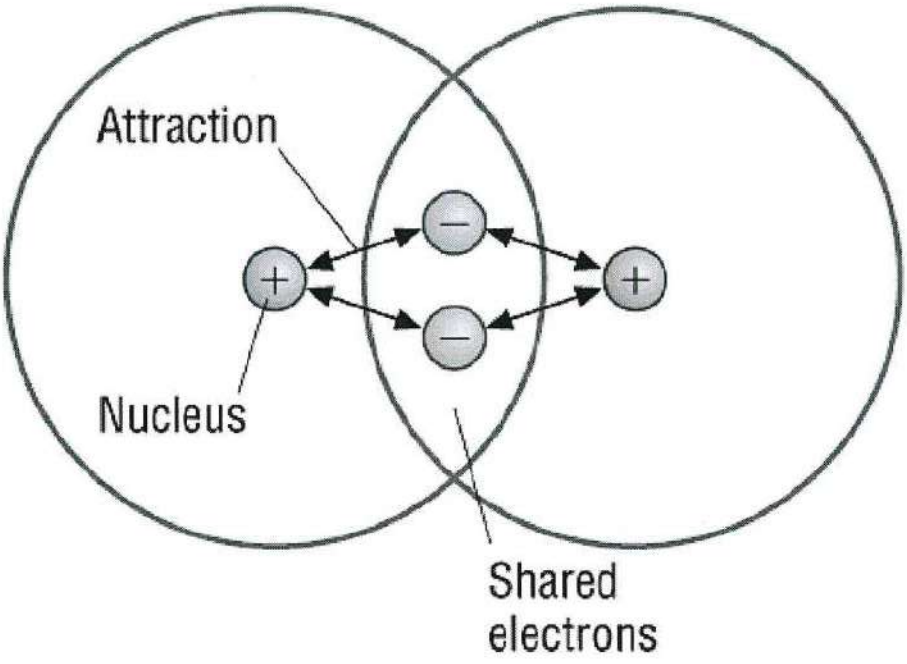
Shell Chemistry 19-20

Topic E

Simple Molecules & Covalent Bonding



Name:_____

Teacher:_____

You must keep this book

The Periodic Table of the Elements

1	2											3	4	5	6	7	0
							1 H hydrogen 1										4 He helium 2
7 Li lithium 3	9 Be beryllium 4											11 B boron 5	12 C carbon 6	14 N nitrogen 7	16 O oxygen 8	19 F fluorine 9	20 Ne neon 10
23 Na sodium 11	24 Mg magnesium 12											27 Al aluminium 13	28 Si silicon 14	31 P phosphorus 15	32 S sulfur 16	35.5 Cl chlorine 17	40 Ar argon 18
39 K potassium 19	40 Ca calcium 20	45 Sc scandium 21	48 Ti titanium 22	51 V vanadium 23	52 Cr chromium 24	55 Mn manganese 25	56 Fe iron 26	59 Co cobalt 27	59 Ni nickel 28	63.5 Cu copper 29	65 Zn zinc 30	70 Ga gallium 31	73 Ge germanium 32	75 As arsenic 33	79 Se selenium 34	80 Br bromine 35	84 Kr krypton 36
85 Rb rubidium 37	88 Sr strontium 38	89 Y yttrium 39	91 Zr zirconium 40	93 Nb niobium 41	96 Mo molybdenum 42	[98] Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54
133 Cs caesium 55	137 Ba barium 56	139 La* lanthanum 57	178 Hf hafnium 72	181 Ta tantalum 73	184 W tungsten 74	186 Re rhenium 75	190 Os osmium 76	192 Ir iridium 77	195 Pt platinum 78	197 Au gold 79	201 Hg mercury 80	204 Tl thallium 81	207 Pb lead 82	209 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac* actinium 89	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated						

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

** The lanthanoids (atomic numbers 58-71) and the actinoids (atomic numbers 90-103) have been omitted.*

+ The relative atomic masses of copper and chlorine have not been rounded to the nearest whole number.

Specification Checklist

1:14	know what is meant by the terms atom and molecule
1:15	know the structure of an atom in terms of the positions, relative masses and relative charges of sub-atomic particles
1:16a	know what is meant by the terms atomic number, mass number and relative atomic mass (A_r)
1:18	understand how elements are arranged in the Periodic Table: in order of atomic number, in groups and periods
1:19	understand how to deduce the electronic configurations of the first 20 elements from their positions in the Periodic Table
1:21	identify an element as a metal or a non-metal according to its position in the Periodic Table
1:22	understand how the electronic configuration of a main group element is related to its position in the Periodic Table
1:23	understand why elements in the same group of the Periodic Table have similar chemical properties
1:24	understand why the noble gases (Group 0) do not readily react
1:44	know that a covalent bond is formed between atoms by the sharing of a pair of electrons
1:45	understand covalent bonds in terms of electrostatic attractions
1:46	understand how to use dot-and-cross diagrams to represent covalent bonds in: diatomic molecules, including hydrogen, oxygen, nitrogen, halogens and hydrogen halides, inorganic molecules including water, ammonia and carbon dioxide, organic molecules containing up to two carbon atoms, including methane, ethane, ethene and those containing halogen atoms
1:47	explain why substances with a simple molecular structures are gases or liquids, or solids with low melting and boiling points. The term intermolecular forces of attraction can be used to represent all forces between molecules
1:48	explain why the melting and boiling points of substances with simple molecular structures increase, in general, with increasing relative molecular mass
2:44	describe tests for these gases: hydrogen, oxygen, carbon dioxide, ammonia, chlorine
2:49	describe a test for the presence of water using anhydrous copper(II) sulfate

Terminology

Term	Definition
Atom	The smallest stable part of an element
Nucleus	This is the central part of an atom
Proton	A positively charged particle found in the nucleus
Neutron	A neutral particle found in the nucleus
Electron	A negatively charged particle found in shells around the nucleus
Electron configuration	How the electrons are arranged in an atom
Group	A group of elements is found in one column of the periodic table
Period	A period of elements is found in one row of the periodic table
Element	A substance which contains only one type of atom
Covalent bond	The attraction between two positive nuclei and a shared pair of electrons
Intermolecular force	Electrostatic attraction between molecules
Molecule	A particle with a fixed number of atoms chemically combined together by covalent bonds.
Diatomic molecule	A molecule containing only two atoms

Atoms & Molecules

Learning Outcomes:

1) Define the terms atom and molecule
2) Describe tests for hydrogen, oxygen, carbon dioxide, water, ammonia and chlorine

Key Definition

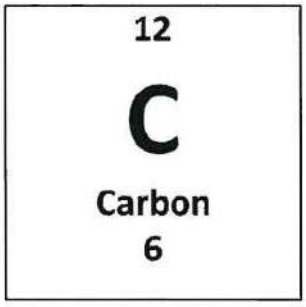
Atoms are the smallest stable part of an element.

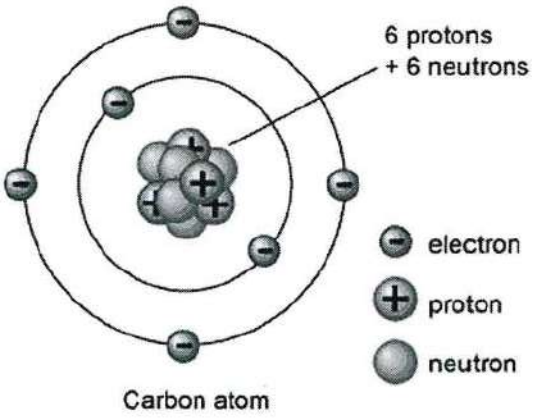
Atoms are made up of protons, neutrons and electrons.

The protons have a positively charge and are found in the nucleus.

The neutrons are neutral and are also found in the nucleus.

The electrons are negatively charged and are found in electron shells.





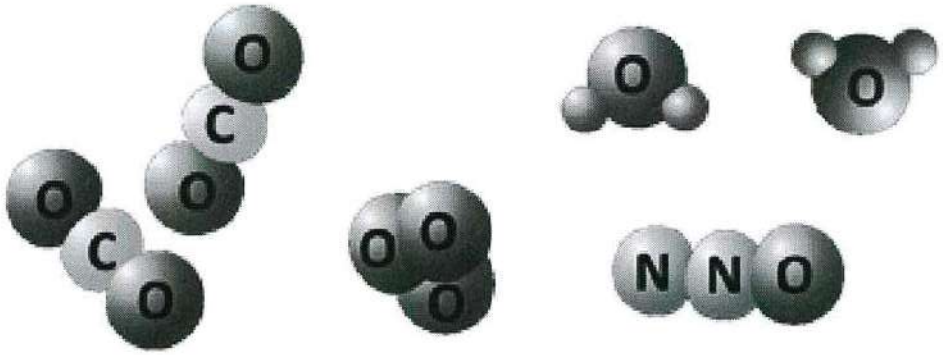
Carbon atom

Subatomic particles

Particle	Mass	Charge
proton	1	+1
neutron	1	0
electron	negligible	-1

Key Definition

A **molecule** is a particle with a fixed number of atoms chemically combined together by covalent bonds.



Examples

Name	Formula	Diatomic molecule?	Relative Formula Mass (M_r)
Oxygen	O_2	yes	32
Nitrogen	N_2	yes	28
Ammonia	NH_3	no	17
Water	H_2O	no	18
Carbon dioxide	CO_2	no	44
Chlorine	Cl_2	yes	71
Hydrogen	H_2	yes	2
Methane	CH_4	no	16
Hydrogen chloride	HCl	yes	36.5
Hydrogen peroxide	H_2O_2	no	34

Key Definition

A **diatomic molecule** is a molecule containing only two atoms

Task What other diatomic molecules can you think of?

Demo / Practical: Testing for simple molecules

Safety 1) goggles must be warn at all times
2) ensure the lab is well ventilated
3) use the correct technique for smelling gases

Method:

1. Carbon dioxide – place a spatula of marble chips into a test tube of $2cm^3$ hydrochloric acid and test for CO_2 using limewater
2. Hydrogen – place a strip of magnesium into a test tube of $2cm^3$ hydrochloric acid. Collect gas using a boiling tube and test with lit splint
3. Oxygen (demo only) – decomposition of hydrogen peroxide using MnO_2 catalyst. Demo testing for oxygen.
4. Water – place ¼ of a spatula of anhydrous copper(II) sulfate into a test tube and pipette a few drops of water. Pupils can also observe heat given off.
5. Ammonia – dissolve a spatula of ammonium salts into water. Gently heat and test gas using damp red litmus paper.
6. Chlorine (demo only) – Use pre-prepared chlorine gas and test with damp litmus paper.
Reaction: $Cl_2 + H_2O \rightleftharpoons HOCl + HCl$.

Molecule	Test	Result
Carbon dioxide	lime water	turns milky
Hydrogen	lit splint	popping / sparks
Oxygen (demo)	glowing splint	splint is re-lit
Water	add anhydrous copper (II) sulfate	turns blue
Ammonia	heat + test for gas with damp red litmus paper	litmus paper turns blue
Chlorine (demo)	test for gas with damp blue litmus paper	litmus paper bleaches

Write the chemical equations for the reactions which take place during the tests on the previous page.

Test for Carbon Dioxide: $Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$

Test for Hydrogen: $H_2(g) + O_2(g) \rightarrow H_2O(l)$

Test for Oxygen: Not really an equation, the oxygen enables the wood to combust

Test for presence of Water: $CuSO_4\ (s) + 5H_2O\ (l) \rightleftharpoons CuSO4.5H_2O\ (s)$

Test for presence of ammonia: No equation, just an indicator paper being used

Test for Chlorine: $Cl_2 + H_2O \rightleftharpoons HOCl + HCl$

Naming Molecules

Rules for naming molecules:

- The first element is named first, using the element's name
- Second element is named as anion (suffix "-ide")
- Prefixes are used to denote the number of atoms
- "Mono" is not usually used to name the first element

Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-

Name these:

a) PH_3 phosphorous trihydride

b) CO Carbon Monoxide

c) HI Hydrogen Iodide

d) N_2O_3 Dinitrogen Trioxide

e) SO_2 Sulphur dioxide

f) SCl_6 Sulphur Hexachloride.

Now try naming these:

1) N_2F_6 dinitrogen hexafluoride

2) CO_2 Carbon Dioxide

3) SiF_4 Silicon Tetrafluoride.

4) CBr_4 Carbon Tetra bromide.

5) NCl_3 Nitrogen Trichloride.

6) P_2S_3 Diphosphorus Sulphide

7) NO_2 Nitrogen Dioxide

8) SF_2 Sulphur difluoride

9) PF_5 Phosphorous pentafluoride.

10) NO Nitrogen Monoxide.

11) CCl_4 Carbon Tetra Chloride.

12) P_2O_5 Diphosphorus Pentaoxide

Covalent Bonding

Learning Outcomes:

1) Recall the term covalent bonds
2) Draw dot-and-cross diagrams to represent covalent bonds in a molecules

Task What do you remember about electron arrangement? Delete words below to complete the sentences.

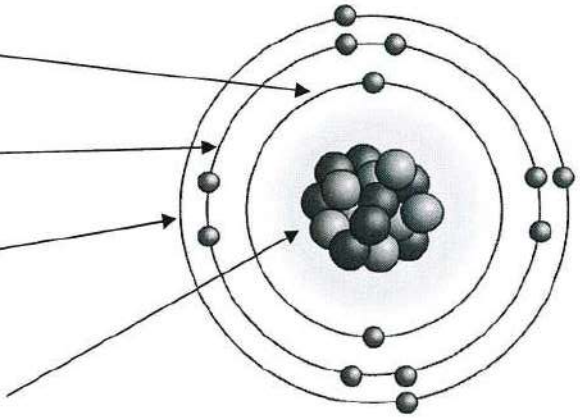
1) Electrons are arranged in energy levels **(shells / ~~cones~~ / ~~circles~~)** around the **nucleus / ~~electron~~ / ~~neutron.~~**
2) The lowest energy level (innermost first shell) can hold only **~~8~~ / 2 / ~~10~~** electrons.
3) The second energy level (shell) can hold only **8 / ~~2~~ / ~~10~~** electrons.
4) The third energy level (shell) can hold **8 / ~~2~~ / ~~10~~** electrons.
5) Electrons occupy the lowest energy shell available. The innermost shells fill up **~~last~~ / first**.
6) Atoms with full outer shells are chemically **stable / ~~unstable~~**

The innermost electron shell is full. It has 2 electrons.

The second energy level is full. It has 8 electrons.

The third energy level has the remainder of the electrons.
That shell is not full. It has 2 electrons.

This is the nucleus, containing the protons and neutrons both of which have a relative mass of 1u



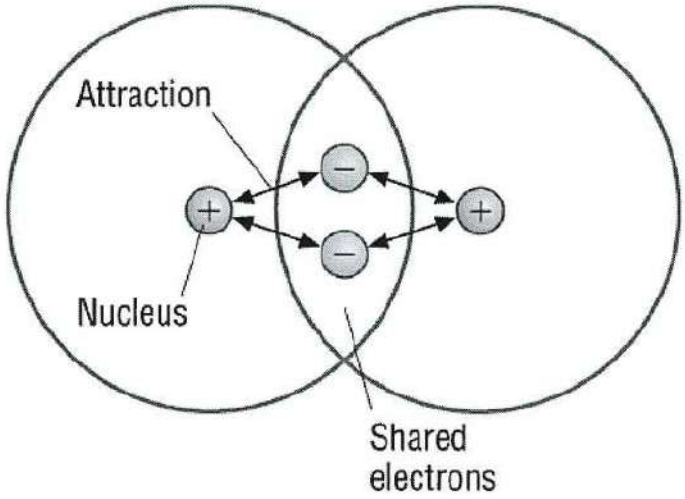
Element	Number of outer-shell electrons	How many electrons are needed for a full shell?
Oxygen	6	2
Fluorine	7	1
Sulphur	6	2
Carbon	4	4
Nitrogen	5	3
Bromine	7	1
Neon	8	0
Phosphorus	5	3
Silicon	4	4
Hydrogen	1	1

In covalent bonding, **non-metals** share their outer electrons so that they gain a full outer shell.

Covalent bonding involves the pairing of previously unpaired electrons.

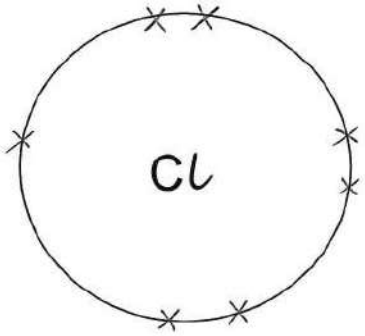
Key definition

Covalent bond: A strong electrostatic attraction between a pair of electrons (negatively charged) and two nuclei (positively charged).



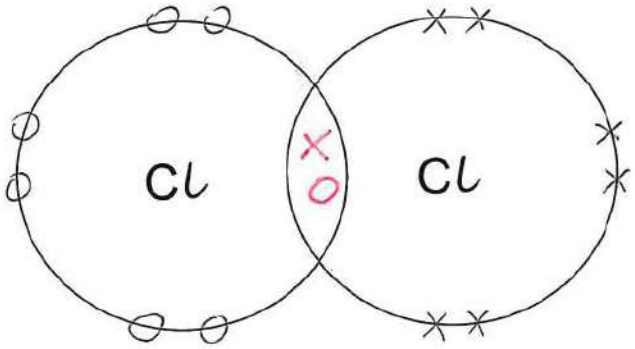
Example for dot-and-cross diagram to represent the covalent bonding in a chlorine molecule

Task: Complete the diagram to show the electrons in the outer shell of an atom of chlorine.



Two chlorine atoms form a chlorine molecule, Cl_2.

Task: complete the dot and cross diagram of the electrons in a molecule of chlorine (show outer electrons only):



This chlorine molecule can also be represented by:

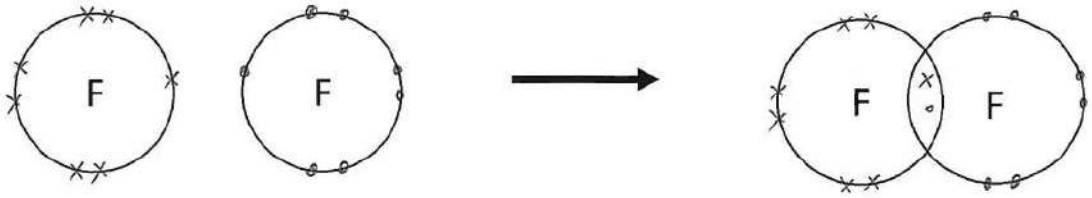
1) Displayed formula: **Cl - Cl**
2) Molecular formula: **Cl_2**

Use dot and cross diagrams to show the covalent bonding the following molecules:

1) hydrogen (H_2)

Displayed formula: H—H

2) fluorine (F_2)

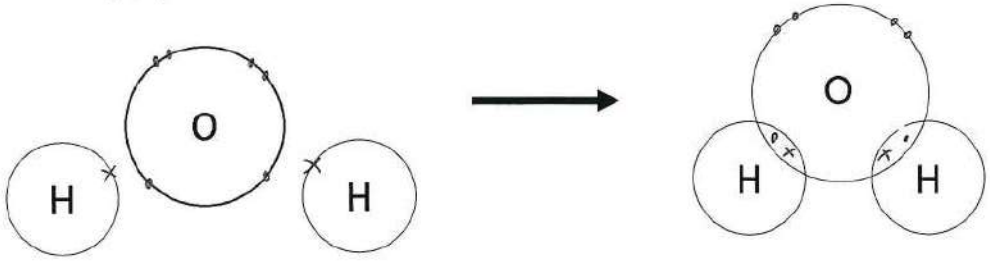


Displayed formula: F - F

3) hydrogen chloride (HCl)

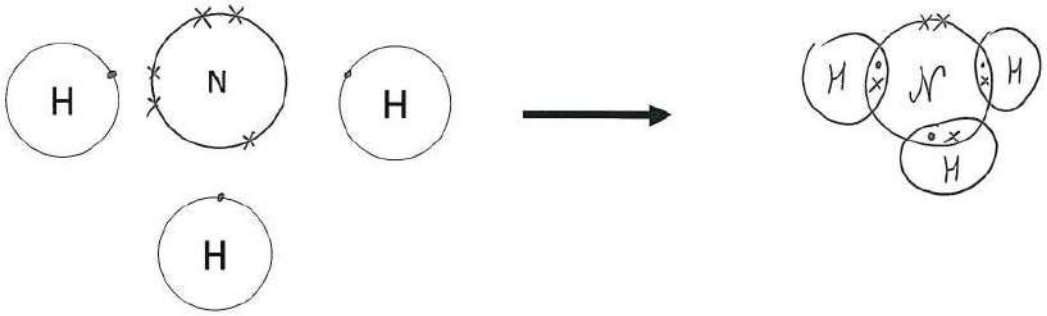
Displayed formula: H – Cl

4) water (H_2O)

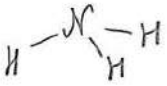


Displayed formula: H–O–H

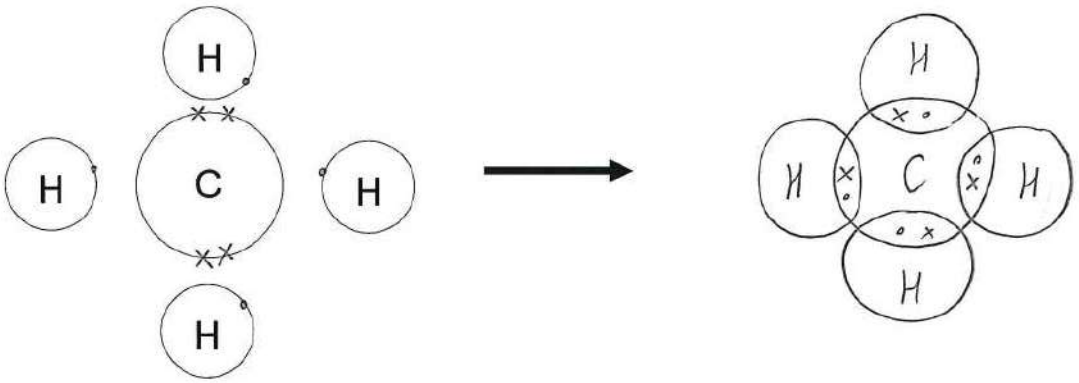
5) ammonia (NH_3)



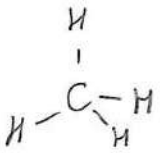
Displayed formula:



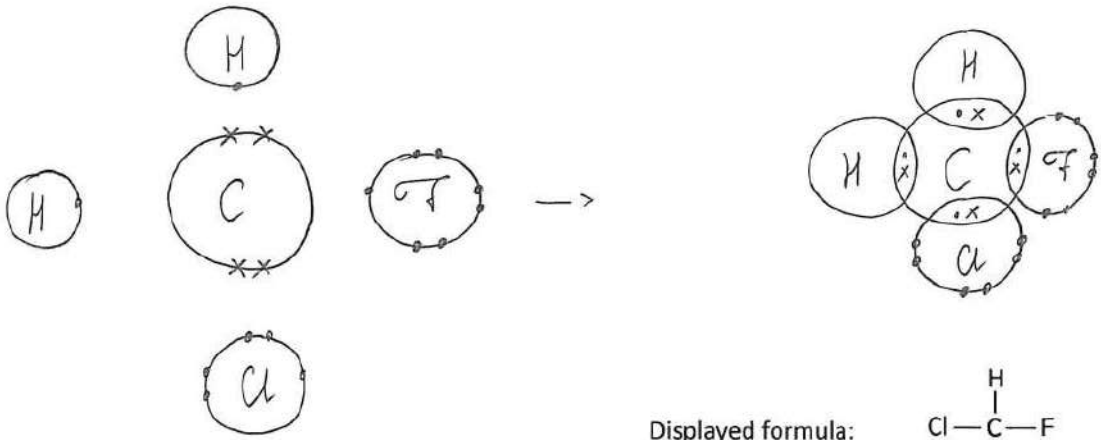
6) methane (CH_4)



Displayed formula:



7) Chlorofluoromethane, (CH_2ClF)



Displayed formula:

1) Indicate whether each statement is *true* or *false*

		TRUE	FALSE
a.	Covalent bonding involves sharing electrons	✓	.....
b.	Atoms react to gain a full outer shell of electrons	✓	.....
c.	Hydrogen can form two covalent bonds	.....	✓
d.	Carbon can form four covalent bonds	✓	.....
e.	A triple covalent bond contains 6 electrons (3 pairs)	✓	.....
f.	A double covalent bond contains 2 electrons	.....	✓

For any of the statements which are false, re-write the statements with corrections:

c. Hydrogen can form one covalent bond

f. A double covalent bond contains 4 electrons

2) Complete the following table to show how many electrons are needed to fill up the outer shell of these atoms

Atom	carbon	chlorine	hydrogen	nitrogen	oxygen
Number of electrons needed to fill outer shell	4	1	1	3	2
Number of bonds this atom can form	4	1	1	3	2

3) Why do some atoms share electrons?

To gain electrons and obtain a full outer shell

4) Why do the noble gases not form covalent bonds?

They already have a full outer shell

Use dot and cross diagrams to show the covalent bonding the following molecules

The molecules below have double or triple covalent bonds

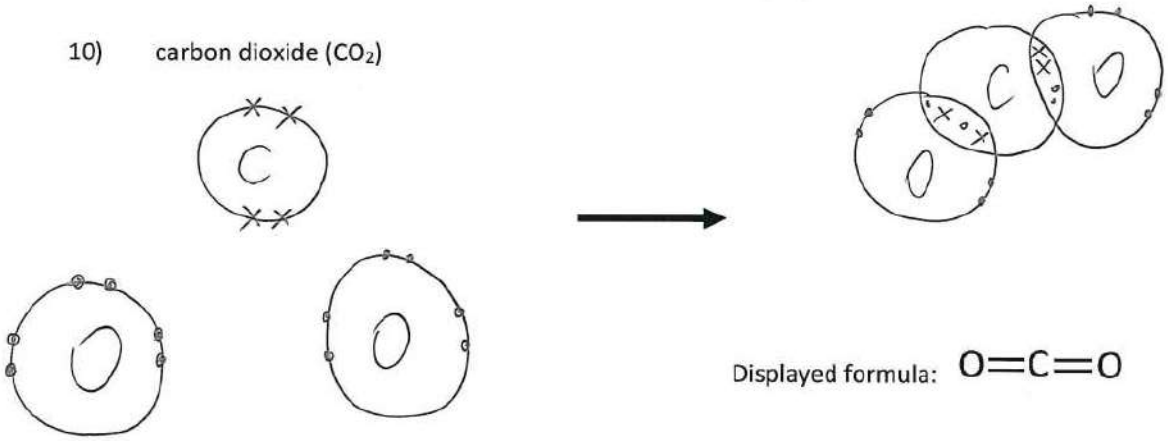
8) oxygen (O_2)

Displayed formula: O=O

9) nitrogen (N_2)

Displayed formula: N≡N

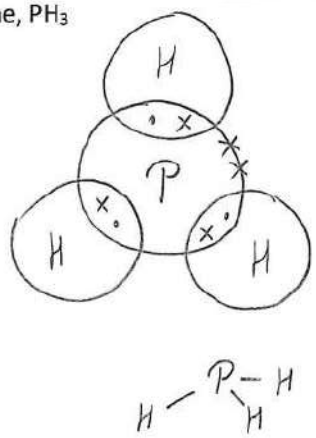
10) carbon dioxide (CO_2)



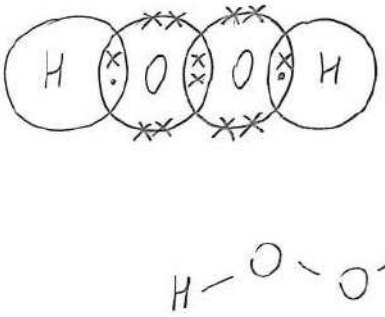
Displayed formula: O=C=O

Draw dot and cross diagrams and displayed formula for each of these compounds

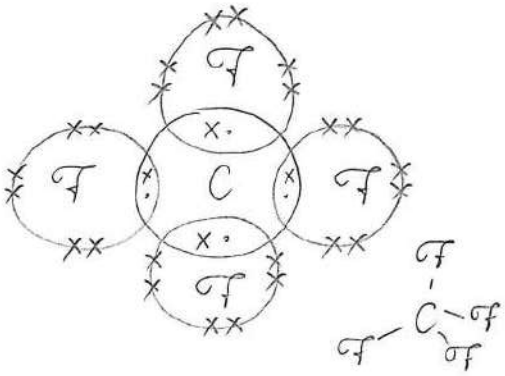
Phosphine, PH_3



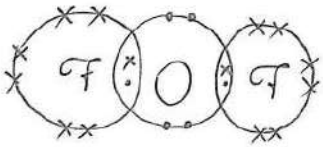
Hydrogen peroxide, H_2O_2



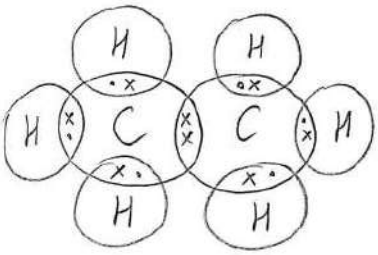
Tetrafluoromethane, CF_4

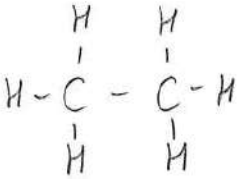


Oxygen difluoride, F_2O

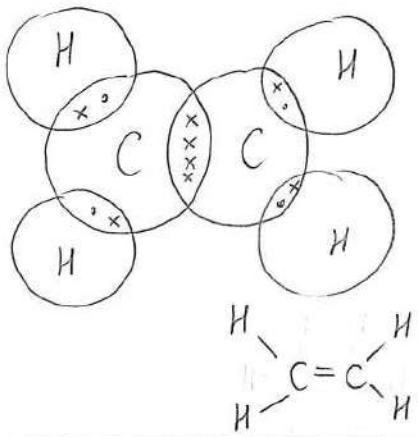
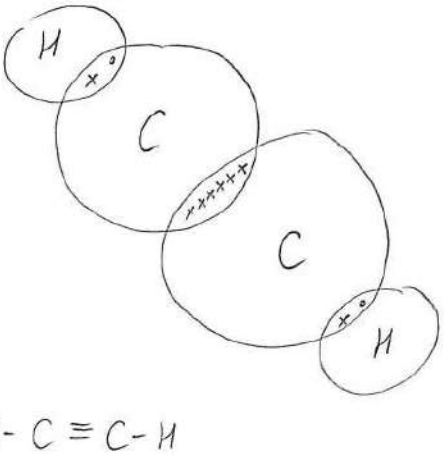
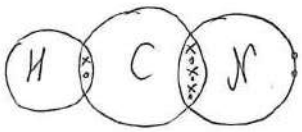
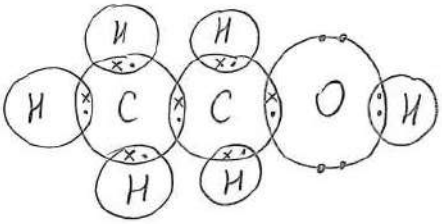
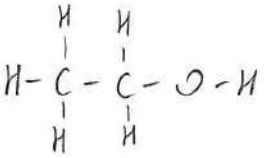
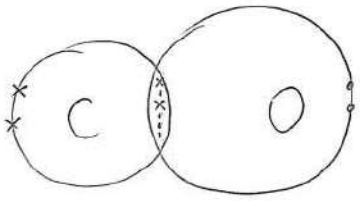
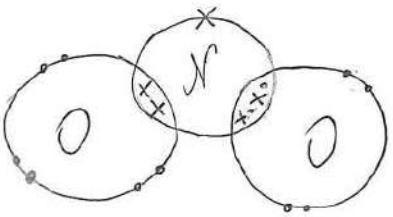


Ethane, C_2H_6





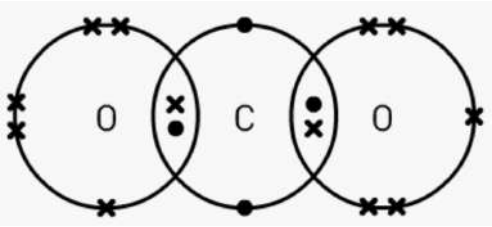
Challenge: Draw dot and cross diagrams and displayed formula for each of these compounds

Ethene, C_2H_4 	Ethyne, C_2H_2  $H-C\equiv C-H$
Hydrogen cyanide, HCN  $H-C\equiv N$	Ethanol, C_2H_5OH (hint – try to work out the displayed formula first)  
Carbon monoxide, CO  $C\equiv O$ NOT GCSE	Nitrogen dioxide, NO_2  $O-\dot{N}=O$ NOT GCSE

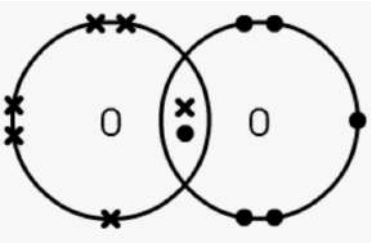
Big mistakes

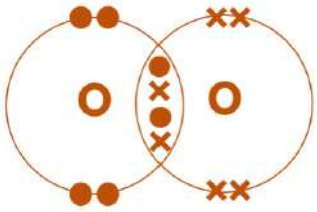
The following diagrams are all WRONG. For each, say why it is wrong, and if it can be fixed, fix it.

1) The diagram below is wrong because double bonds should be present.

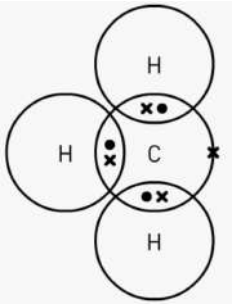


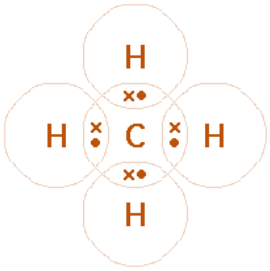
2) The diagram below is wrong because double bond should be present.



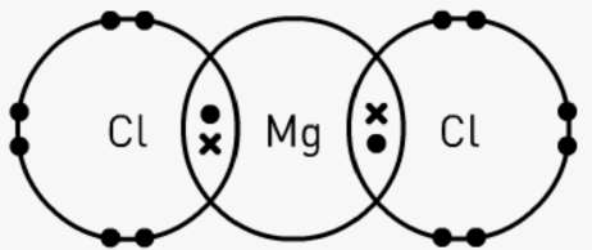


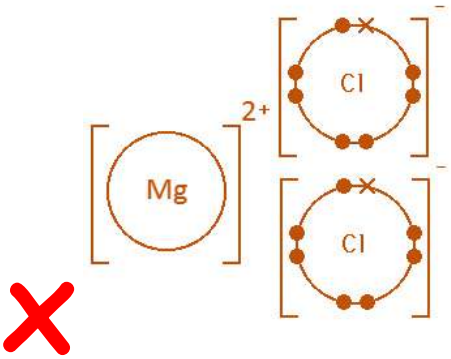
3) The diagram below is wrong because Hydrogen missing





4) The diagram below is <u>very wrong indeed</u> because IT'S IONIC – PLEASE! NEVER MAKE THIS MISTAKE!

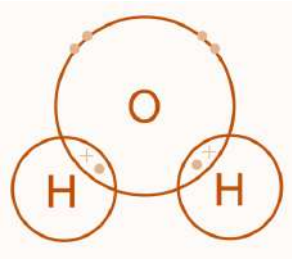




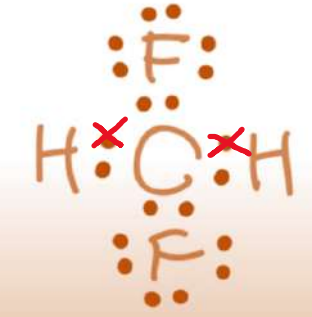
More covalent dot and cross practice (try to do these without looking back at your notes)

In each of the following, draw a diagram to show the bonding, showing the outer electrons only.

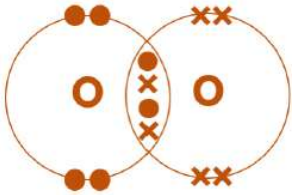
1) Water, H_2O



2) Difluoromethane, CH_2F_2

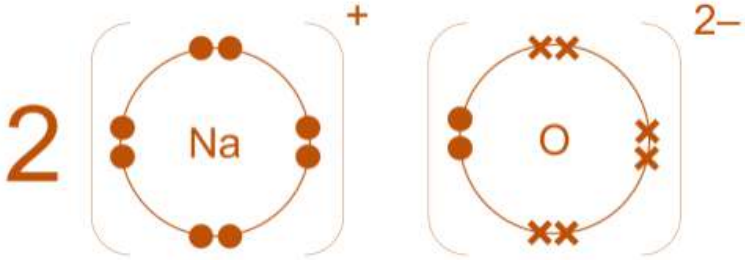


3) Oxygen, O_2



4) Carbon dioxide, CO_2

5) Sodium oxide, Na_2O (ALERT: trick question!! Always be on the lookout for this!)



Properties of Simple Molecules

Learning Outcomes:

1) Explain why substances with a simple molecular structures are gases, liquids, or solids with low melting and boiling points
2) Explain why the melting and boiling points of substances with simple molecular structures increase, in general, with increasing relative molecular mass

Comparing the T_m & T_b of some simple molecules:

Substance	T_m / °C	T_b / °C
H_2	-259	-253
H_2O	0	100
O_2	-218	-183
Cl_2	-101	-35
HCl	-115	-85
CH_4	-182	-161
NH_3	-78	-33
CO_2	-57	-79
N_2	-210	-196

1) What is the state of chlorine (Cl_2) at 12°C?

gas

2) What is the state of ammonia (NH_3) at -96°C?

solid

3) How many of the substances are gases at -65°C

6

4) How many of the substances are liquids at -110°C

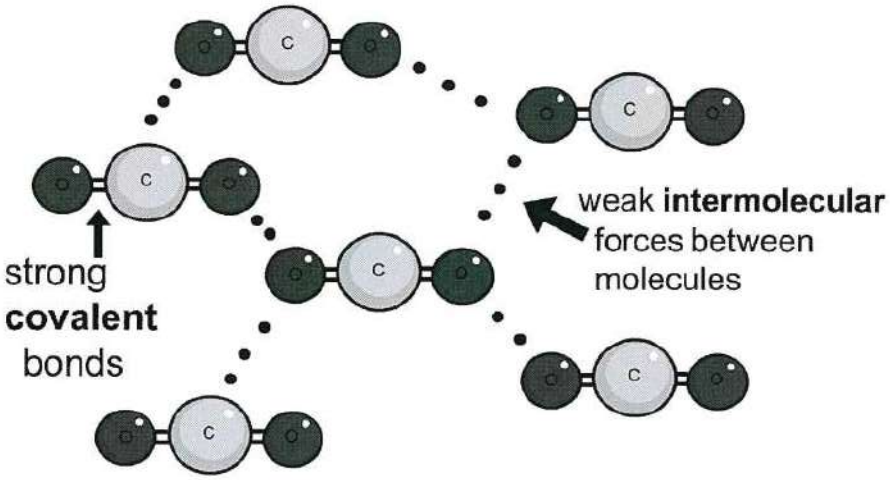
1

5) Can you identify the error in the table

The melting point of CO_2 is wrong!
It should be below the boiling point.

Explaining why simple molecules have low boiling points

- The covalent bonds between atoms within a simple molecule are strong.
- There are also weak intermolecular forces between different molecules.



- When a substance with a simple molecular structure boils.

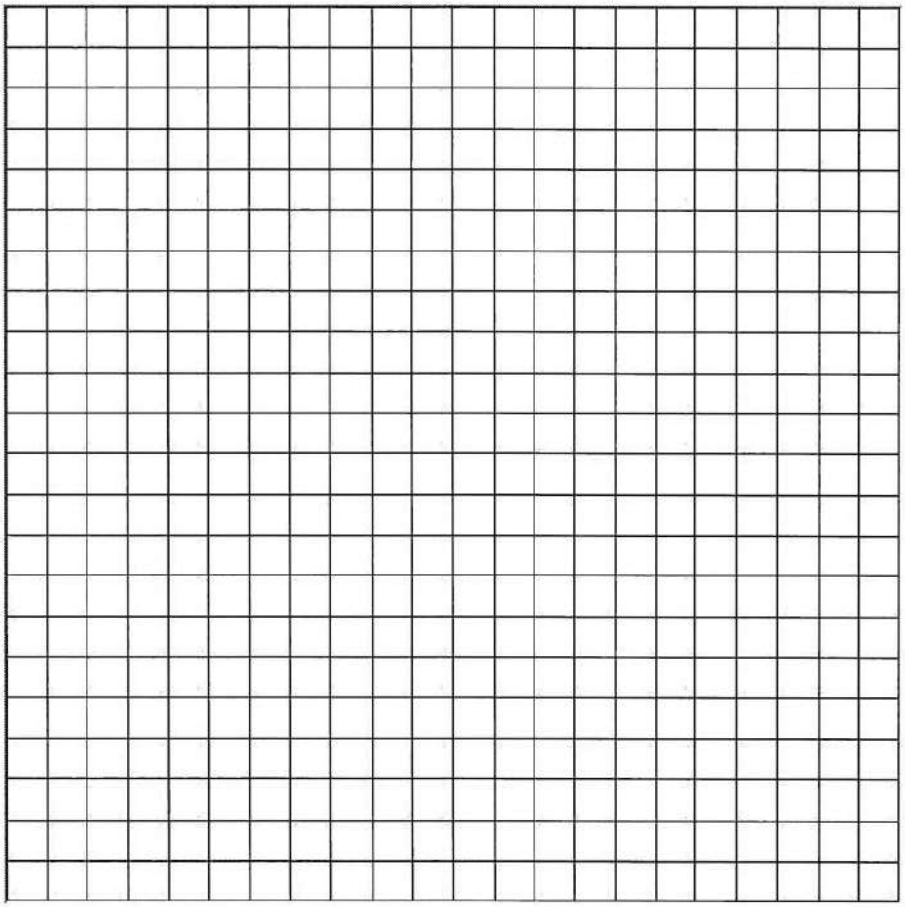
  The strong covalent bonds do not break but instead the weak intermolecular force are overcome.

Explain why nitrogen, N_2 has a very low boiling point.

Nitrogen has a simple covalent structure with weak intermolecular forces which require very little energy and low tempreratures to overcome - hence, Ntrogen has a low boiling point.

Task Plot the data onto the graph below.

Formula	Boiling point (°C)	Relative Formula Mass (M_r)
CH_4	−161	16
C_2H_6	−89	30
C_3H_8	−42	56
C_4H_{10}	0	58
C_5H_{12}	36	72
C_6H_{14}	69	86



Describe what the graph shows.

As the relative formula mass increases, the boiling point increases.

Explain why this trend occurs, using the diagram below to help.

As the relative formula mass increases, the intermolecular forces are stronger and require more energy to overcome, achieved by higher temperatures.

For each of the following, explain which has the higher boiling point:

1)Methane (CH4) or octane (C8H18)?

Octane as it has a higher Mr so has stronger intermolecular forces which require more energy and higher temperatures to overcome.

2)Hexane (C6H14) of pentane (C5H12)?

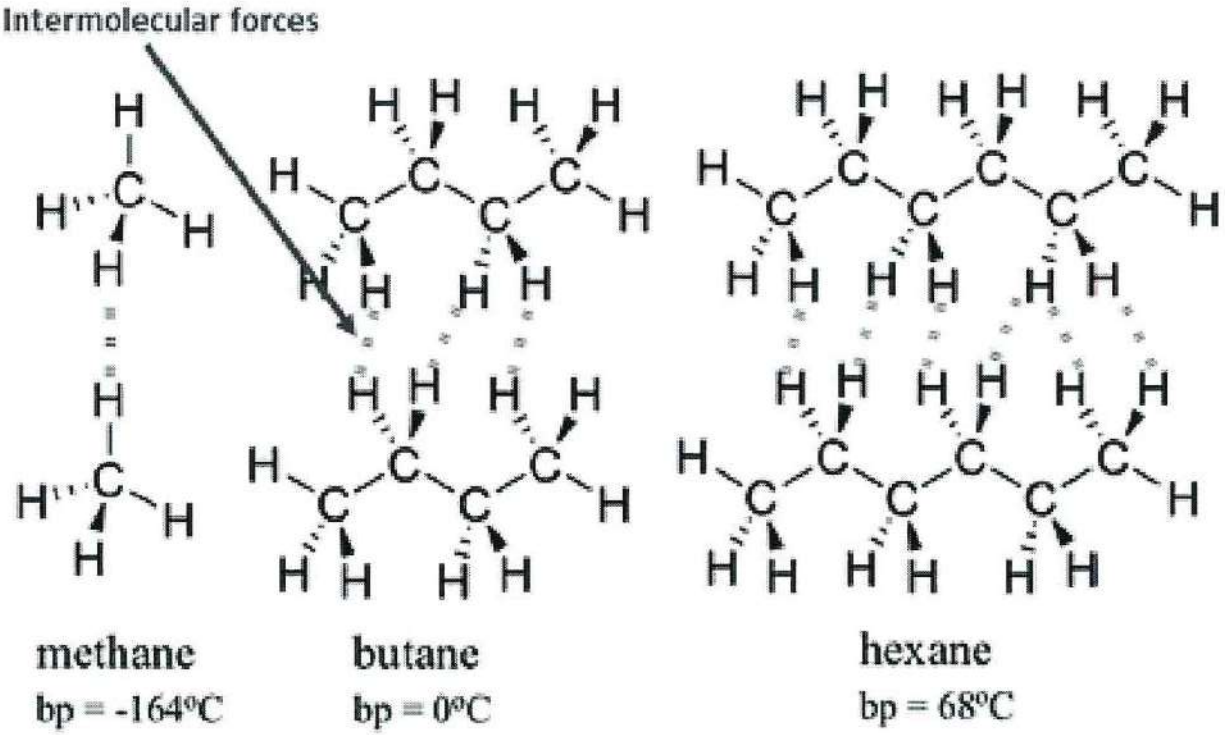
Hexane as it has a higher Mr so has stronger intermolecular forces which require more energy and higher temperatures to overcome.

3)Fluorine (F2) or bromine (Br2)?

Bromine as it has higher Mr so has stronger intermolecular forces which require more energy and higher temperatures to overcome.

4)Iodine (I2) or hydrogen (H2)?

Iodine as it has higher Mr so has stronger intermolecular forces which require more energy and higher temperatures to overcome.



How does carbon dioxide boil at -79°C without breaking a bond?

Your answer should include the following:

- give a detailed explanation of what occurs during boiling.
- explain the difference between intermolecular forces and covalent bonds.
- explain why the bonds are strong in terms of electrostatic forces.
- include a description of the type of bonding with reference to electrons. A diagram can be used.

Try to use as many of these keywords and phrases as possible:

covalent	nucleus	electrons	weak	intermolecular forces
energy	electrostatic attraction		positive	negative
charge	temperature	overcome	forces	break bonds

Terminology – Test Yourself

Term	Definition
	The smallest stable part of an element
	This is the central part of an atom
	A positively charged particle found in the nucleus
	A neutral particle found in the nucleus
Electron	A negatively charged particle found in _____ around the nucleus
	How the electrons are arranged in an atom
Group	A group of elements is found in one _____ of the periodic table
	A period of elements is found in one row of the periodic table
Element	A substance which contains _____ _____ _____ _____ _____
Covalent bond	The attraction between ___ _____ _____ and __ _____ _____ ___ _____
	Electrostatic attraction between molecules
	A particle with a fixed number of atoms chemically combined together by covalent bonds.
Diatomic molecule	A molecule containing _____ _____ _____

QuestionsAtTheBackOfTheBook

1)

Hydrogen chloride is formed in the reaction between hydrogen and chlorine.
The equation for the reaction is

$$H_2 + Cl_2 \rightarrow 2HCl$$

(a) Each molecule in this equation contains the same type of bonding.

Name this type of bonding.

(1)

covalent

(b) The bonding in a hydrogen molecule is strong.

Explain why the boiling point of hydrogen is low.

(2)

There are weak forces between the molecules which require little energy to overcome

(c) Explain how the two atoms in a chlorine molecule are held together.

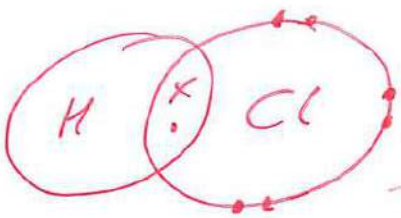
(2)

The 2 atoms within a molecule of chlorine are bonded covalently, which means there is a strong attraction between the 2 nuclei and the shared pair of electrons.

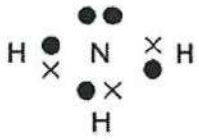
(d) Draw a dot and cross diagram to show the bonding in a hydrogen chloride molecule.

Show only the outer electrons in each atom.

(2)



2) The diagram represents a particle of ammonia.



(a) This particle of ammonia is

(1)

- ☐ **A** an atom
- ☐ **B** an ion
- ☐ **C** a lattice
- ☒ **D** a molecule

(b) Which type of bonding is present in this particle of ammonia?

(1)

- ☒ **A** covalent
- ☐ **B** hydrogen
- ☐ **C** ionic
- ☐ **D** metallic

(c) What is the formula of ammonia?

(1)

NH_3

d) The products of the complete combustion of hydrocarbons are carbon dioxide and water.

(i) Balance the equation to show the complete combustion of ethene (C_2H_4).

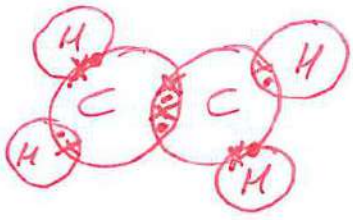
(2)

$C_2H_4 + \underline{3}\ O_2 \rightarrow \underline{2}\ CO_2 + \underline{2}\ H_2O$

(ii) Draw a dot and cross diagram to show the bonding in an ethene molecule.

Show only the outer electrons in each atom.

(2)

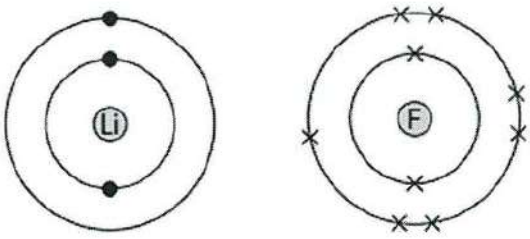


3)

Lithium and carbon both form fluorides.

(a) Lithium reacts with fluorine to produce the ionic compound lithium fluoride.

The diagrams show the arrangement of electrons in a lithium atom and in a fluorine atom.

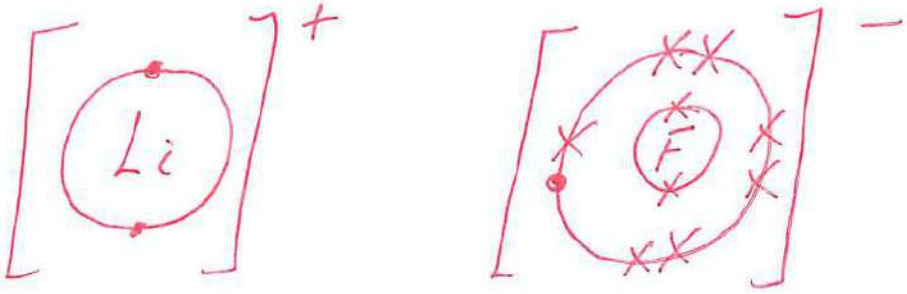


lithium atom fluorine atom

Draw similar diagrams to show the arrangement of the electrons in the ions formed when lithium reacts with fluorine.

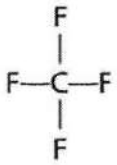
Show all the electrons in each ion.

(2)



(b) Carbon tetrafluoride is a simple molecular compound.

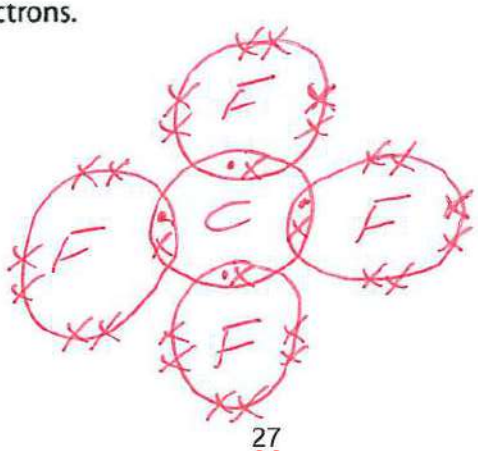
The displayed formula for a molecule of carbon tetrafluoride is



Draw a dot and cross diagram to show the arrangement of the electrons in this molecule.

Show only the outer electrons.

(2)



4)

a) What is the test for chlorine gas? (2)

- Damp litmus paper
- Bleaches

b) What is the test for carbon dioxide gas? (2)

- Bubble through limewater
- Turns cloudy

c) What is the test for hydrogen gas? (2)

- Lit splint
- Burns with a pop

d) What is the test for ammonia gas? (2)

- Damp red litmus paper
- Turns blue

e) What is the test for oxygen gas? (2)

- Glowing splint
- Relights

f) What is the chemical test for the presence of water? (2)

- Add anhydrous copper (II) sulfate
- Turns from white to blue

g) What is the physical test for the purity of water? (2)

- Heat until it boils
- If it boils at 100°C, the water is pure.