Al_2(CO_3)_3$	

- Although 'Al' contains 2 letters, it represents a single atom, so no brackets are required.

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Properties of ionic compounds

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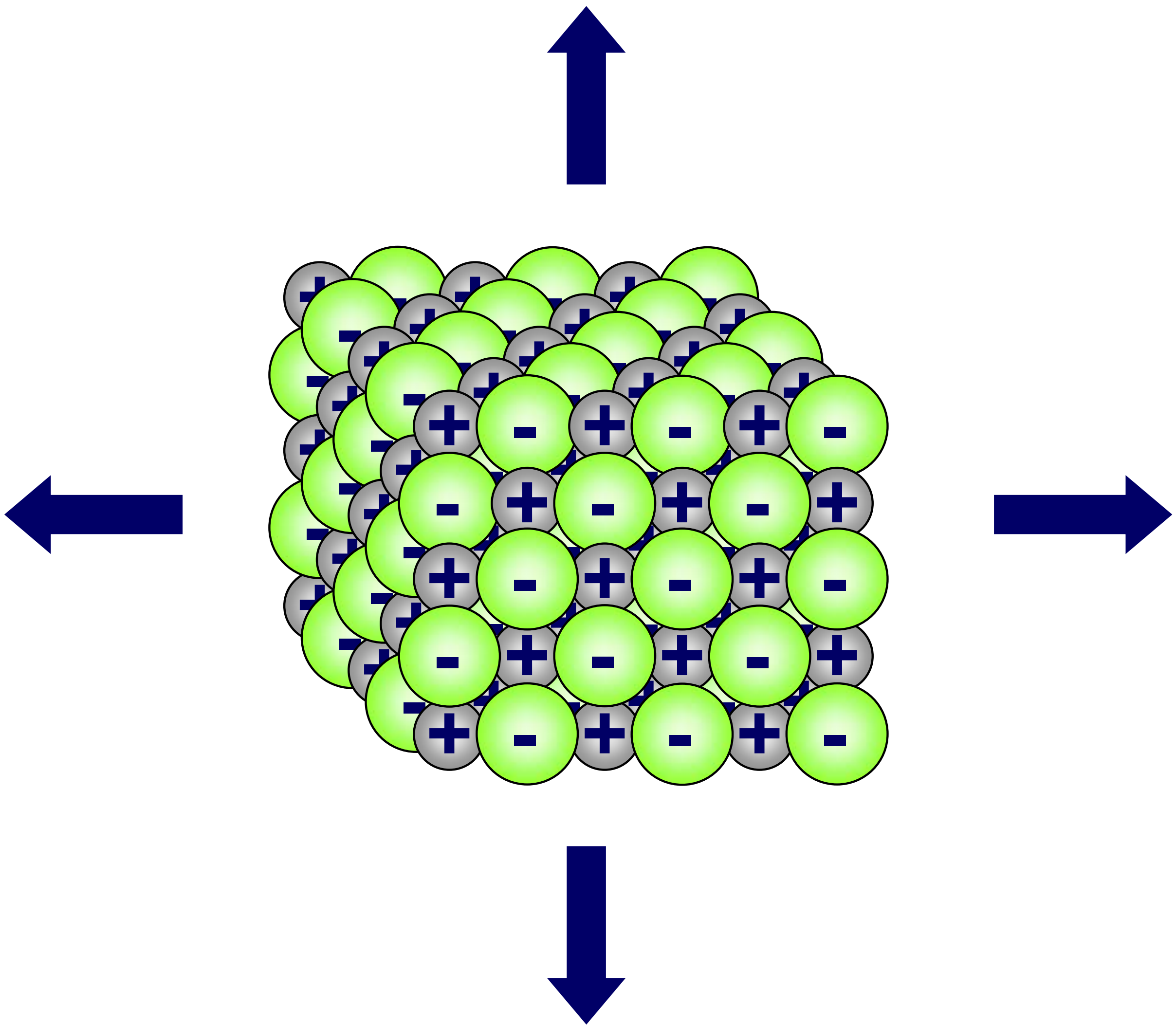
Ionic lattices

- In an ionic compound, millions and millions of ions are packed together in a regular cubic arrangement, joined by ionic bonds. This forms a giant 3D structure called an **ionic lattice**.



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Ionic lattices and crystals

- The structure of the lattice means that the ionic compound forms a crystal. This has flat sides and straight edges.

These are crystals of sodium chloride

All ionic compounds form lattices and crystals when solid.

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Heating ionic compounds

- Ionic bonds are strong and require a lot of heat to break them. This means that ionic compounds are solid at room temperature.

  A larger ionic charge produces stronger ionic bonds, which means that more heat is required to break the bonds.

Compound	**Ion charges**	**Melting point (°C)**	**Boiling point (°C)**
sodium chloride	1^+ and 1^-	801	1,413
magnesium oxide	2^+ and 2^-	2,852	3,600

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Electricity, solubility and ionic compounds

- Ionic compounds do not conduct electricity when they are solid because the ions are packed together and cannot move.

  When molten, however, the lattice breaks up and the ions are free to move. Because they are charged particles, they can carry an electric current.

- Ionic compounds are usually soluble in water because water molecules have a slight electrical charge and can attract the ions away from the lattice.

  When dissolved, the ions are free to move and can carry an electric current.

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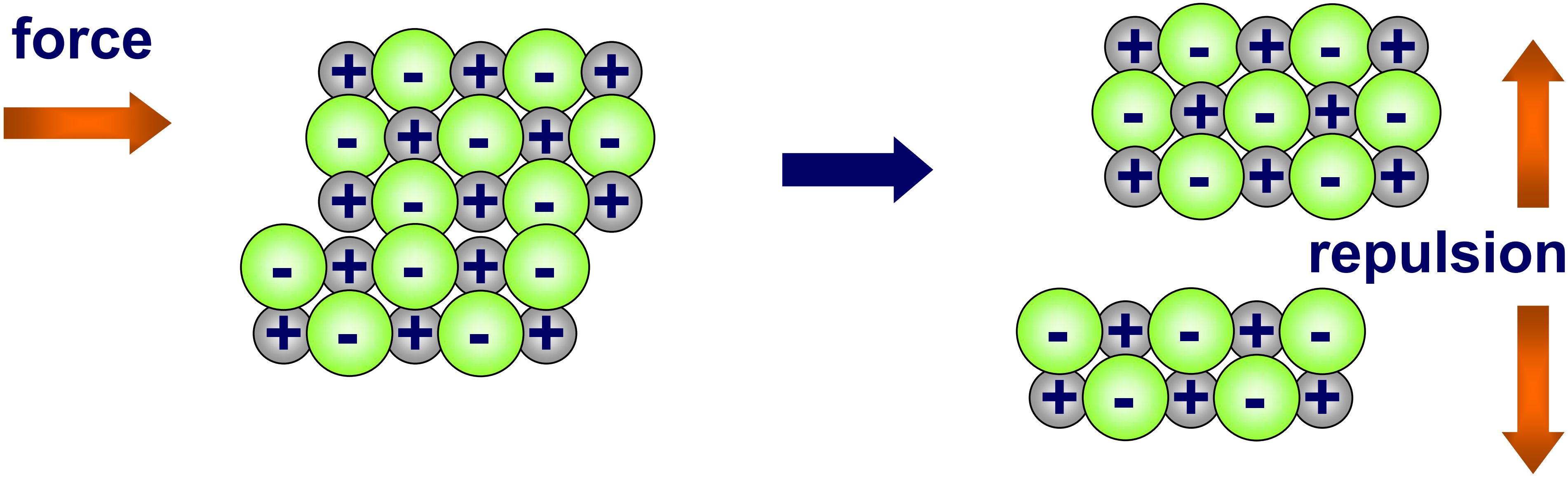
Strength of ionic compounds

- Ionic compounds are brittle – they shatter when they are hit.



When the lattice is hit, a layer of ions is shifted so that ions with the same charges are lined up together.

These like charges repel each other, thereby splitting the lattice.

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Properties of ionic compounds

Decide whether each statement is true or false.

Ionic compounds only contain non-metals.	
Ionic compounds always conduct electricity.	
A lot of energy is needed to break ionic bonds.	
Ionic compounds are soft.	
Ionic compounds are usually soluble in water.	
Ionic compounds form giant structures.	

true false

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Summary activities

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Glossary

- **bond –** A strong force that joins atoms or ions together in molecules and giant lattices.
- **compound ion –** An ion made up of a group of atoms, rather than one single atom.
- **ionic bond –** The electrostatic force of attraction between oppositely charged ions.
- **ionic compound –** A compound made up of ions.
- **ionic lattice –** A giant 3D structure of closely packed, oppositely-charged ions.
- **negative ion –** An atom or group of atoms that has gained electrons and so has a negative charge.
- **noble gas –** An element that has a full outer electron shell and so is very stable and unreactive.
- **positive ion –** An atom or group of atoms that has lost electrons and so has a positive charge.